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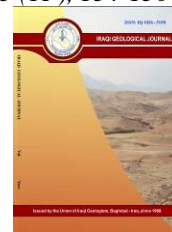


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Hydromorphometric Analysis of Wadi Al-Batin Alluvial Fan Using Remote Sensing and GIS Techniques, Southwestern Iraq

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Abstract

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Wadi Al-Batin alluvial fan starts from Wadi Al-Rummah in Saudi Arabia and passes through the Kuwait and Iraq borders. The fan represents the southern and northern limits of the Iraq and Kuwait national boundary, respectively, deposited by Wadi Al-Batin on the southern border of the main wide depression formed by the effectiveness of the Abu Jir-Euphrates Fault. The present study aims to evaluate the hydrological properties of the fan and perform a morphometric analysis to find the groundwater flow, structural, and drainage network of the study area based on fieldwork information and satellite images using remote sensing technique and GIS environment. The hydrological analysis shows that the drainage density pattern direction in Wadi Al-Batin alluvial fan is from the southwestern to the northeastern parts of the Wadi Al-Batin alluvial fan. The morphometric analysis results show that the Wadi Al-Batin fan is divided into five watersheds; each has seven stream orders, watershed 1 has the highest value of stream order, and watershed 2 has the lowest value of stream order. The drainage texture value range between fine, moderate, and very fine, which indicates the geological setting of the region consists of the Dibdibba Formation exposed in the study area. Watershed 3 has the highest value, and watershed 1 has the lowest value of stream frequency. The form factor value for all watersheds is less than 0.5 and has an elongated shape. The watershed 3 has the highest basin relief value, while the watershed 4 has the lowest value of basin relief.

Keywords: Hydrological analyses; Morphometric analyses; GIS; Al-Batin alluvial fan

1. Introduction

Alluvial fans are known as fan-shaped or conical entities that form on land in front of deep valleys with relatively steep gradients. This fan comprises a variety of coarse rocks deposited sporadically by streams (Al-Sulaimi et al., 1995). Most of the major land features, including alluvial fans and dry valleys, have become important to return to those waterways at this time, whether they occur during rainy periods or in the current climate condition, especially those that occur in dry and semi-arid locations (Al-Sahlan, 2020). Wadi Al-Batin fan is located in the southeastern part of the western plateau in southern Iraq and covers part of the Dibdibba Formation (Jassim and Goff, 2006, Awadh and Al-Ankaz, 2016). This fan, with its head in the south and its base in the north and northeast, takes an important role in the transfer of igneous sediments and rock fragments after their erosion from the Arabian shield and deposition in the form of a fan (Al-Gurairy et al., 2017). The Wadi Al-Batin alluvial

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fan was located in the Mesopotamian Zone, and the dominant sediments are the Dibdibba Formation deposits (Sissakian et al., 2014). The research area has a desert environment with high-temperature extremes and precipitation that are modest and seasonal, with low humidity levels and a rise in the number of hours of sun brightness (Abdulameer, 2016). Wadi Al-Batin Alluvial fan considers the main source in supplying the southern governorates, such as Basra and Samawah with water requirements. It has been studied by many authors like Al-Sharbaty and Ma'ala (1983) that recognized four stages of the fan, Sissakian and Abdul Jab'bar (2014), considered Al-Batin alluvial fan as multistage, and large fan which covered by gypcrete. Al- Kinani and Merkel (2017) describe the Hydrochemical and isotopic investigation of groundwater of the Al-Batin alluvial fan aquifer, while Abd Al Karim (2009) pointed out that the fan of Wadi Al-Batin was formed during the rainy period of the Pleistocene era and mentioned a number of dry valleys that cut through its surface.

Perception of the connection between geological processes and hydrological requires a quantitative morphometric examination of watersheds (Kaliraj et al., 2014). The morphometric properties of a drainage basin-like shape, slope of the drainage area, and drainage density can be linked to a variety of hydrological phenomena (Magesh et al., 2013). The morphometric analysis is used to recognize, describe, and evaluate landform changes across time, from thousands to millions of years. Major elements such as topography, climate, lithology, and landscape all influence geomorphic processes. Morphometric analysis can also help with the development of a water resource management plan and the identification of water quality monitoring sites. The main objective of the research is to study the hydromorphometric characteristics of the Wadi Al-Batin by conducting a hydrological analysis to extract the main hydrological watersheds and their relation with the movement of surface runoff in the region. In addition to calculate the morphometric analyses to study the drainage network and structural analysis of the area based on geological and compositional information and specific data from satellite images.

1.1. The Study Area

The Wadi Al-Batin is an intermittent river in Saudi Arabia, Iraq and Kuwait. It starts from Wadi Al-Rummah in Saudi Arabia, passes through the Kuwaiti border and ends in Iraq. Al-Batin alluvial fan is the biggest fan in Iraq in the Southern Desert (Sissakian et al., 2014). It is located between latitude (30 23-30 51) N and (46 43-4715) E. to extend from the line of equal height (100 m) above sea level and even a streak (5m) above sea level to occupy an estimated space (5.573- 2 m) inside Iraqi boundary (Al-Sulaiman et al., 1995). The fan has 153.6 km in length and 110.192 km in width with an elevation of about (0 – 313) (Sissakian et al., 2011) (Fig 1).

1.2. Geological and Tectonic Setting

Wadi Al-Batin Alluvial fan located within Mesopotamian Zone, Salman Zone, and Zubair Subzone, the Formation exposed in the study area is the upper unconfined of Dibbdba Formation (Sissakian, et al., 2014). the Dibdibba Formation exposed in the study area, it consists of poorly sorted sand and sandstone with gravel. The sand and sandstone are mostly quartz (Al-Sulaimi & Pitty, 1995). Which is bounded by the Takhadid Al-Qurna Fault in the north. It has a regional dip toward the east and northeast (Jassim and Guff, 2006). Al-Batin Fault extended from SE-NE over Wadi Al-Batin from the national border between Kuwait and Iraq and originates from the eastern extremity of the Arabian Shield. The Takhadid-Qurna Transversal fault forms the Basra Transversal Block's northern border, representing Kuwait's southern boundary (Figs. 2 and 3).

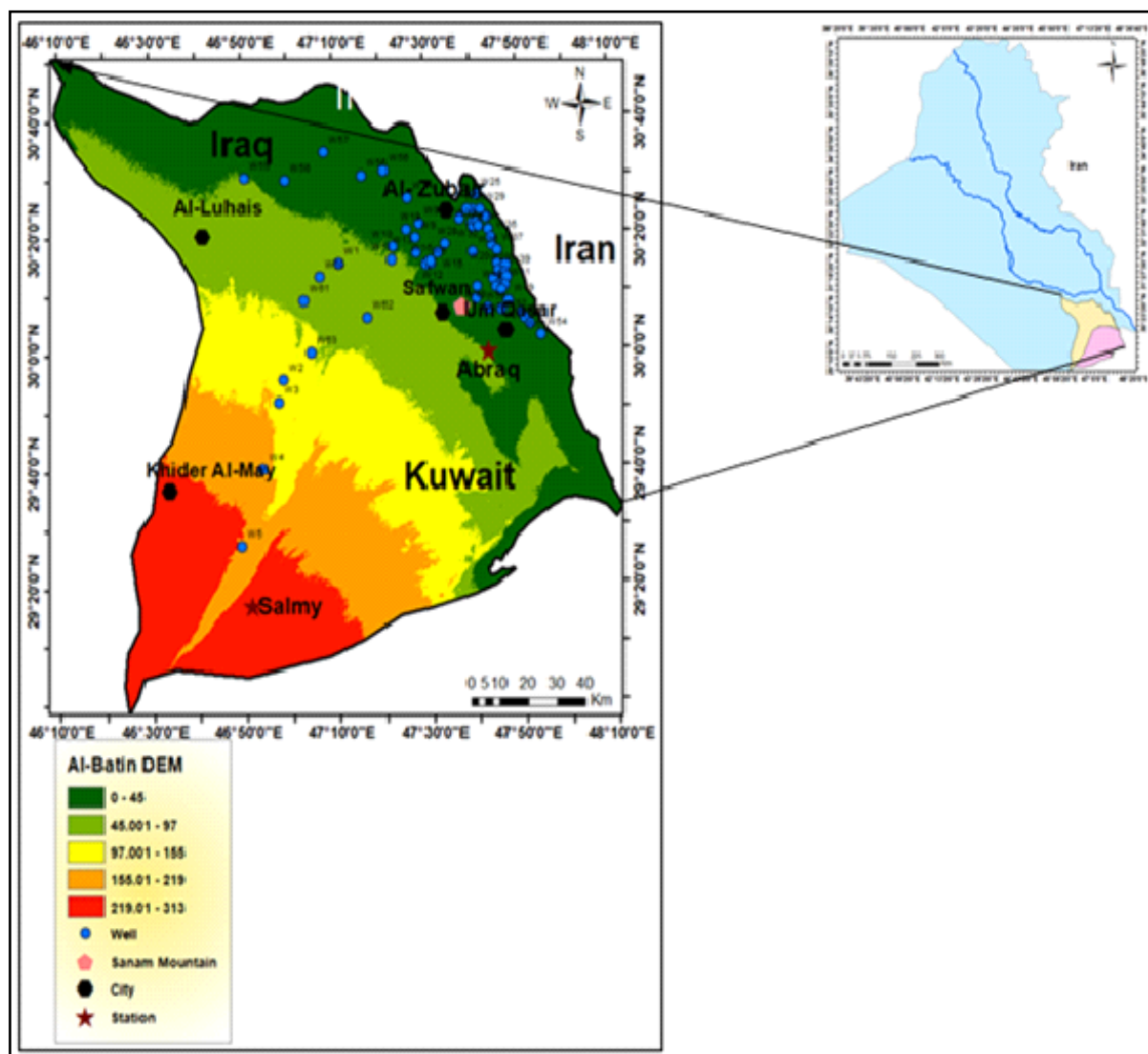


Fig. 1. Location map of the study area

2. Materials and Methods

The hydrological analysis relies on digital elevation model raster DEM data to set up a water system. Three types of morphometric parameters can be divided into linear, aerial, and relief aspects. The hydrological and morphometric analyses were done using Remote Sensing and GIS techniques. Remote sensing data like Global digital model (ASTER GDEM) with 30 m resolution and Landsat oli 8 (USGS earth explorer). The ancillary data consist of the topographic and geologic map. ArcGIS 10.4.1 was used to generate drainage basin characteristics in the Wadi Al-Batin Alluvial fan. Otherwise, the stream order and geometry of the Wadi Al-Batin alluvial fan and its watersheds were extracted using the ArcGIS software's Hydrology toolbox with (UTM - WGS-1984- 38S) coordinate system. The basic mathematical methods are used to calculate morphometric parameters using the GIS program environment by the mathematical equations (Table 1).

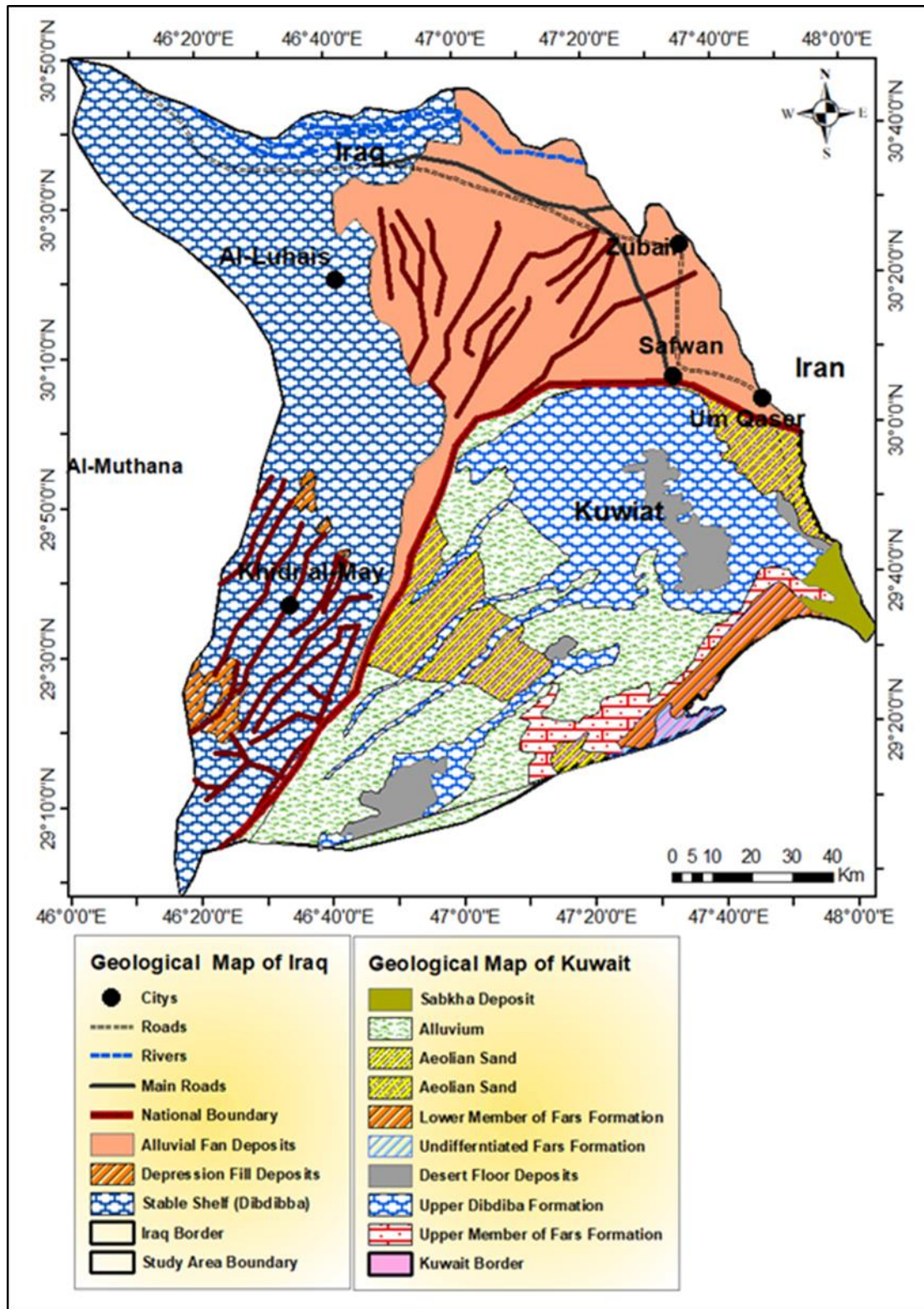


Fig. 2. Geological map of Wadi Al-Batin (Aqrabi et al., 2006; Sissakian and Fouad, 2012)

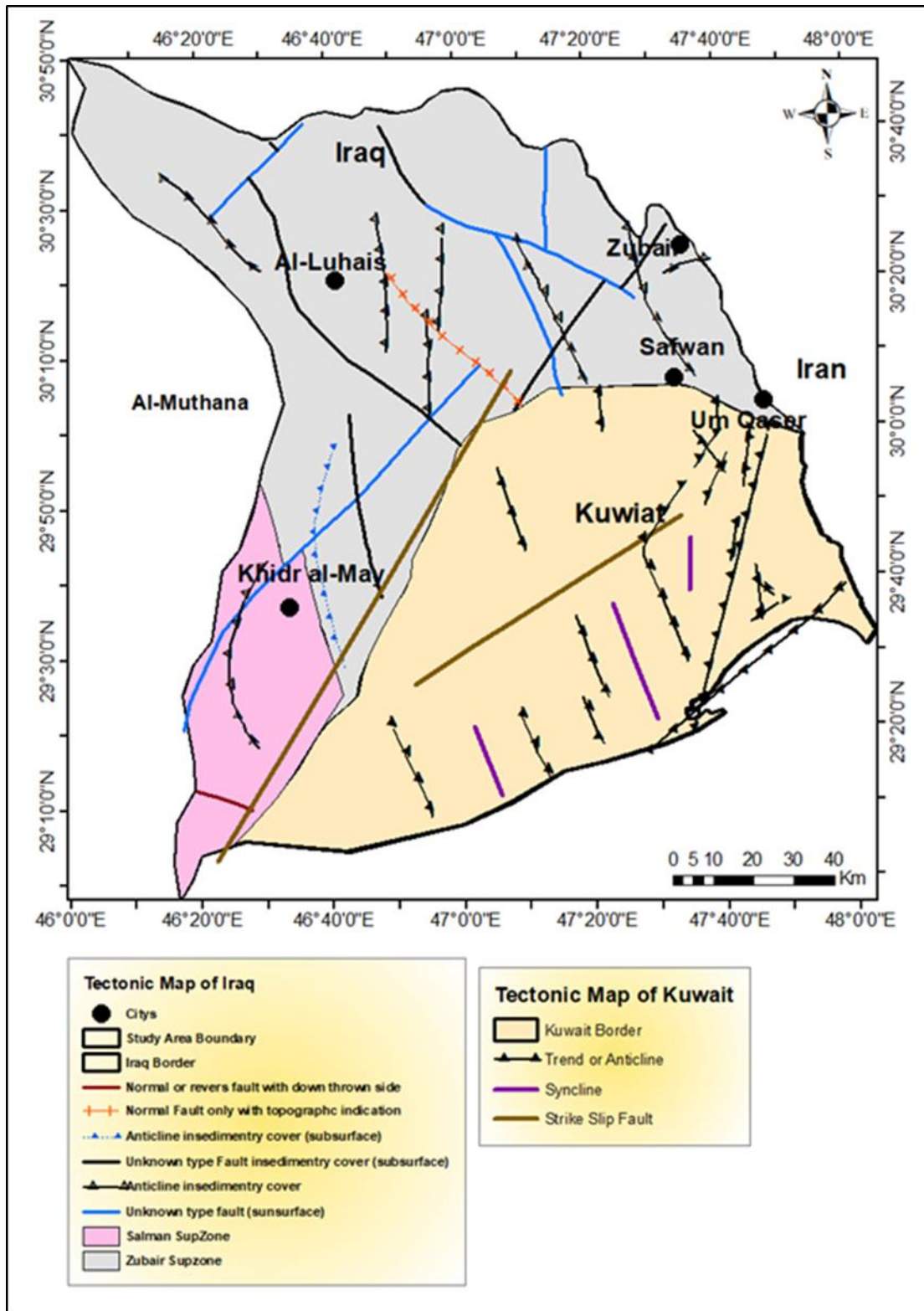


Fig 3. Tectonic map of the Wadi Al-Batin area (Jassim and Goff, 2006)

Table 1. Morphometric parameters mathematical equations.

Morphometric parameters	Formula	Preface
Stream order (U)	Hierarchical rank	(Strahler 1964)
Stream length (Lu)	Length of the stream	(Horton 1945)
Bifurcation ratio (Rb)	$Rb = Nu / Nu + 1$; Nu = Total no. of stream segments of order 'u'; Nu + 1 = No. of segments of next higher order	(Schumm 1956)
Perimeter (P)	The horizontal projection of its water divide	(Zăvoianu 1978)
Basin area (Ba)	The entire area is drained by a stream or system of streams	GIS
Drainage density (Dd)	$Dd = Lu / Ba$; Lu = Total stream length of all orders; Ba = Area of the basin (km ²)	(Horton 1932)
Stream frequency (Fs)	$Fs = Nu / Ba$; Nu = Total no. of streams of all orders	(Horton 1932)
Drainage texture (Dt)	$Dt = Nu / P$; Nu = Total no. of streams of all orders; P = Perimeter (km)	(Horton 1945)
Form factor (Rf)	$Rf = Ba / Lb^2$; Ba= Area of the basin (km ²); Lb ² = Square of basin length	(Horton 1945)
Constant channel maintenance (C)	$C = 1/Dd$; Where, Dd = Drainage density	(Schumm 1956)
Basin Relief (R)	$R = Hmax - Hmin / length$	(Strahler 1952)

3. Results

3.1. Hydrological Analysis

Hydrological analysis can be summarized in Fig. 4.

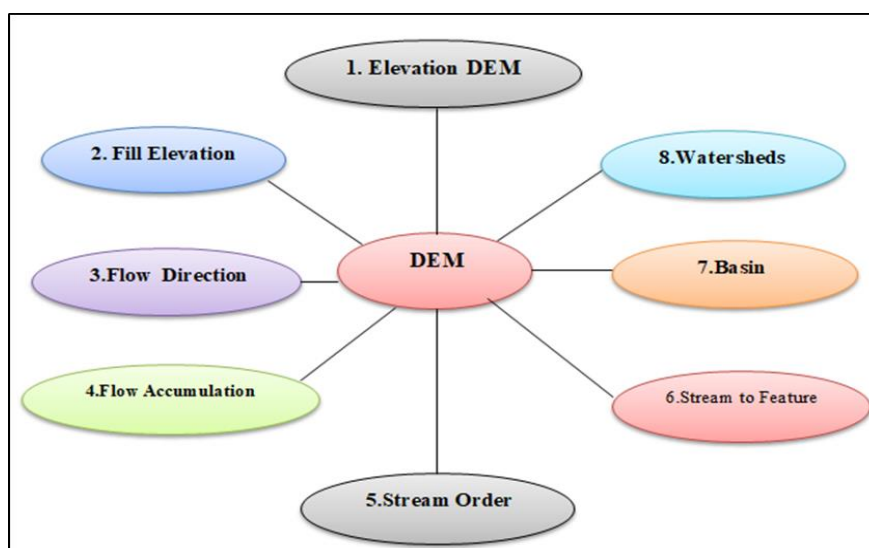


Fig. 4. Hydrological analysis of Wadi Al-Batin Alluvial Fan

3.1.1. Flow direction

Flow direction determines which direction water will flow in a given cell, based on the direction of the steepest descent in each cell (Huggett & Cheesman, 2002). The flow direction in the study area is North and Northeast. Wadi Al-Batin indicates it comprises permeable gravels and coarse sand, alternating with marl. The groundwater level seasonal fluctuations are very small. Alluvial fan lies within the Mesopotamian Zone, which is formed by the active Abu Jir-Euphrates Fault. the transversal Fault system in the study area includes two trends (Al-Batin Fault zone and Al-Batin Fault zone) Extended from NE along Wadi Al -Batin, so we notice many wells in the lower part of the fan and the water flow direction is (South west- North east). It also notes a locality of flow towards the south, which corresponds to the linear structures in the area that may be represented by the structures of the oil fields that are located within the Batin fan (Fig 5).). It uses a pour-point model to show how and in which direction water travels. The eight adjacent cells in the pour point model have a value expressing how water drops.

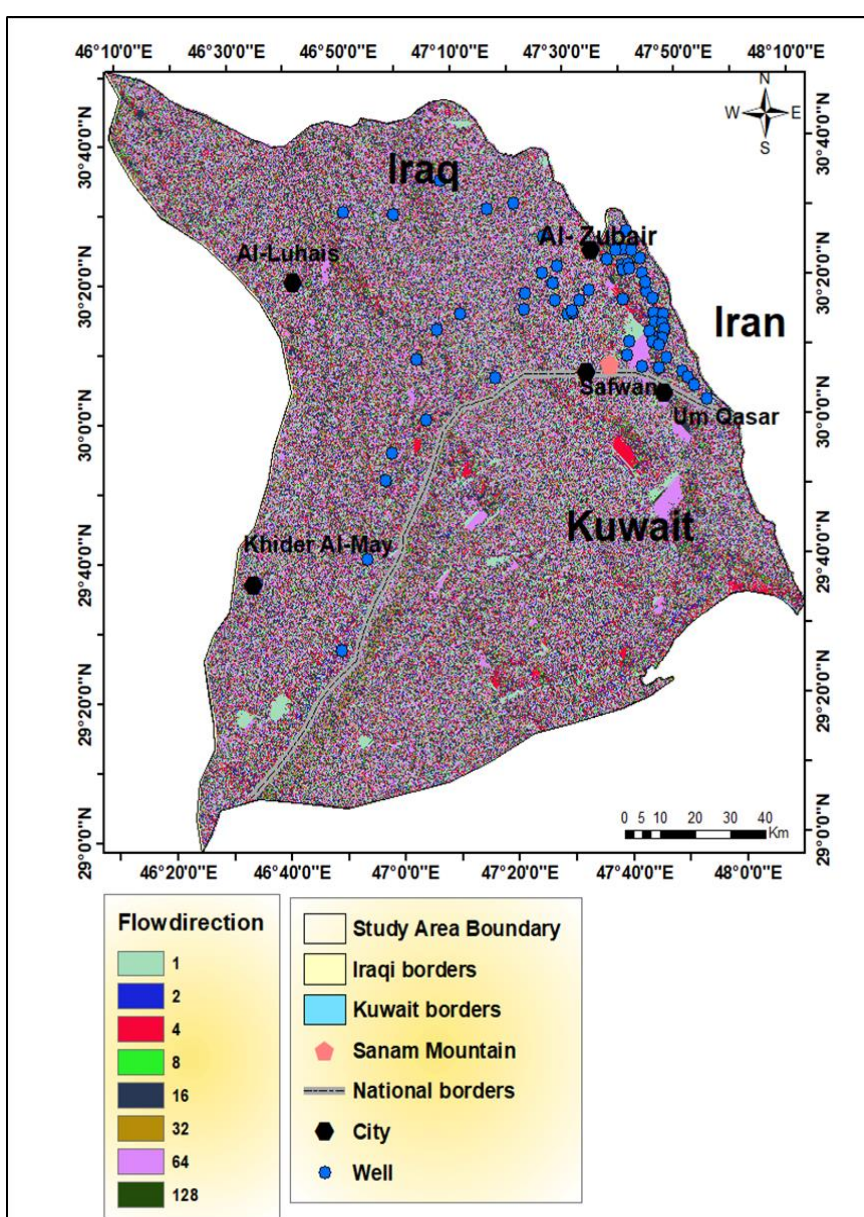


Fig. 5. Flow direction map of Wade al-Batin alluvial fan

3.1.2. Flow accumulation

The tool flow accumulation calculates the total flow for all cells flowing into each downslope cell in the output raster. In the process of modeling runoff, the flow accumulation is determined by estimating the flow direction. The flow accumulation value for each cell is determined by the number of cells that pass through that cell; if the flow accumulation value is lower, the area will be more difficult to create runoff. (Al-Bahadli, 2016). If the flow accumulation value is greater the area will be easier to form runoff. The higher value of flow accumulation of the study area is in the lower part of Fan, while the lower value is in all the Fan is shown in Fig. 6, the precipitation rate is low because the climate of the study area is desert so the value of the flow accumulation is low, depending on that the area will be hardest to form surface runoff. It is seen that the main water accumulation corresponds to the valleys of the main fan of the Batin, such as main valley of the Batin and some of its sloping valleys north and east of the fan are compatible with the slope of course.

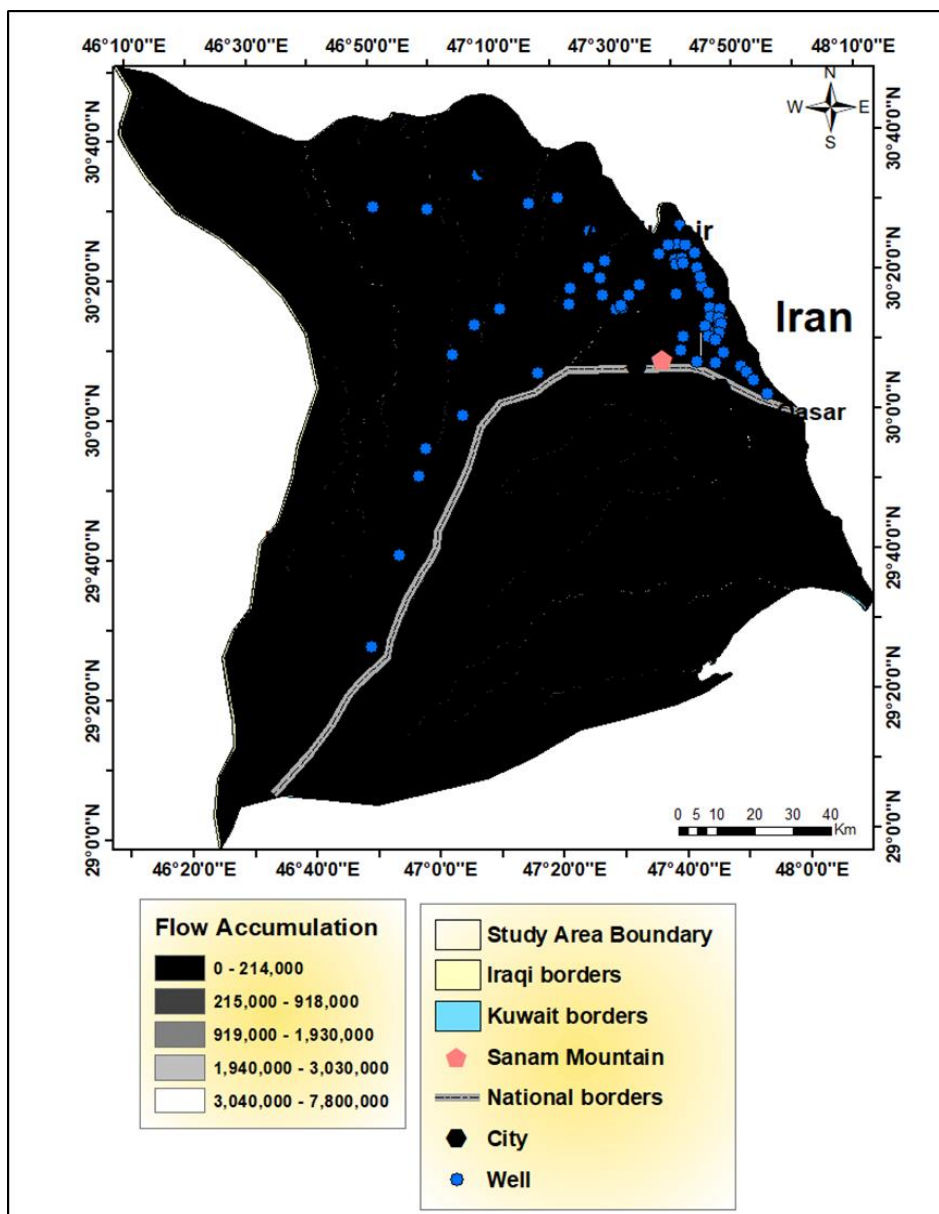


Fig. 6. Flow accumulation map of Wade al-Batin alluvial fan

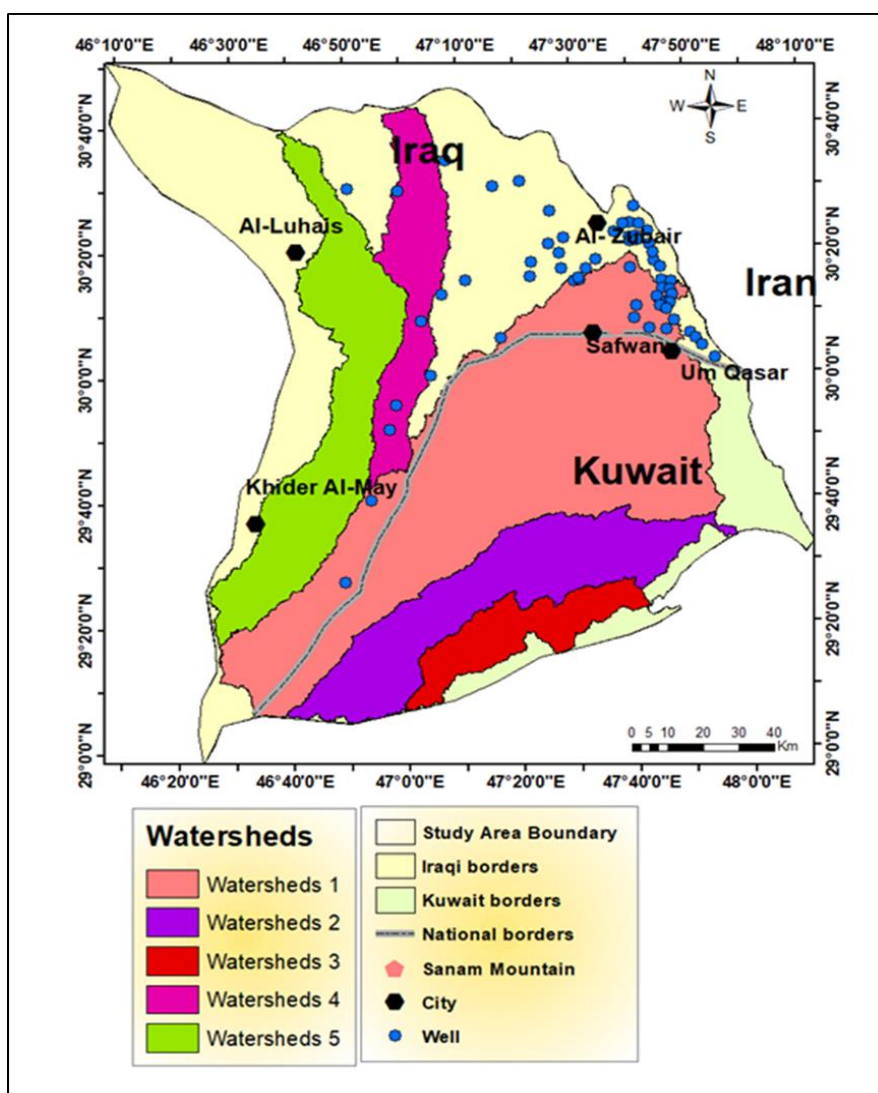


Fig.7. watersheds map in Wadi Al-Batin

3.2. Morphometric Parameters

The morphometric parameters were calculated in Table 2.

Table 2. The Morphometric parameters value for each watersheds

Morphometric parameter	Watershed1 (Wsh1)	Watershed2 (Wsh2)	Watershed3 (Wsh3)	Watershed4 (Wsh4)	Watershed5 (Wsh5)
Stream order (U)					
Stream length (Lu)	172.4	133.87	73.07	114.92	152.56
Bifurcation ratio (Rb)	2.107	2.243	2.05	2.068	20.34
Perimeter (P)	688.17	483.90	284.77	372	558.22
Basin area (Ba)	7021.32	2270.71	876.27	1320.74	2581.78
Drainage density (Dd)	1.54	1.44	1.47	1.46	1.471
Stream frequency (Fs)	1.486	1.580	1.593	1.555	1,505
Drainage texture (Dt)	15.16	7.41	4.90	5.52	6.96
Form factor (Rf)	0.236	0.126	0.164	0.100	0.110
Constant maintenance (C)	0.64	0.69	0.678	0.68	0.679
Basin Relief (R)	1.75	2.21	3.65	1.69	1.92

3.2.1. Linear aspect of wadi al-batin

The liner aspect consists of parameters shown in Table 1. This parameter clearly discussed below.

3.2.1.1. Stream order (U)

The higher number of stream orders in the region associated the steep slopes between the head of the fan and the toe of it. The sediment loads of Wadi AlBatin will increased with increasing stream order as a result from increasing velocity. The geomorphological, topographic, and structural conditions of the studied area have a considerable role in the basin's stream orders. Geological factors such as underlying structures, similar lithology, low reliefs, and easily eroded sediments influence a vast variety of stream orders (Jassim and Guff, 2006). The drainage patterns are located in the upper part of the Wadi al- Batin alluvial fan, where the upper parts are located within the Mesopotamian Zone (Zubair Zubzone) Fig (8). There are many of fault in Al-Batin fan like Al-Batin fault and Abu jir –Euphrates fault . In the south of Iraq the Fault zone including a series of faults sometimes associated with grabens, and a large number of sulfur springs. Wadi alBatin Alluvial fan Southern parts are characterized with high velocity causing increasing in discharge in the vally as a result of the high stream orders.

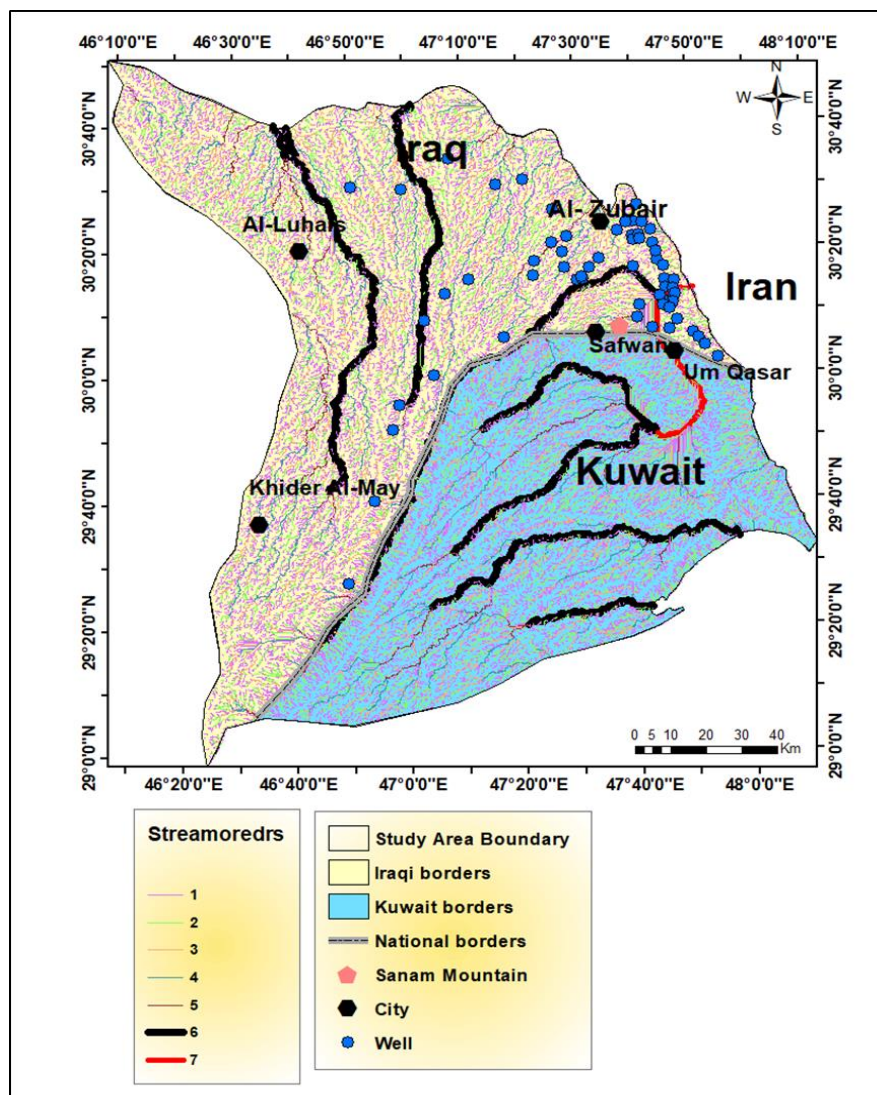


Fig 8. The drainage network(stream order) map of Wade al-Batin alluvial fan

3.2.1.2. Stream length (*Lu*)

The total length of stream segments is at its maximum in the case of the first order, it calculated from the digital elevation model map using GIS for all watersheds. Increasing in stream order can reduce the length of stream in all watersheds. The longest is watershed 1, it is length is 172.4 Km. The shortest is watershed 3, its length 73.078 Km (Table 2), that indicate the hydrological activity in watershed 1. The longer and smaller watersheds of watersheds 1 and 3 indicated flat and steep gradient respectively. Additionally, sub surface structured features like faults and folds control the length of watersheds and their patterns and shapes (Al-Saady, 2016).

3.2.1.3. Bifurcation ratio (*Rb*)

The *Rb* ratio is the number of stream segments of one order divided by the number of stream segments of the next higher order. It's a one-dimensional characteristic that depicts the degree of integration between streams of different orders in a drainage basin. The *Rb* can be linked to a number of critical pollutant transporters and hydrologic watershed parameters (Krenkel, 2012). Thomas (2012) found that low values of *Rb* indicates increasing infiltration rates few channels, while Strahler (1964) concluded it with poorly structural disturbance and lower drainage patterns. The higher *Rb* values indicate high overland flow rate and increased in potential for flash flooding during storm (Kanth & Hassan, 2012). Furthermore, a high *Rb* value suggests a terrain with great structural complexity and limited permeability. Over a long length of time, basins with high ratios produce modest peaks. Furthermore, greater *Rb* values result in decreased sediment delivery, whereas low *Rb* results in flood hydrographs with distinct discharge peaks (Krenkel & Novotny, 1980). The *Rb* values generally ranges between 3-5 which indicates that the drainage patterns are not distorted due to geological structures (Strahler, 1964). The highest *Rb* value of Wadi Al- Batin is 20.34 for watershed 5 and the lowest *Rb* value is 2.05 for watershed 4 (Table 2). *Rb* irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler, 1964). The *Rb* value is proportional to the slope value, with a high *Rb* value suggesting low permeability rocks and steep slopes, also connected to the region's lithology and sediments. Wadi al Batin fan also contains subordinate layers and lenses of silty and sandy clay, as well as sorted gravely sand, sandy gravel, and gypcrete (Sissakian et al., 2014). The area's geological heterogeneity, increased permeability, and structural control are also indicated by the lower *Rb* value.

3.2.2. Areal aspects

The areal characteristics of a basin are its two-dimensional properties. Measurements of areal factors such as watershed shape, watershed area, drainage density, drainage texture, stream frequency, and consistent channel maintenance that included (Al- Sahlani, 2020).

4.2.2.1. Perimeter(*P*) and Basin Area

Basin perimeter (*P*) is a significant parameter in quantitative morphometric research are can be used to determine the size and shape of a watershed. It's the watershed's outer boundary, which could surrounded its area and can be calculated along the line represent the water divide between watersheds. The higher basin perimeter is 687.72 Km for watershed 1, while the lowest basin perimeter is 284.48 km for watershed 3 (Table 2). Basin area controls the surface runoff volume ratio more than the other geomorphic parameters (Murphey et al., 1977). It has a great influence on the relation with the maximum discharge per unit area, where the smallest basin area has rapid rain water. the higher basin area is 7021.31 Km² for watershed 1, while the lowest basin area is 876.27 km² for watershed 3 (Table 2).

3.2.2.2. Drainage density (Dd)

The total length of all orders per unit drainage area is known as drainage density which can be determined by the basin's geology and physiographic properties, such as rock type, climate, soil type, tectonic activity, the form of basin, relief, and land cover type. The highest value results of Dd is 1.54 Km/Km² for watershed 1 while lowest value was 1.44 Km/ Km² for watershed 2. The Dd values were ranged between (0.483-6.45), (0.07 – 2.49), (0.04- 9.63), (0- 14.02), and (0.12- 7.87) in watershed 1, watershed 2, watershed 3, watershed 4, and watershed 5 respectively. Fig. 9 shows the distribution of the Dd in watershed 1 were the higher value located at upper and middle parts from watershed 1, the lower value of Dd located in the lower part of watershed1 , in watershed 2, the higher value of Dd located in the higher part and lower value of Dd located in the lower part. The Drainage density results show that the higher and lower value were concentrated at the upper middle parts and the lower part of watershed watershed 3, the higher and lower values of Dd over occur in the middle and rest parts of watershed watershed 4. In watershed 5 the higher value of Dd is located in the upper part and the lowest value located in the lower part (Table 2). There are three types of Dd according to Deju(1971) as Poor, Medium, and excellent with 0.5, 0.5 – 1.5 and 1.5 respectively. The lower values of drainage density can be attributed to the increases in topography, subsurface structures (lineaments) density, and resistant rock in comparison with the lower part which are characterised by nonresistant or impermeable subsurface geological materials, little plants and lower in reliefs and basins.

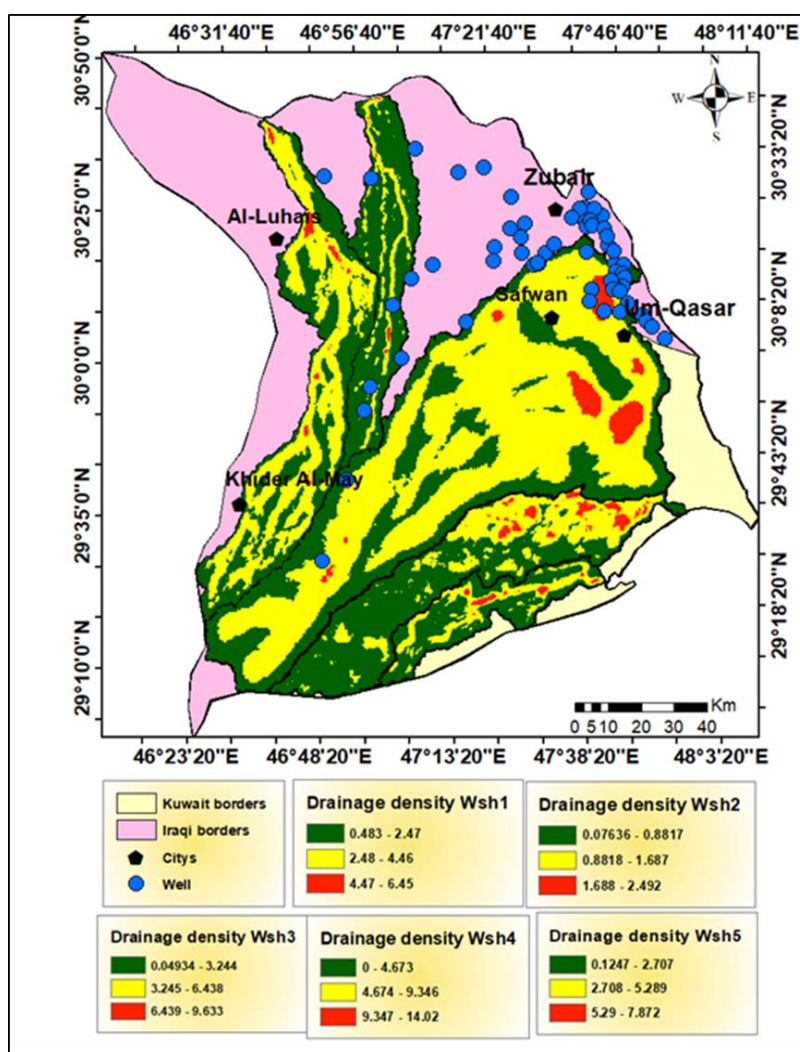


Fig. 9. Drainage density map of Wade al-Batin alluvial fan

3.2.2.3. Drainage texture (Dt)

The total number of stream branches of all orders per unit basin perimeter is known as drainage texture. The distance between drainage networks is represented by Smith (1950) divided the Dt into five textures: extremely coarse (number 2), coarse (2–4), moderate (4–6), fine (6–8), and very fine (number >8). Dt is considered as coarse in the beginning of the erosion cycle, while it considered fine in the maturity stage (Smith, 1950). Fine texture is produced by soft or weak rocks exposed by plants, and coarse texture is produced by huge and resistant rocks. Arid climates have finer textures than those generated on similar rocks in humid climates (Dornkamp & King 1971). The lower of the infiltration will be resulting in the higher runoff. The results Dt values in the present study show highest value of Dt is 15.16 indicated very fine for watershed 1 while the Lowest value of Dt is 4.90 considered as moderate for Wsh3. According to (Smith, 1950), the Dt value IN Wadi Al-Batin range between fine, moderate, very fine, that indicate the geological setting of the region consists of the Dibdibba Formation exposed in the study area, the thickness ranges from 3-8 m. It is made up of poorly sorted sand and sandstone, gravel, and climatic influences such as the region's desert temperature, lack of vegetation, low infiltration rates, and soil exposed to weathering and erosion. As a result of all of these factors, the soil textures of Wadi Al-Batin ranged from fine to moderate to very fine (Table 2).

3.2.2.4. Stream frequency (Fs)

The number of stream branches of all sorts per unit drainage basin area is stream frequency (Horton, 1932). Rainfall amount, lithology, permeability, infiltration capacity, relief, basin form, and the type of structural characteristics all influence the stream frequency. The highest value of Fs is 1.59 for watershed 3 while the lowest value is 1.48 for watershed 1 as shown in Table 2, that because a large number of well concentrated in this Watersheds in comparison with the other watershed in region. Also, The topography of the region is described as flat, rising in elevation southwards. The primary landscape is plateaued, with extensive valleys running across it. Fault escarpments, some of which extend for tens of kilometers, are other distinctive features. All of these reasons lead to the increasing value of Fs for watershed watershed 3. The Fs results are ranged between 1,33-11,68 for watershed 1, (212.3-3.29) for watershed 2, (34.59- 1,972) for watershed 3, (0- 4,469) for watershed 4, and (47.11- 3,63) for watershed 5 (Fig. 10). The stream frequency has positive relationship with Drainage density in all subbasin of the study area where, the high value of stream frequency indicate the occurrence of impermeable geological materials. The lower values of Dd and Fs with the steep gradient of the basin indicates increasing and decreasing in surface runoff and infiltration rate, respectively which can result in high flooding and landslides (Rekha et al., 2011).

3.2.2.5. Form Factor (Rf)

The form factor is calculated as the ratio of basin area to stream length squared. Rf can range from 0 (for a severely elongated shape) to unity 1 (for a completely circular shape) (Babar, 2005). The Rf results show that the higher RF value is (0.236) for watershed 1, while the lowest RF value is 0.100 for watershed 4 as shown in Table 2. Increasing in form factor causing circular shape of the basin. The watershed with a high value of Rf has a high peak flows of shorter duration, while the lower values indicate an elongated shape of the basin. The RF value of all watersheds is less than 0.5, and they have an elongated or fern-like structure. Because all of the streams are almost the same length, a fan-shaped watershed delivers increased runoff, the fern shape result of the basin indicate decreasing discharge rate that need longer time to accumulate (Raghunath, 2006).

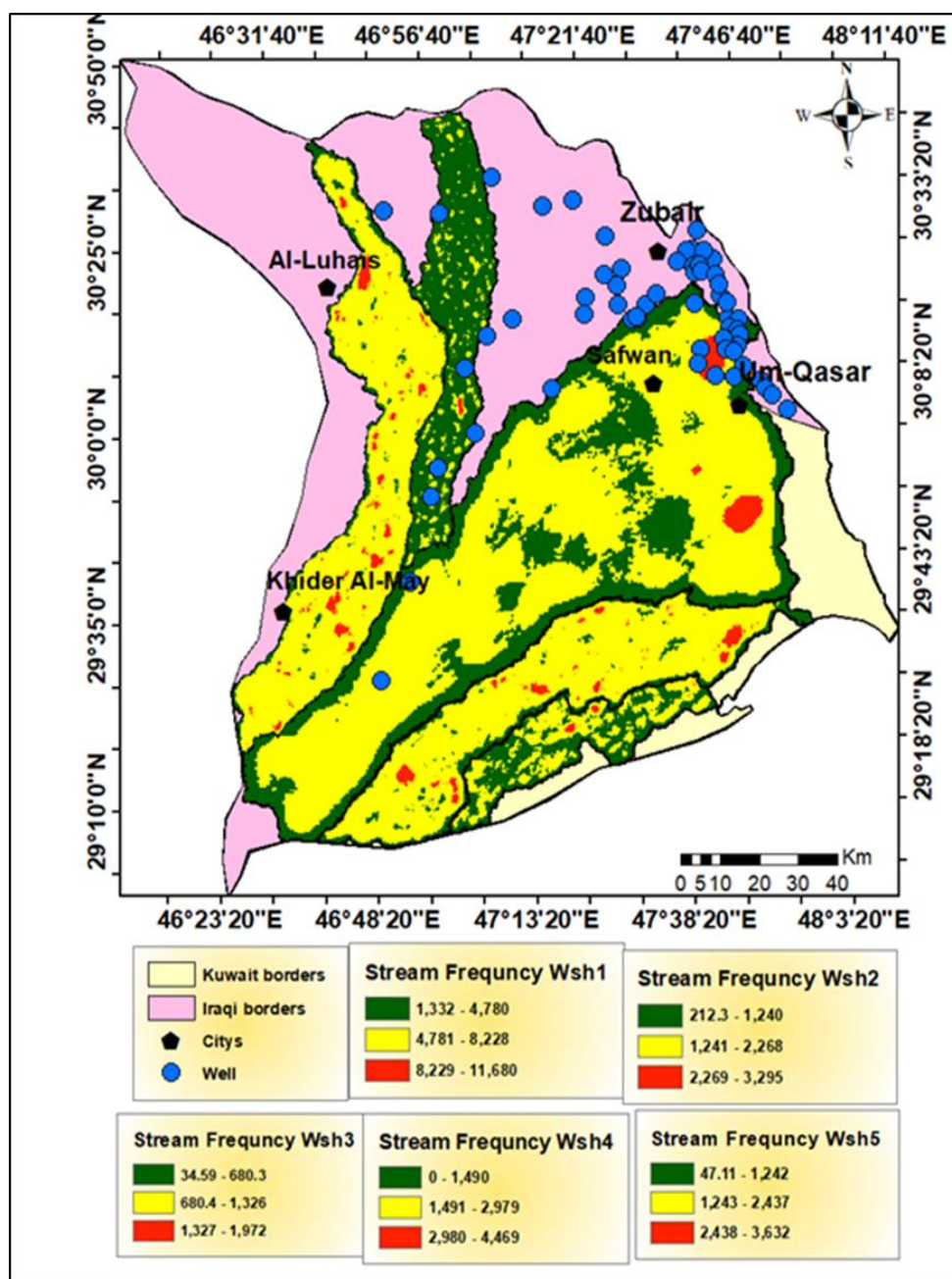


Fig. 10. Stream frequency map of Wade al-Batin alluvial fan

4.2.2.5. Constant of channel maintenance (C)

The channel maintenance constant is a texture measure; this constant is a great way to compare the surface readability erodible or other morphologic elements. This factor is greatly affected by the erosion process at the surface and change in drainage patterns, it can be used to estimate areas of future sediment loss in parts of a drainage system that have yet to be dissected (Schumm, 1956). The highest C value results is 0.69 for watershed 2, while the lowest value of C is 0.64 for watershed 1 (Table 2). The different in the slope factor of the basin is the main reason for change in C values, the infiltration rate is low in the region because it has arid climate, vegetation cover, lithology, and rainfall intensity. The C value for watersheds suggest longer flows and gentle slopes. The high value suggests increase and decreasing in infeltration and credibility, permeability and runoff rate respectively (Ritter et al., 2006).

3.2.3. Relief aspect

The Relief aspect parameters consist of the elevation of highest and lowest points, basin relief. Basin relief defined as the change between the highest and the lowest point of the drainage basin. The highest elevation areas are located in the northern parts of Al-Batin Fan and which reaches up 313 m, the lowest elevations 0 m are located in the southeast parts for Al-Batin fan in the basins (Fig. 1). The highest basin reliefs value is 3.65 m of watershed 3, while the lowest basin reliefs value is 1.69 m for watershed 4 as shown in Table 2. The increasing and decreasing in basin relife values will occurred in complex terriansn and hille and flat terrian respactive. Higher relief caused increasing flow rate, subsedance and lowering in infiltration rate (Patton & Baker 1976). The results show that the groundwater catchments in the eastern and northeastern parts of the fan are represents the lowest parts in elevation as well as the basins between the fan valleys. It is also possible to notice in Fig. 11, that is consistent with the gathering of groundwater catchments and wells with linear shapes such as faults and subsurface structures such as the Euphrates fault along Khor Al -Zubair as well as Al-Batin transversal fault and other lineaments appeared in shaded reliefs map

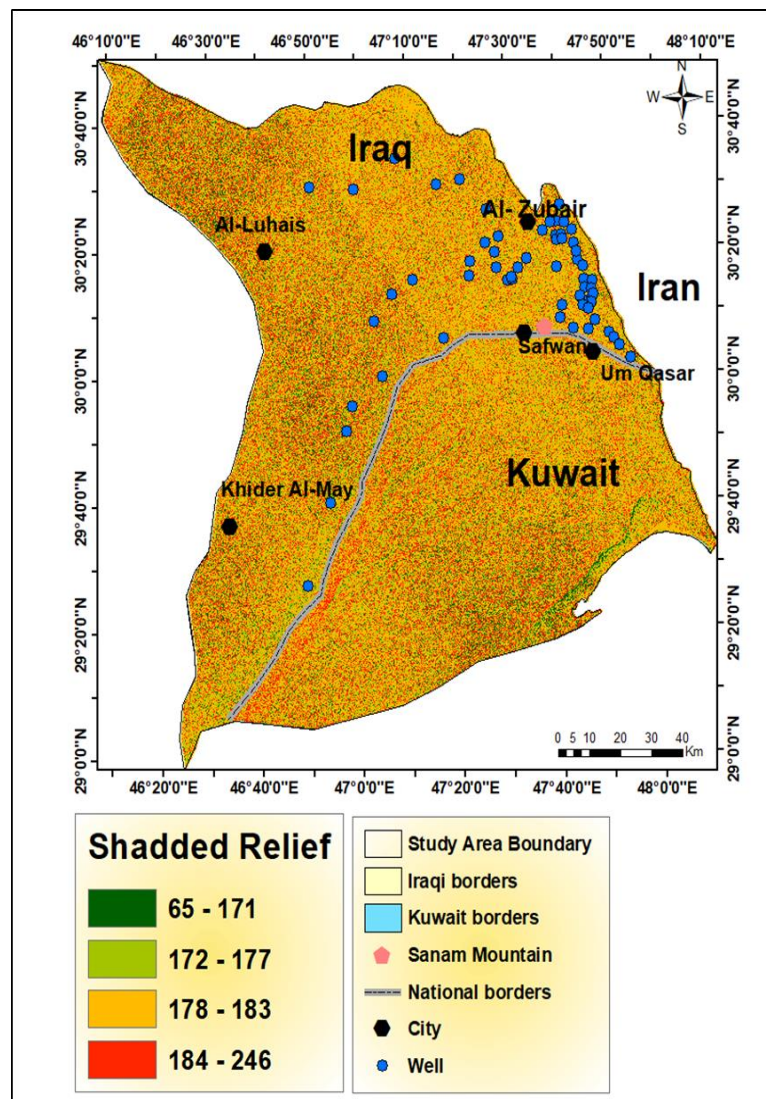


Fig. 11. Shaded reliefs map of Wadi Al-Batin alluvial fan

4. Conclusions

- The morphometric characteristics and hydrological drainage network of the Al-Batin alluvial fan were extracted using remote sensing (ASTER GDEM) data and GIS techniques which reveal a very useful tool
- The flow direction of Al- Batin alluvial fan is from southwestern to northeastern in addition to a locality direction to the north which corresponds to the linear structures represented by the structures of the oil fields within Al-Batin alluvial fan.
- The hydrological analyses result show that Al-Batin alluvial fan consists of five watersheds classified according to the local structural and topographical situation. There is a strong relationship between stream order and morphometric characteristics in all watersheds of the Al-Batin alluvial fan where the maximum stream order in all five watersheds is 7 .
- Watershed 1 is the longest watershed in the present study area in compared to the other watersheds that are dependent on the nature of the study region's subsurface structure.
- Because the Bifurcation value has a direct relationship with slope, and the Wadi Al-Batin is known for its steep slope, the Bifurcation value for the studied area is high.
- The watershed 1 is notable for having a high basin parameter, a large basin area, and a high drainage density. Drainage texture is also present in Al-Batin fans as fine to moderate or very fine. In addition to the topography of the region is flat and rising in elevation southwards.
- The basin relief parameter depends on the height of the basin, as well as the greatest elevation area located in the northern part of the fan and the lowest elevation area located in the southeast parts of the Al-Batin fan. All the watersheds have low relief aspect parameters except for watershed 3 which has the largest basin relief.

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