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MORPHOMETRIC ANALYSES OF WADI AL-AJEEJ DRAINAGE BASIN, USING GIS TECHNIQUE

Luay D. Yousif[1]

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Key words: Drainage basin; Morphometry; Water harvesting; Al-Jazirah; Wadi Al-Ajeej; Iraq

ABSTRACT

Wadi Al-Ajeej" drainage basin is one of the areas in the Al-Jazirah Province, experiencing shortage in water-resource in Iraq. Morphometric analyses are made in this study for "Wadi Al-Ajeej" drainage basin to support formulating plans, on the basis of the results, and to help in a better implementation. GIS techniques have been adopted to identify morphologic features and analyse their properties. Morphometric parameters such as linear, aerial and relief aspects of the drainage basin were computed and determined. The entire drainage basin of Wadi Al-Ajeej covers 3804.7 Km² with seventh order stream network, comprising three contiguous sub-basins; Al-Badee, Al-Khazrajia and Al-Hamal sub-basins which occupy 80% of the area in the northern and eastern parts of the basin. The drainage network of the three sub-basins in addition the entire Al-Ajeej basin are delineated using the Digital Elevation Model (DEM) 30 m resolution. The drainage network shows that the terrain exhibits dendritic, sub-parallel and trellis drainage patterns. Estimated drainage density is approximately 1.3 Km/Km² and has coarse drainage texture. The bifurcation ratio in all subbasins has experienced moderate structural disturbances, by "Tel-Hajar" subsurface extensional structure, that change the main streams flow from NNW – SSE to NNE – SSW. Al-Badee, Al-Khazrajia and Al-Ajeej subbasins are the highest relief ratios (17.2, 15.6, and 12.7 respectively), due to their high reliefs (1126 m, 966 m, and 1162 m respectively), while Al-Hamal subbasin has low relief ratio (2.14) due to its low relief (128 m). Drainage density results refer to excellent drainage basin (with moderate rates of infiltration and surface runoff) and coarse texture (indicate low erosion and high relief). The elongation ratio shows that three subbasins (Al-Badee, Al-Khazrajia and Al-Hamal) possesses an elongated shape pattern, but only Al-Ajeej subbasin seems to be close to a circular shape.

التحليل المورفوميتري لحوض وادي العجيج، باستخدام نظم المعلومات الجغرافية (GIS)

لؤي داود يوسف

المستخلص

منطقة الجزيرة، التي فيها حوض تصريف مياه وادي العجيج، من المناطق التي تعاني من شحة في مصادرالمياه في العراق. وعليه تم اجراء تحليل مورفوميتري لحوض تصريف مياه "وادي العجيج" لدعم القرارات (على اساس النتائج) التى قد تساعد في تحسين تنفيذ المخططات ذات الصلة باحواض الانهار. استخدمت في هذه الدراسة تقنية نظم المعلومات الجغرافية لاستنباط ودراسة الظواهر المورفوميترية وتحليل خصائصها في حوض "وادي العجيج" في منطقة الجزيرة، شمال غرب العراق. تم احتساب المعاملات المورفوميترية مثل المعاملات الخطية والمساحية والتضاريسية للحوض والتي

[1] Senior Chief Geologist, Iraq Geological Survey, (GEOSURV) P.O. Box 986, Baghdad, Iraq, e-mail: luaygeo@yahoo.com

بينت ان المساحة الكلية للحوض 3804.7 كم² وان الحوض يحتوي على شبكة مجاري مياه ذات السبعة رتب، ويتضمن ثلاثة احواض ثانوية متجاورة هي: البادية والخزرجية والحمال (تغطي 80% من منطقة الدراسة)، تحتل الأجزاء الشمالية والشرقية من الحوض الرئيس. شبكة مجاري المياه للأحواض الثانوية الثلاثة علاوة على الحوض الكلي، تم تحديدها باستخدام نموذج الأرتفاعات الرقمية بدقة 30 م. أظهرت شبكة مجاري المياه ان الحوض ذو نظامي تصريف شجيري- شبه متوازي وعريشي. كثافة مجاري التصريف 1.3 كم/كم² (تدل على معدلات متوسطة من الرشح والجريان السطحي) وذات نسيج خشن (يدل على قابلية تعرية ضعيفة وتضاريس عالية نسبيا). نسبة التشعب في كل الأحواض الثانوية المدروسة تظهر تاثر الحوض بتشوه متوسط بسبب تركيب تل حجر تحت السطحي الأمتدادي الذي حول اتجاه جريان الروافد الرئيسية نحو الجنوب الغربي. الأحواض الثانوية الثلاثة البادية والخزرجية والعجيج ذات قيم نسبة استطالة عالية بسبب تضاريسها العالية نسبيا في حين ان حوض الحمال ذو نسبة تضاريس واطئة بسبب تضاريسها المنخفضة. هذه القيم تدل على انها ذات شكل مستطيل بالرغم من ان حوض العجيج الكلي قريب للشكل الدائري.

INTRODUCTION

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998; Reddy *et al*., 2002). Morphometric studies in the field of hydrology were first initiated by Horton (1945) and Strahler (1957). The morphometric analysis of the drainage basin and channel network play a vital role for understanding the geo-hydrological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology, structural, and etc. of the catchments. A drainage map of basin provides a reliable index of permeability of rocks and their relationship between rock type, structures and their hydrological status.

Digital Elevation Models (DEMs), have been used to extract different geomorphological parameters of drainage basins, including drainage networks, catchment divides, slope gradient and aspect, and upstream flow contributing areas (Mark, 1984). Geographic Information System (GIS) based drainage basin evaluation data have given a precise, fast, and an inexpensive way for analyzing hydrological systems (Farr and Kobrick, 2000; Grohmann *et al*., 2007; and Panhalkar, 2014).

Wadi Al-Ajeej drainage basin is located in Al-Jazira Province, within Ninawa Governorate, NW of Iraq. It lies within the following coordinates; 41° 10' – 42° 00' East and 35° 20' – 36° 25' North, as shown in Fig. (1). There are many previous studies concerning Al-Jazira Area, which involve Wadi Al-Ajeej drainage basin, but most of them deal with the general geology, geomorphology, tectonics, geological hazards, and few historical studies. The most relevant are:

- Sissakian and Abdul Jabbar (2009) used remote sensing and GIS applications in geohazards assessment of Al-Jazira area, nearby Wadi Al-Ajeej.
- Ma'ala and Al-Kubaisi (2009) compiled the geological map of Al-Jazira Plain and reported on the exposed formations in the area, including the terrace system.
- Fouad and Nasir (2009) compiled the tectonic map of Al-Jazira Plain and discussed the structural evolution of the plain and its subsurface structures, which have indirect impact on the Al-Ajeej valley.
- Ma'ala (2009) compiled the geomorphological map of Al-Jazira Plain and demonstrated the geomorphological units and features.
- Sissakian *et al.* (2015) deduced the origin and evolution of Wadi Al-Ajeej. They discussed how the ancient river was separated to form the nowadays Wadi Al-Ajeej, and why the main trend was shifted from NNW – SSE to NNE – SSW.

The present study presents a hydrological and topographical feasibility study for water resources development in Wadi Al-Ajeej drainage basin by surface water harvesting during rainy season. The hydrological analysis of the basin and its morphometric evaluation are carried out for water resource management through the use of DEM, satellite images and GIS analysis. The results of the current morphometric analyses are used for;

1. Assessment of modern tools, such as GIS, in morphometric analysis.
2. Elaborate proposals that help in the process of environmental rehabilitation of the basin for the development of future projects.
3. Identify sites for the construction of dams that contribute to agricultural development.

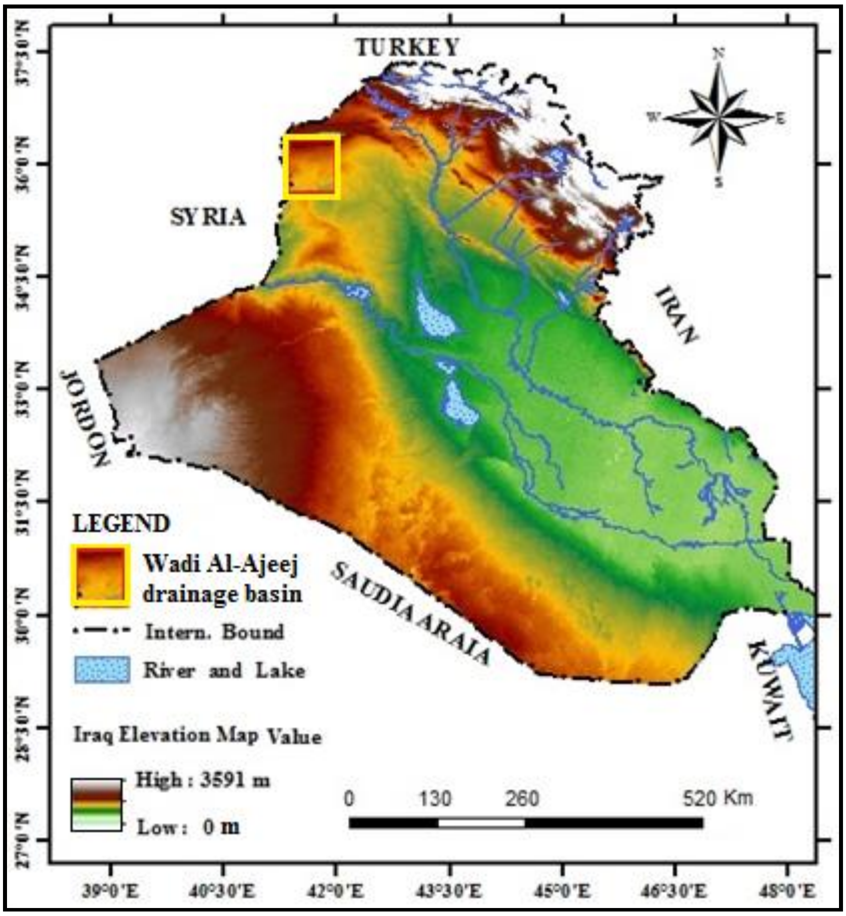

Fig. 1: Location map of Wadi Al-Ajeej drainage basin

GEOLOGICAL SETTING

▪ Geomorphology

The main geomorphological units and features in the Wadi Al-Ajeej drainage basin are briefly described. The drainage basin area is classified as plain lands except Sinjar Mountain and some high lands north of the basin (Ma'ala, 2009 and Yacoub *et al*., 2012).

- Al-Ba'aj Plain. It is the main geomorphological feature in the Al-Ajeej drainage basin. It is developed where the exposed strata of the Injana Formation (Upper Miocene) are more or less horizontal. This plateau occupies a wide area of Al-Ajeej drainage basin, over the pediment and Al-Ba'aj plain.
- Sinjar Mountain. It involves the high lands and represents the structural ridge of the Al-Ajeej basin. It extends, with E – W trend, along the northern part of Al-Ajeej drainage basin with an altitude of more than 1300 m above sea level (a.s.l.)

- **Stratigraphy**

In Wadi Al-Ajeej drainage basin, the Injana Formation is the only exposed formation of the Pre-Quaternary sediments, at the base of the main course of Al-Ajeej valley in the southwestern part of the basin (Fig.2). It consists predominantly of red, brown and grey claystone, siltstone and sandstone, overlying the last gypsum bed of the Fatha Formation (Middle Miocene) (Ma'ala, 1976). In the Al-Jazira area, different types of Quaternary sediments cover outcrops of all formations with variable thicknesses ranging from few centimeters up to 10 m (Ma'ala and Al-Kubaysi, 2009).

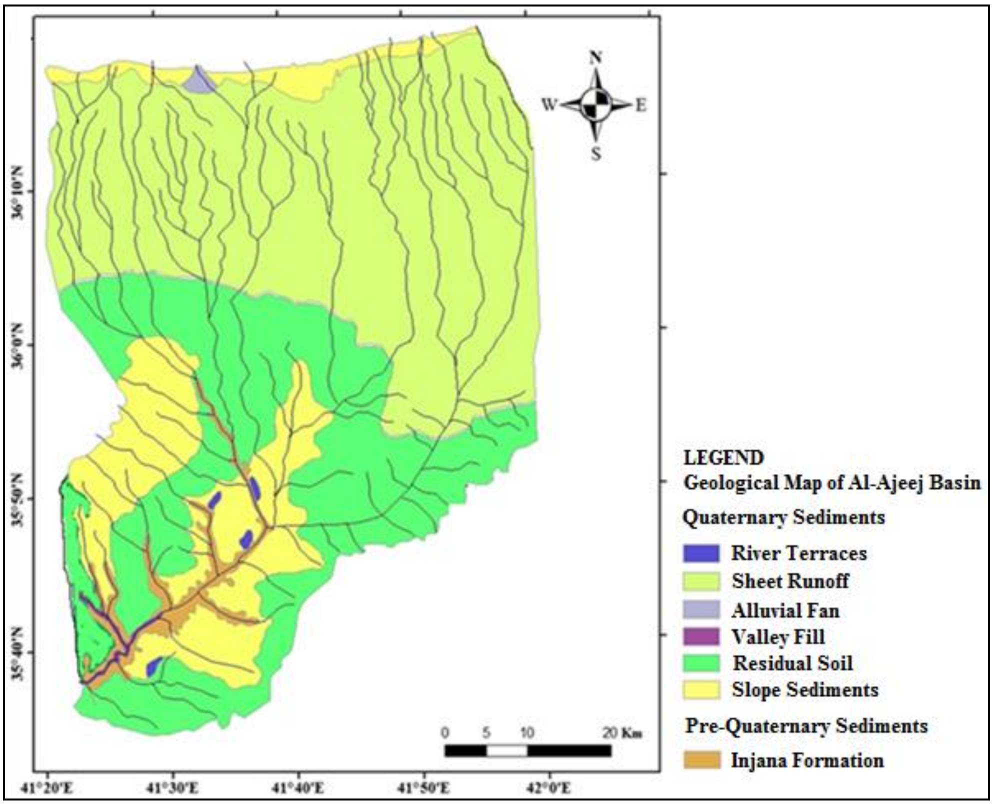

Fig.2: The Geological map of Wadi Al-Ajeej drainage basin
(Hagopian and Ma'ala, 2012)

A- Alluvial Sediments:

1. River Terraces. They are concentrated locally along Wadi Al-Ajeej stream course. The pebbles are well rounded to sub-angular, mainly limestone, chert, flint, sandstone, subordinate igneous and metamorphic rocks and gypsum. The thickness is ranging from (1 – 3) m.
2. Sheet Runoff Sediments. They are developed on the pediments along the southern slopes of the Sinjar Mountain. They consist of fine clastics with small rock fragments admixture. The thickness ranges from 9 to 12 m in Al-Ba'aj vicinity (Ma'ala, 1976).
3. Alluvial fans. Only one alluvial fan was mapped, west of Jadalah village (Hagopian and Maala, 2012). Gravel accumulations were recognized at the foot of Snaisla – Tel Abta Cliff. The gravels are well rounded to sub-rounded, mainly of limestone, chert and sandstone mixed with sandy, silty material and partly cemented by secondary gypsum.
4. Valley Fill Sediments. They fill the main valleys by different clastic sediments of carbonate and evaporites. The pebbles are rounded to sub-rounded, with average size of (1 – 10) cm, but may reach to 30 cm, the thickness ranges from 0.5 to 1.5 m.

B- Residual Soil: Two types of residual soils are recognized in the area; sandy-silty soil covers the northern part of the area, with variable thicknesses (0.5 – 3 m), and gypsious soil covers the middle part of the area and composed of sand, silt, clay and gypsum, with thicknesses range from 0.5 to 1 m.

C- Slope Sediments: They are accumulated along the slopes of the erosional cliffs, which extend between Bawara and Tel Abta. They are composed of reddish brown sandstones and siltstone fragments. The thickness ranges from few centimeters up to 0.5 m (Ma'ala and Al-Kubaysi, 2009).

- **Structure and Tectonics**

Tectonically, Al-Jazira area is part of the Stable Shelf, represented by the Rutbah – Jazira Zone (Buday and Jassim, 1987) and Salman – Hadhar Zone (Al-Kadhimy *et al*., 1996). According to Fouad (2012), the Al-Jazira Zone, is located in the Mesopotamia Foredeep, which is a part of the Outer Platform (Unstable Shelf) of the Arabian Plate. It is dominated by a network of subsurface extensional structures. These structures are mainly ENE – WSW and NW – SE trending grabens and normal faults. Tel-Hajar structure, is a subsurface structure, located at the southwestern part of the drainage basin. It is an inverted half graben bounded by one major boundary fault (Fouad and Nasir, 2009).

- **Hydrology**

The main water resources are rain water, which charges the main valleys and their tributaries distributed through the basin, in addition to the springs located in the north of the basin, south of the Sinjar Mountain. The ground water covers the shortage in surface water, but its quantity and quality are variable in the Al-Ajeej basin according to the climate, topography, and lithology. The high number of closely distributed narrow valleys and their parallel drainage pattern lead to direct flash flow during rainfall without any time for infiltration processes (Al-Taiee and Rasheed, 2011) which in-turn increase the opportunity of harvesting those surface runoff quantities by constructing a small dam.

- **Climate**

According to the data recorded by the Iraqi Meteorological Organization during the period 1941 – 2000 (I.M.O., 2000), in Al-Jazira Province, the climate is characterized by mean annual temperature of (30 – 33) °C, mean annual amount of evaporation (3000 – 3200) mm and the average annual rainfall, obtained from three meteorological stations (Sinjar, Tela'afar, and Ba'aj) is about 320 mm for the last 20 years. The potential of evaporation in the area is several times more than the average rainfall (Al-Ansari *et al*., 2013). Accordingly, the area is under the influence of arid to semiarid climatic conditions (Ma'ala, 2009). For the period considered, the maximum total annual rainfall depth recorded is 502 mm and the minimum total rainfall depth is 102 mm. This depth is of a non-uniform temporal distribution and the total effective depth is insufficient for average yields of wheat and barley in some years. The required rainfall for cereal crops is of the order of 300 – 600 mm/year (Oweis *et al*., 1999).

- **The drainage basin**

The studied drainage basin has an area 3804.7 Km^2, perimeter equal to 373.534 Km, basin length 91.6 Km and elevations between 200 m to more than 1300 m above sea level. Wadi Al-Ajeej is one of the main valleys in Al-Jazira Plain with a trend of NNE – SSW for the main valley, however, the main branches, which drain from the southern flank of the

Sinjar Mountain; west of the longitude 41° 40' N have a NNW – SSE trend (Sissakian *et al*., 2015). Wadi Al-Ajeej drainage basin consists of three main branches (Al-Hammal, Al-Khazrajia and Al-Badee) which originate from the southern side of the Sinjar Mountain and extends between the water divide of Al-Khabour basin from the west and Al-Tharthar basin from the east (Al-Taiee and Rasheed, 2011). These branches are combined together to form the main course of Wadi Al-Ajeej (Fig.3).

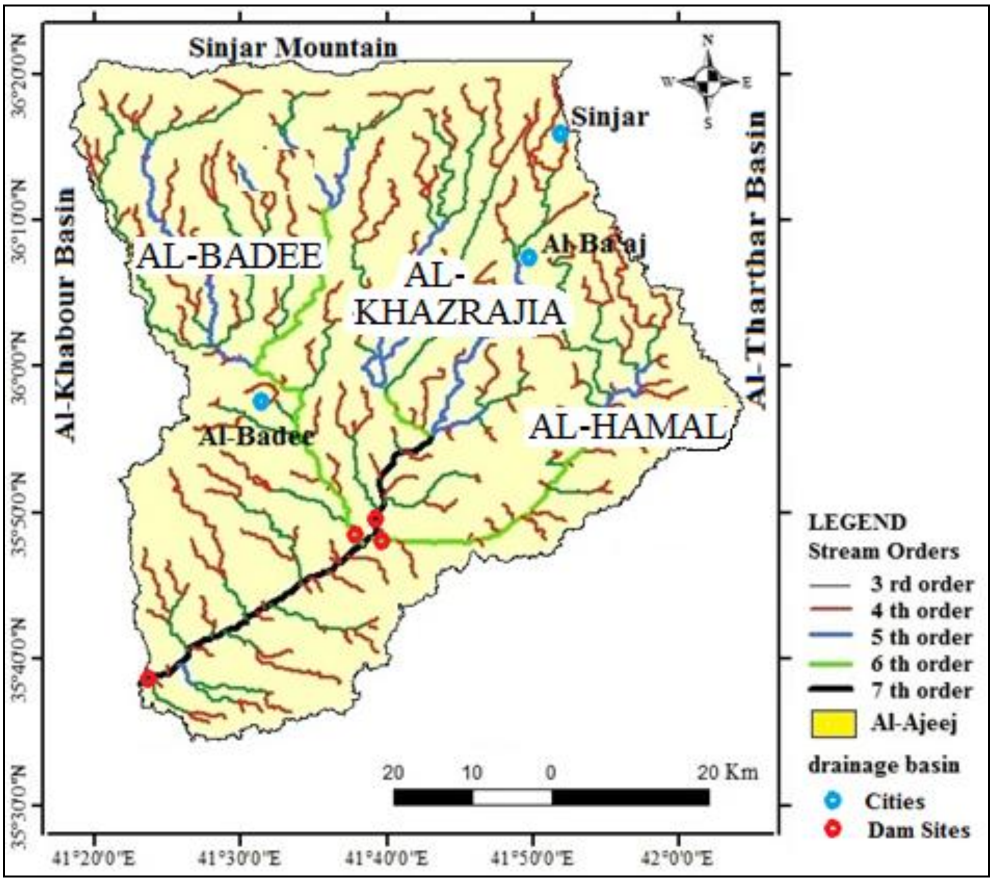

Fig.3: Stream network of Wadi Al-Ajeej drainage basin and the proposed dam sites

METHODS

In the present study, the drainage basin of Wadi Al-Ajeej, has been extracted from the DEM with 30 m resolution and classified as seventh order stream network, according to Strahler (1952) method (Fig.3). The morphometric parameters of the entire basin are computed using the "Spatial analysis" tool of Arc GIS 9.3 software which is used immensely throughout the study to carve out different topographic and morphometric components of the drainage basin. Then, by using the pour point of the hydrology tool within Arc GIS, the extracted basin is subdivided into four sub-basins for the purpose of studying their attributes when creating dams for water conservation. The methodology and mathematical equations adopted for the quantitative analysis of different morphometric parameters are mentioned in Table (1).

To understand the topographic expression of the study area, parameters like slope, relief pattern and DEM, are analysed thoroughly. Similarly, for the formulation of sustainable basin management strategy factors like length of the overland flow and channel maintenance factors are studied based on the equations developed by Chorley (1969). In addition, morphometric parameters, such as relief, shape and length, which can strongly influence basin discharge pattern through their varying effects on lag time (Gregory and Walling, 1968) are studied.

Table 1: Methodology adopted for computations of morphometric parameters

Parameters	Formula	References
Stream order (***U***)	Hierarchical rank	Strahler (1964)
Stream length (***Lu***)	Length of the stream	Horton (1945)
Mean stream length (***Lsm***)	***Lsm = Lu / Nu***	Strahler (1964)
Stream length ratio (***RL***)	***RL = Lu / Lu -1***	Horton (1945)
Bifurcation ration (***Rb***)	***(Rb) = Nu / Nu +1***	Schumm (1956)
Mean bifurcation ratio (***Rbm***)	***Rbm*** = average of bifurcation ratios of all orders	Strahler (1957)
Drainage density (***Dd***)	***Dd = Lu /A***	Horton (1945)
Drainage texture (***T***)	***T = Dd * Fs***	Smith (1950)
Stream frequency (***Fs***)	***Fs = Nu / A***	Horton (1945)
Elongation ratio (***Re***)	***Re*** = 2/***Lb****(***A/π***) ½	Schumm (1956)
Circularity ratio (***Rc***)	***Rc*** = 4 л ***A / P***^{2}	Strahler (1964)
Form factor (***Ff***)	***Ff = A / Lb***^{2}	Horton (1945)
Relief (***R***)	***R = H – h***	Hadley and Schumm (1961)
Relief ratio (***Rr***)	***Rr = (H – h) / Lb***	Schumm (1963)
Relative Relief (***Rhp***)	***Rhp= (H – h) / P***	Schumm (1963)
Length of Overland Flow (***Lg***)	***Lg*** = ½ ***(Lu/A)***	Horton, (1945)

Lu-1= the least (Lower) order and ***Lu + 1*** = the greatest (higher) order

RESULTS AND DISCUSSION

The properties of the stream networks are very important to study the landform development processes (Strahler and Strahler, 2002). Wadi Al-Ajeej drainage basin consists of three ephemeral main tributaries that conjugate to feed the main course of Wadi Al-Ajeej River. Accordingly, the basin is subdivided into three separated sub-basins namely; Al-Badee, Al-Khazrajia and Al-Hamal (Fig.4A, B and C). In the present study, the morphometric characteristics of the entire Al-Ajeej basin (Fig.4D), in addition to the three sub-basins, are analysed as separate sub-basins. The morphometric analysis is carried out with respect to parameters like stream order, ***Lu***, ***Rb***, ***RL, Lb, Dd, Fs, Re, Rc, Ff*** and ***Rr***. The morphometric analysis of the parameters for each of the four sub-basins is carried out using the mathematical formulae given in Table (1) and their geomorphic characteristics are listed in Table (2).

▪ Linear Parameters

In the present study, the linear aspects of Wadi Al-Ajeej basin, such as stream order, stream length, mean stream length, stream length ratio and bifurcation ratio, are determined and the results are discussed as follows:

– **Stream Order:** The designation of stream orders is the first step in drainage basin analysis and is based on a hierarchic ranking of streams. In the present study, ranking of streams is carried out based on the method proposed by Strahler (1964) (Table 1). The order wise stream numbers and stream lengths of the four sub-basins are given in Table (3). Out of these sub-basins, 'Al-Badee', and 'Al-Hamal' are sixth order streams (Fig.4A and C), whereas 'Al-Khazrajia' and 'Al-Ajeej' sub-basins are seven order streams (Fig.4B and D).

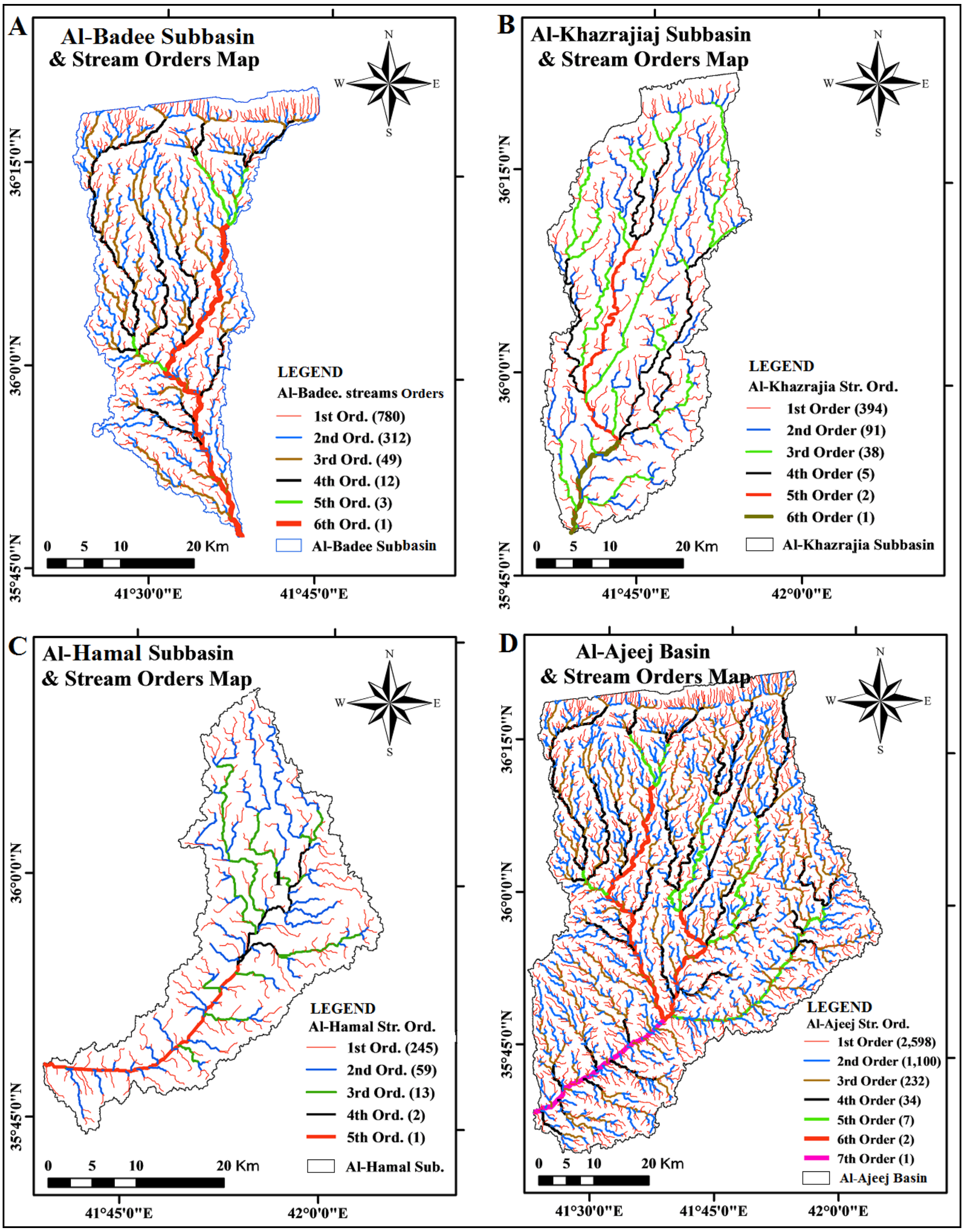

Fig.4: Sub-basins and stream orders of Wadi Al-Ajeej drainage basin

Table 2: Results of geomorphic characteristics of the four sub-basins of Wadi Al-Ajeej drainage basin

Subbasin	Al-Badee	Al-Khazrajia	Al-Hamal	Al-Ajeej
Area (Km²)	1235.4	1122.2	691.2	3804.7
Perimeter (Km)	240.3	212.4	213.4	373.6
Length (Km)	65.6	61.8	59.9	91.6
H- Highest Elevation (m)	1370	1188	377	1370
h- Lowest Elevation (m)	244	222	249	208

Table 3: Stream orders and stream lengths of the studied four subbasins

Subbasin	Stream Order (Nu)							Stream Length (Km)						
	1ST	2nd	3rd	4th	5th	6th	7th	1st	2nd	3rd	4th	5th	6th	7th
Al-Badee	1305	283	65	14	3	1	-	980.6	498.5	255.6	172.8	60.2	58.6	-
Al-Khazrajia	1141	250	53	16	4	2	1	831.3	410.2	262.7	157.1	76.4	10.0	16.9
Al-Hamal	749	151	34	9	2	1	-	515.6	269.4	150.1	73.3	19.1	31.3	-
Al-Ajeej	3962	835	477	48	10	4	1	2907.0	1486.2	820.3	476.7	159.4	100.5	50.3

– **Stream Length (*Lu*):** The number of streams of various orders in a drainage basin are counted and their lengths from mouth to the drainage divide are measured (Table 3) with the help of GIS software. The stream length (***Lu***) is computed based on the law proposed by Horton (1945) for all the four sub-basins (Table 1). Generally, the total length is maximum in stream segments of the first order streams and decreases as the stream order increases. This change may indicate that the flowing of streams from high altitude, with lithological variation and moderately steep slopes (Singh and Singh, 1997) especially, in the Al-Badee and Al-Khazrajia sub-basins, because of their closer proximity to the Sinjar Mountain.

The stream length is a measure of the hydrological characteristics of the bedrock and the drainage extent. Wherever the bedrock and formation are permeable, only a small number of relatively longer streams are formed, whereas, a large number of streams of smaller length are developed where the bedrocks and formations are less permeable (Sethupathi *et al*., 2011). The latter case is well developed in the down streams of both the Al-Hamal and the Al-Ajeej sub-basins. The 3rd order stream segments are directly connected with 6th order stream segments in the Al-Hamal subbasin and the 4th order streams are directly connected with the 7th order stream, in the Al-Ajeej sub-basin.

– **Mean stream length (*Lsm*):** According to Strahler (1964), the mean stream length is a characteristic property related to the drainage network and its associated surfaces. The mean stream length (***Lsm***) is calculated in this study by dividing the total stream length of order '***u***' by the number of streams of segment of order '***u***' (Table 1). It is noted from the results (Table 4) that ***Lsm*** varies from 0.69 Km (1st order in Al-Ajeej sub-basin) to 58.6 Km (6th order in Al-Badee sub-basin). Moreover, ***Lsm*** of any given order is greater than that of the lower order and less than that of its next higher order, except of the ***Lsm*** value of the 6th order of Al-Khazrajia sub-basin. This may be due to variation in slope and topography (Wilson *et al*., 2012).

Table 4: Mean stream length and stream length ratio of the studied sub-basins

Subbasin	Mean Stream Length (*Lsm*)							Stream Length Ratio (*RL*)					
	1st	2nd	3rd	4th	5th	6th	7th	2nd/ 1st	3rd/ 2nd	4th/ 3rd	5th/ 4th	6th /5th	7th/ 6th
Al-Badee	0.75	1.76	3.93	12.4	20.1	58.6	-	0.51	0.51	0.68	0.35	0.97	-
Al-Khazrajia	0.73	1.64	4.96	9.8	19.1	5.0	16.9	0.49	0.64	0.60	0.49	0.13	1.7
Al-Hamal	0.69	1.79	3.13	8.1	9.6	31.8	-	0.52	0.56	0.49	0.26	1.66	-
Al-Ajeej	0.73	1.78	1.72	9.9	15.9	25.1	50.3	0.51	0.55	0.58	0.33	0.63	0.5

– **Stream Length Ratio (*RL*):** It is defined as the ratio of the mean length of one order to the next lower order of stream segment (Table 1). Horton's law (1945) of stream length states that mean stream length segments of each of the successive orders of a basin tends to approximate a direct geometric series with streams length increasing towards higher order of streams. The

RL between streams of different order in the study area reveals variation in ***RL*** in each sub-basin (Table 2). There is a change from one order to another order indicating late youth stage of geomorphic development (Singh and Singh, 1997). These variations might be due to changes in slope and lithology from the high lands of the Sinjar Mountain in the north to the elevated lands of Al-Ba'ag plain in the south.

– **Bifurcation Ratio (*Rb*):** The term ***Rb*** is defined as the ratio of the number of stream segments in a given order to the number of segments in the next higher order (Table 1). Horton (1945) considered the bifurcation ratio as an index of relief and dissections. Strahler (1957) demonstrated that ***Rb*** shows a small range of variation for different regions or for different environment except where the powerful geological control dominates (structural disturbance). The bifurcation ratio ranges between 3 and 5. It is observed from Table (5), that the ***Rb*** is not the same from one order to its next order. These irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler, 1964). Lower values of ***Rb*** are characteristics of sub-basins, which have suffered less structural disturbances and the drainage patterns has not been distorted (Nag, 1998).

In the present study, the higher values of ***Rb*** of the studied sub-basins indicates strong structural control on the drainage pattern, of the Tel-Hajar subsurface structure, which is an inverted half graben bounded by one major boundary fault (Fouad and Nasir, 2009). This structure makes the main stream of Al-Khazrajia, Al-Hamal branches deviated from south direction to the southwest and then to the west direction, while the lower values are indicative of sub-basins that are not affected by structural disturbances. The mean bifurcation ratio (***Rbm***), defined as the average of bifurcation ratios of all orders (Table 1), varies in the present study from 3.43 to 4.62 (Table 5) suggesting that all sub-basins have experienced moderate structural disturbances (Strahler, 1964).

Table 5: Bifurcation ratio, mean bifurcation and length of overland flow results of the studied subbasins

Subbasin	Bifurcation Ratio (*Rb*)						Mean Bifurcation Ratio (*Rbm*)	Length of Overland Flow (*Lg*)
	1st/ 2nd	2nd/ 3rd	3rd/ 4th	4th/ 5th	5th/ 6th	6th/ 7th		
Al-Badee	4.61	4.35	4.64	4.67	3.0	-	4.25	0.30
Al-Khazrajia	4.56	4.72	3.31	4.0	2.0	2.0	3.43	0.32
Al-Hamal	4.96	3.15	5.33	4.5	2.0	-	4.0	0.33
Al-Ajeej	4.74	1.75	9.94	4.8	2.5	4.0	4.62	0.39

– **Length of Overland Flow (*Lg*):** The term length of overland is used to describe the length of flow of water over the ground before it becomes concentrated in definite stream channels. Horton (1945) expressed it as equal to half of the reciprocal of the ***Dd***. Generally higher value of ***Lg*** is indicative of low relief, whereas low value is indicative of high relief (Kanth and Hassan, 2012). The high ***Lg*** value indicates that the rainwater has to travel relatively longer distance before getting concentrated into stream channels (Chitra *et al.*, 2011). However, low ***Lg*** values indicate that the rainwater can enter the stream quickly. The ***Lg*** values between 0.2 and 0.3 Km/Km² indicate the presence of moderate ground slopes, where the run-off and infiltration are moderate. ***Lg*** values less than 0.2 Km/Km² indicates short flow-paths, with steep ground slopes, reflecting the areas associated with more run-off and less infiltration. Watersheds having ***Lg*** greater than 0.25 are under very low structural disturbance, less runoff condition and having higher overland flow (Patil *et al*., 2015). In the four studied sub-basins, the ***Lg*** ranges between 0.30 and 0.39, which indicate the occurrence of long flow-paths, and thus, gentle ground slopes that reflects areas of less surface run-off and more infiltration (Rama, 2014). The lowest value (0.30 Km/Km^2) is found in the Al-Badee sub-basin, while the highest value (0.39 Km/Km^2) is found in Al-Ajeej sub-basin (Table 5).

- **Areal Parameters**

– **Drainage Density (*Dd*):** It is defined as the closeness of spacing of channels (Prasad *et al*., 2008). It is a measure of the total length of streams in a catchment per unit area, and it is a measure of landscape dissection and runoff potential of the basin. A high value of the ***Dd*** indicates high density of steams and thus, a rapid stream response. High ***Dd*** of an area is indicative of high run-off, and consequently a low infiltration rate, whereas, low ***Dd*** implies low run-off and high infiltration (Prasad *et al*., 2008). Slope steepness and ***Rhp*** are the main morphological factors controlling ***Dd***. Strahler (1957) concluded that low ***Dd*** occurs where basin relief (***R***) is high. Other important factors determining ***Dd*** are infiltration capacity of the soil, and initial resistance of the terrain towards erosion. ***Dd*** is classified into three types according to (Deju, 1971); poor (<0.5), medium (0.5 – 1.5) and excellent (>1.5). The ***Dd*** value for the Wadi Al-Ajeej drainage basin is 1.22, while, ***Dd*** values of the sub-basins range between 1.54 in Al-Hamal sub-basin to 1.64 in Al-Badee sub-basin (Table 6). Such values are classified as excellent ***Dd*** (Smith, 1950).

Table 6: Areal parameters results of the studied sub-basins

Subbasin	Drainage Density (*Dd*)	Stream Frequency (*Fs*)	Drainage Texture (*T*)
Al-Badee	1.64	1.35	2.21
Al-Khazrajia	1.57	1.31	2.06
Al-Hamal	1.54	1.39	2.14
Al-Ajeej	1.58	1.40	2.22

– **Drainage Texture (*T*):** is an expression of the relative spacing of drainage lines in a fluvial-dissected terrain (Smith, 1950). It is defined as the total number of stream segments of all orders per perimeter of that area (Horton, 1945). ***T*** is considered one of the main concepts in drainage basin geomorphology. It depends on several intrinsic physical factors such as climate, rainfall, vegetation, soil, lithology, infiltration-capacity, relief, and stage of drainage basin development. High ***T*** values indicate the presence of soft rock with low resistance against erosion. According to Smith (1950), ***T*** is classified into four categories: coarse (***T*** < 4), moderate (***T*** = 4 – 10), fine (***T*** value 10 – 15), and ultra-fine or badlands topography (***T*** value is >15). It is obvious from such classification, that the drainage texture of the four sub-basins of Wadi Al-Ajeej basin fall in the coarse class where the ***T*** value is 2.22 (Table 6). This low value of watershed implies that the area is less prone to soil erosion and has intrinsic structural complexity in association with relief and ***Dd***.

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– **Stream Frequency (*Fs*):** It is the total number of stream segments of all orders per unit area (Horton, 1932). ***Fs*** mainly depend on the lithology of the basin and reflect the texture of the drainage network. Reddy *et al*. (2002) stated that low values of ***Fs*** indicate presence of a permeable subsurface material and low relief. The ***Fs*** value of the Al-Ajeej drainage basin is 1.40 Km/Km² and in the sub-basins range between 1.31 and 1.40 Km/Km² (Table 6), which mean the basin is covered by soft sediments with high humidity.

- **Relief Parameters**

The relief aspects determination includes Basin Relief (***R***)**;** Relief Ratio (***Rr***) and Relative relief (***Rhp***). The results of the analyses are given in Table (7).

Table 7: the relief aspect parameters of the Wadi Ajeej drainage basin

Sub-basin	Basin Relief (*R*)	Relief Ratio (*Rr*)	Relative Relief (*Rhp*)
Al-Badee	1126 m	17.2	4.7 m
Al-Khazrajia	966 m	15.6	4.55 m
Al-Hamal	128 m	2.1	4.5 m
Al-Ajeej	1162 m	12.7	3.1 m

– **Basin Relief (*R*):** The elevation difference between the highest and lowest points on the valley floor of a basin is known as the total relief of that basin (***R***). It means the general relief of the basin (high and low topography). It determines the speed with which the runoff will reach a basin. Clearly, rain that falls in steep mountainous areas will reach the river faster than in flat or gently sloping areas. It is measured by the difference between the highest point in the basin and lowest point at the mouth level of the valley. The relief of the entire Al-Ajeej basin is 587.75 m. The Al-Badee and Al-Khazrajia sub-basins are of relatively high relief, being so close to the Sinjar Mountain, while Al-Hamal and Al-Ajeej sub-basins are of relatively low relief, being relatively away from the Sinjar Mountain.

– **Relief Ratio (*Rr*):** It is the ratio of ***R*** divided by ***Lb*** (Gallagher, 1999). ***Rr*** defines the difference in elevation between the highest and the lowest points in the basin and controls the stream gradient, thus influences flood patterns and amount of transported sediment. Hadley and Schumm (1961) showed that sediment load increase exponentially with ***R*** (Gallagher, 1999). It plays an important role in drainage development, surface and sub surface water flow, permeability, landforms development and erosion properties of the terrain (Bagyaraj and Gurugnanam, 2011). Table (7) shows that Al-Badee, Al-Khazrajia and Al-Ajeej subbasins are the highest ***Rr*** (17.2, 15.6 and 12.7 respectively), due to their close proximity to the Sinjar mountain and the general slope towards south and southwest directions, while Al-Hamal subbasin is the lowest ***Rr*** (2.1), due to the plateau geomorphologic landform of Al-Ba'aj Plain.

– **Relative relief (*Rhp*):** It is the ratio of relief to the perimeter of basin. It is an important morphometric variable used for the overall assessment of morphological characteristics of terrain (Suresh, 2002). The relative relief for the four sub-basins varies from 0.6 to 4.7. For the entire drainage basin, it is 2.7 (Table 7). The sub-basin with higher relative relief has higher potential runoff than others. Therefore, Al-Badee and Al-Khazrajia sub-basins have the highest potential runoff, because they are relatively close to the Sinjar Mountain, while

Al-Hamal and Al-Ajeej sub-basins have the lowest potential runoff, because they are relatively away from Sinjar Mountain.

- **Shape Parameters**

– **Elongation ratio (*Re*):** It is defined as the ratio of diameter of a circle having the same area as of the basin and maximum basin length (Schumm, 1956). It is a measure of the shape of the river basin and it depends on the climatic and geological conditions. A circular basin is more efficient in runoff discharge than an elongated basin (Singh and Singh, 1997). The values of ***Re*** generally vary from 0.6 to 1.0 over a wide variety of climatic and geological conditions. It can be classified, based on these values, as circular (0.9 – 1), oval (0.8 – 0.9), less elongated (0.7 – 0.8), elongated (0.5 – 0.7) and more elongated (< 0.5) (Schumm, 1956). The ***Re*** values of the studied sub-basins range from 0.49 in Al-Hamal sub-basin to 0.76 in Al-Ajeej sub-basin (Table 8). These ***Re*** values suggest that the Al-Hamal sub-basin belongs to the more elongated shape basin, low relief, low infiltration capacity, high runoff, high susceptibility to erosion and sediment load (Reddy *et al*., 2002), while the value obtained for Al-Ajeej sub-basin refers to less elongated shape basin.

Table 8: Shape parameters results of the studied four sub-basins

Subbasin	Elongation Ratio (*Re*)	Circularity Ratio (*Rc*)	Form Factor (*Ff*)
Al-Badee	0.60	0.52	0.29
Al-Khazrajia	0.61	0.56	0.29
Al-Hamal	0.49	0.45	0.19
Al-Ajeej	0..76	0.59	0.45

– **Circularity ratio (*Rc*):** Miller (1953) defined dimensionless ***Rc*** as ratio of basin area to the area of circle having the same perimeter as the basin. The ratio is equal to unity when the basin shape is a perfect circle, decreasing to 0.785 when the basin is square and continues to decrease to the extent to which the basin becomes elongated (Zavoianu, 1985). ***Rc*** values between 0.4 and 0.5 indicate mature stage of topography, while higher values indicate old stage and lower values of youth stage of the tributary basin. For two basins of the same size, the flood potential would be considered greatest for the one with the smallest circularity coefficient (Rodda, 1969).

The ***Rc*** of the sub-basins are; 0.52, 0.56, 0.45 and 0.59 respectively, which indicate strongly elongated and highly permeable homogenous geologic materials. The ***Rc*** (0.59) of Al-Ajeej sub-basin indicates elongated shape which may be due to the ENE – WSW subsurface extensional structures (Sissakian *et al*., 2015), although its shape, ***Re*** and ***Ff*** parameters suggest it is close to the circular shape (Table 8).

– **Form factor (*Ff*):** According to Horton (1932), ***Ff*** may be defined as the ratio of the basin area to square of the basin length. The ***Ff*** indicates the flow intensity of a basin for a defined area. The ***Ff*** value should always be less than 0.7854. The smaller the value of the ***Ff***, the more elongated will be the basin. Basins with high ***Ff*** experience larger peak flows of shorter duration, whereas elongated basin with low ***Ff*** experience lower peak flows of longer duration. The observed ***Ff*** values of the first three sub-basins are 0.29, 0.29 and 0.19, respectively, which suggest that the shape of these sub-basins is elongated (Table 8). The elongated basin with low ***Ff*** indicates that it will have a flatter peak of flow for longer duration. The fourth sub-basin (Al-Ajeej sub-basin) has ***Ff*** value 0.45, which indicates less elongated form and may experience larger peak flows of shorter duration.

- **Aspect map**

Aspect map generally refers to the direction to which mountain slope faces the sun. It is a very important parameter to understand the impact of the sun on local climate of the area and has major effects on the distribution of vegetation type (Gebre *et al*., 2015). The aspect map, derived from SRTM DEM, represents the compass direction of the aspect. Generally, west-facing slope shows the hottest time of the day in the afternoon and in most cases a west-facing slope will be warmer than sheltered east-facing slope (Magesh and Chandrasekar, 2012 and Singh *et al*., 2014).

In areas above the Tropic, the surfaces that tend to have aspects-oriented south are hotter and with drought in comparison with those directed to the north (Lepsh, 2002). In this sense, Crepani *et al*., (2001) asserts that any radiation flux that reaches a rather steep aspect positioned to the south in northern semi-arid areas will be more intense than other aspects which have the same slope and location but are positioned to the north, thus, it suffers of the largest weathering factors. The aspect map derived from the Shuttle Radar Topography Mission (SRTM) DEM represents the compass direction of the aspect. 0 – is true north; a 90 – aspect is to the east.

The aspect map of Wadi Ajeej drainage basin shows the predominance of the southeast facing (90 – 180) slopes which cover 1902.35 Km^2 and the southwest facing slopes which cover 1141.41 Km². Therefore, these slopes are hotter, with higher evaporation rates, lesser moisture content and lesser vegetation cover, than the other slope directions (Table 9 and Fig.5).

Table 9: Aspect properties of Wadi Ajeej drainage basin

Aspect (°)	Area (Km²)	%
90 – 180	1902.35	50
180 – 270	1141.41	30
1 – 90	570.70	15
270 – 360	190.24	5

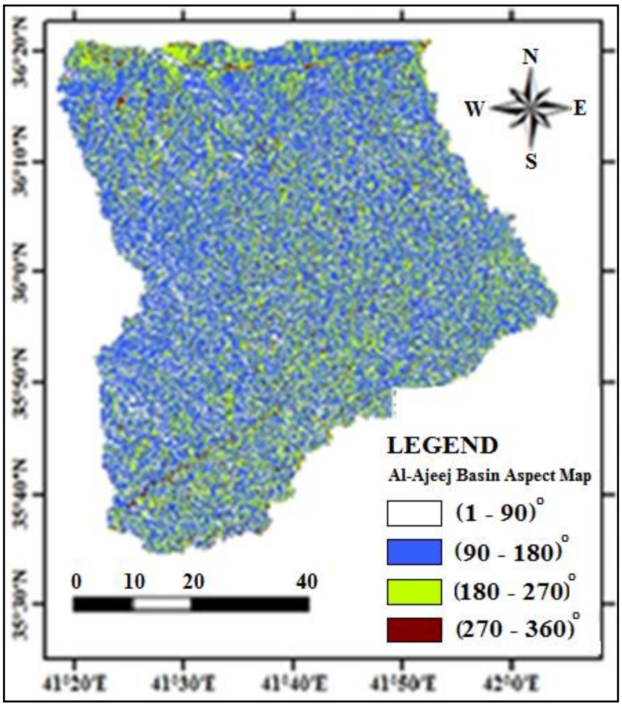

Fig.5: Aspect map of Wadi Al-Ajeej drainage basin

- **Slope map**

Slope is the measure of change in surface elevation value over distance and can be expressed in degrees or as a percentage. In a raster format, the DEM is a grid where each cell is a value referenced to a common datum. Extraction of elevation from remote sensing dedicated software packages are required but most GIS packages have routines for point or contour line interpolation. Any two points on the grid will be sufficient to ascertain a slope. Once the slopes have been calculated, then the maximum difference can be found and the gradient can be determined (Burrough and McDonnell, 1998; and Jha *et al*., 2007).

In the current study, topographic elevation map of the study area is developed by DEM extracted from the SRTM data. To achieve this, the DEM was subjected to two directional gradient filters (one in the x-direction and the other in the y-direction). The resultant maps are used to generate a slope map of the study area using ArcGIS Spatial Analyst tools. The highest topographic elevation (1370 m a.s.l) exists in the extreme northern part and the lowest (208 m a.s.l.) exists in the southwestern part of the area which induces lowest runoff and hence high possibility of rainfall infiltration.

The slope map of the study area identified five classes (in degrees); Very Gentle Slopes (1 – 2)°, Gentle Slopes (2 – 5)°, Moderate Slopes (5 – 10)°, Steep Slopes (10 – 20)° and Very Steep Slopes (20 – 55)°. The largest area is 2064.5 Km² of very gentle slopes followed by 1308.4 Km² area of gentle slopes. These two groups occupy 91.6% of the studied basin area, except the extreme northern part. The moderate slopes occupy an area of 206.4 Km², which represents 5.6% of the basin and are randomly distributed in the area, while the smallest slope areas (102.5 Km^2) are the steepest slopes (Fig.6), concentrated along the southern slopes of Sinjar Mountain, at the extreme northern part of the basin and represents 4.3% of the area (Table 10). Higher slope degrees result in rapid runoff and increased erosion rate (potential soil loss) with less ground water recharge potential.

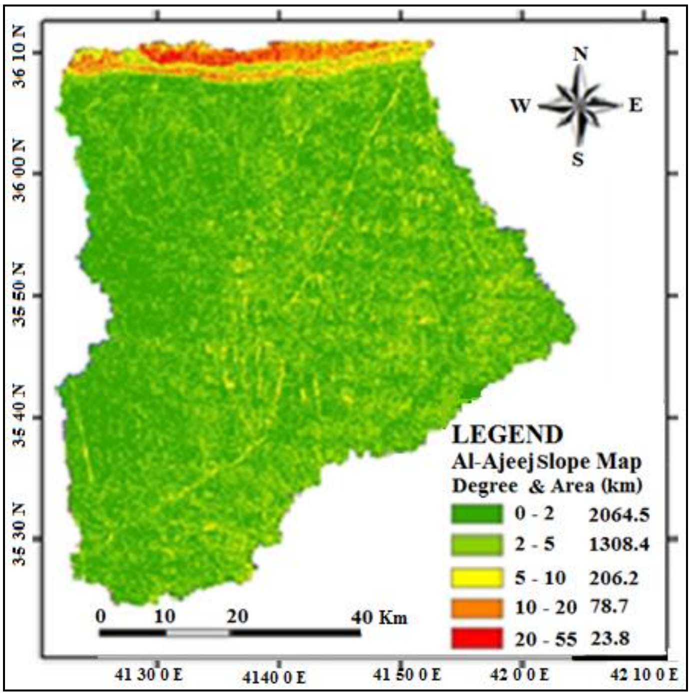

Fig.6: Slope (gradient and slope area) map of “Wadi Al-Ajeej” drainage basin

Table 10: Slope properties of Wadi Al-Ajeej drainage basin

Slope (°)	Area (Km²)	%
0 – 2	2064.5	54.4
2 – 5	1308.4	34.8
5 – 10	206.2	6.5
10 – 20	78.7	3.1
20 – 55	23.8	1.2

It is observed that most of the area of the Wadi Al-Ajeej drainage basin has very gentle and gentle slopes which indicate almost flat topography. Gentle slopes are designated in the ‘‘excellent’’ category for groundwater management as the nearly flat terrain is the most favorable for infiltration. Moderate slopes also come under good zone due to slightly undulating topography which gives maximum percolation or partial runoff. The steep class and having a high surface runoff with a negligible amount of infiltration are marked under good zone for construction of stop dams etc. Slope is a critical parameter which directly controls runoff and infiltration of any terrain. Runoff in higher slope regions causes less infiltration. This factor significantly controls the development of aquifers.

CONCLUSIONS

- Wadi Al-Ajeej drainage basin can be divided into three main sub-basins, named as; Al-Badee, Al-Khazrajia and Al-Hamal in addition to Al-Ajeej sub-basin with stream orders not less than 6^{th} order.
- Dendritic drainage, sub-dendritic and sub-parallel patterns are developed in the Al-Ajeej drainage basin, which reflects the homogeneity in texture and weak structural control.
- Bifurcation ratio values suggest the studied sub-basins are affected by moderate structural control of the subsurface extensional structures that change their directions from WNW – ESE to ENE to WSW.
- Drainage texture of the investigated drainage basin indicates resistant rocks and coarse texture, which is restricted mostly to the zones of secondary porosity developed due to fractures, joints and weathering.
- Low drainage density (***Dd*** < 2) indicates that the basin is made of highly permeable soil and subsoil, low relief and coarse drainage texture.
- Al-Ajeej sub-basin has circularity ratio (0.41) which indicates more or less elongated sub-basin, although its shape, elongation ratio and form factor refer to nearly circular shape. This circularity ratio may be due to the subsurface extensional structures of Tel-Hajar graben.
- The drainage areas of the studied drainage basin are passing through an early mature stage of the fluvial geomorphic cycle. Lower order streams mostly dominate the basin. The development of stream segments in the basin area is more or less affected by rainfall only.
- Low surface runoff in the study area, is due to low relief; it is indicated by the length of overland flow of relatively high values (> 0.3 Km/Km²) which means that the rain water has to run over these distances before getting concentrated in stream channels.
- The aspect map of the studied watershed, shows the predominance of the southeast facing (90° – 180°) slopes and therefore, these slopes have higher moisture content and higher vegetation density compared to the southwest facing (180° – 270°) slopes. The southwest facing slopes will be less stable and more susceptible for erosion.

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About the author

Mr. Luay Dawood Yousif, Graduated from Assiut University, Arab Egypt Republic, in 1979 with B.Sc. in Geology. He got his M.Sc. degree from Baghdad University in 2005, in Rock Slope Engineering Geology. He joined GEOSURV in 1990, and was nominated as Senior Chief Geologist in 2004. His main field of interest is rock slope stability, rock and soil mechanics and construction raw materials. He has contributed to many of the Iraq Geological Survey projects, especially in engineering geology and geological mapping. He has many unpublished reports and nine (9) published papers.

e-mail: luaygeo@yahoo.com; luayyousif55@gmail.com
Mailing address: Iraq Geological Survey (GEOSURV), P.O. Box 986, Baghdad, Iraq.