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

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Abstract

This research aimed to know the tectonic activity of the Wadi Al-Batin alluvial fan using hydrological and morphotectonic analyses. Wadi Al-Batin alluvial fan is deposited from Wadi Al-Rimah in Saudi Arabia, which extended to Iraqi and Kuwait international boundaries. The longitudinal and transverse faults that characterize this region were common. The Abu- Jir-Euphrates faults have a significant impact on the region. The faults zone consists of several NW- SE trending faults running from the Rutba in western Iraq to the south along the Euphrates through Kuwait and meeting the Al-Batin fault to the Jal Al-Zor fault. The Hydromorphometric analysis of the present fan shows five watersheds having asymmetry shapes, more elongated and activity from the elongation ratio and asymmetry factor values. In contrast, transverse topographic symmetry and mountain front sinuosity factor have moderate to low activity from the stream length gradient index. The morphotectonic analysis suggests that the Wadi Al-Batin alluvial fan has a moderate tectonic activity due to the tectonic activity of the subsurface lineaments and the oil field activities found in the region.

Keywords: Watersheds, Morphotectonic analyses, Geographic Information System (GIS), Remote Sensing (RS), Al-Batin alluvial fan, Iraq

التحليل المورفوتكتوني لمروحة وادي الباطن, جنوب العراق, باستخدام التحسس النائي و تقنية نظم المعلومات الجغرافية

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الخلاصة

تبدأ مروحة وادي الباطن بالترسب من وادي الرمة في السعودية وتمتد الى الحدود الدولية للعراق والكويت. الهدف الرئيسي من البحث هو معرفة الفعالية التكتوني لمروحة وادي الباطن، باستخدام التحليلين المورفوتكتوني والهيدرولوجي. تتميز المروحة بمجموعة فوالق طولية وعرضية منتشرة في المنطقة, وقد تأثرت بشدة بنشاط فالق الفرات – ابو جير. تضم المنطقة العديد من الفوالق الشائعة شمال غرب – جنوب شرق الممتدة من منطقة الرطبة في غرب العراق وتستمر جنوبا "على طول نهر الفرات لتصل الكويت مع فالق الباطن المتصل بفالق جال الزور. اظهر التحليل الهايدرومورفومتري للمروحة الحالية ان المروحة تتألف من خمس مستجمعات مائية ذات اشكال غير متماثلة، اكثر استطالة وذات فاعلية عالية من خلال نسبة الاستطالة

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ومعامل عدم التماثل. تبين منخلال نتائج معاملات التدرج الطولي النهري والطوبوغرافية والجبهة الجبلية ان جميع المستجمعات ذات فعالية متوسطة الى قليلة. يستنتج من خلال التحليل المورفوتكتوني ان مروحة وادي الباطن ذات فعالية تكتونية متوسطة نتيجة للتراكيب الخطية التحت سطحية، ونشاط الحقول النفطية المنتشرة في المنطقة.

1. Introduction

Alluvial fans are gently sliding conical fan-shaped slopes that begin at steep mountain drainage outlets and exit into low-relief basins with little stream strength. In plain sight, the cone-shaped deposit is fan-shaped. Stream channels have been formed into the material of alluvial fans in some areas. Alluvial fans differ from alluvial plains in that the fluvial system in fans is a distributary, whereas it is through-flowing in plains. [1] The fan is evidence of a sediment buildup formed like a Shallow cone section, with its apex at a point source of sediments. They are common in mountainous terrain in dry to semiarid climates, although they can also be found in more humid areas with heavy rainfall.

Alluvial fans form in the region of sedimentary basins, which can be tectonic sites with fault movements over the basin's area, causing elevation of the catchment area and basin subsidence. Alluvial occurs at the base of faulted mountain blocks [2]. In tectonically active places that connect mountains and lowland valleys, the most common and optimum conditions for alluvial fans' generation and long-term growth can be found [3].

Wadi Al-Batin Alluvial fan considers the main source in supplying the southern governorates, such as Basra and Samawah, with subsurface water requirements. It has been studied by many authors like [4] that recognized four stages of the fan. [5] described Al-Batin alluvial fan as a "multistage, large fan encased in gypcrete". [6] describe the groundwater of the Al-Batin alluvial fan aquifers with a hydrochemical and isotopic investigation, while [7] pointed out the geomorphology and the type of source rock for the volcanic fragments in Wadi Al-Batin. Found Wadi Al-Batin is the main responsible for the transfer of many types of igneous rock fragments and sediments to Iraq and Kuwait.

Morphotectonic means a fundamental to understand landscape evolutions [8]. The interaction between tectonic and surficial operations that contribute to the production of geomorphological structures is explained by tectonic geomorphology. It also enables geomorphology to determine the date, size, and rate of active tectonics [9].

The present study applies morphotectonic analysis to evaluate tectonic activities. The geomorphic indices have been used to assess the geomorphological analysis of the channels in the study area.
The main objective of the present study area is to evaluate the morphotectonic parameters of the Al-Batin alluvial fan to show the tectonic activity and delineate the present fan's subsurface lineaments.

2. Regional Setting

2.1 Study area location

The Al-Batin alluvial fan is one of Iraq's most significant fans, extending from the Iraq-Kuwait border in the northeast to its origin at 390 km southwest in Saudi Arabia, known as Wadi Al-Rimah [10]. It is the main geomorphological unit in the southwestern area, mainly within Basrah Governorate, south of Iraq, between latitude (30° 23′-30° 51′) N and longitude (46° 43′ - 47°15′) E). The fan represents the southern and northern limits of the Iraqi and Kuwait international borders respectively [11]. It covers 22384 Km^2, with an elevation varied from 0 t0 313m above sea level (Figure 1). The morphometric analysis of the present study area was classified into five watersheds (Figures 2A and B).

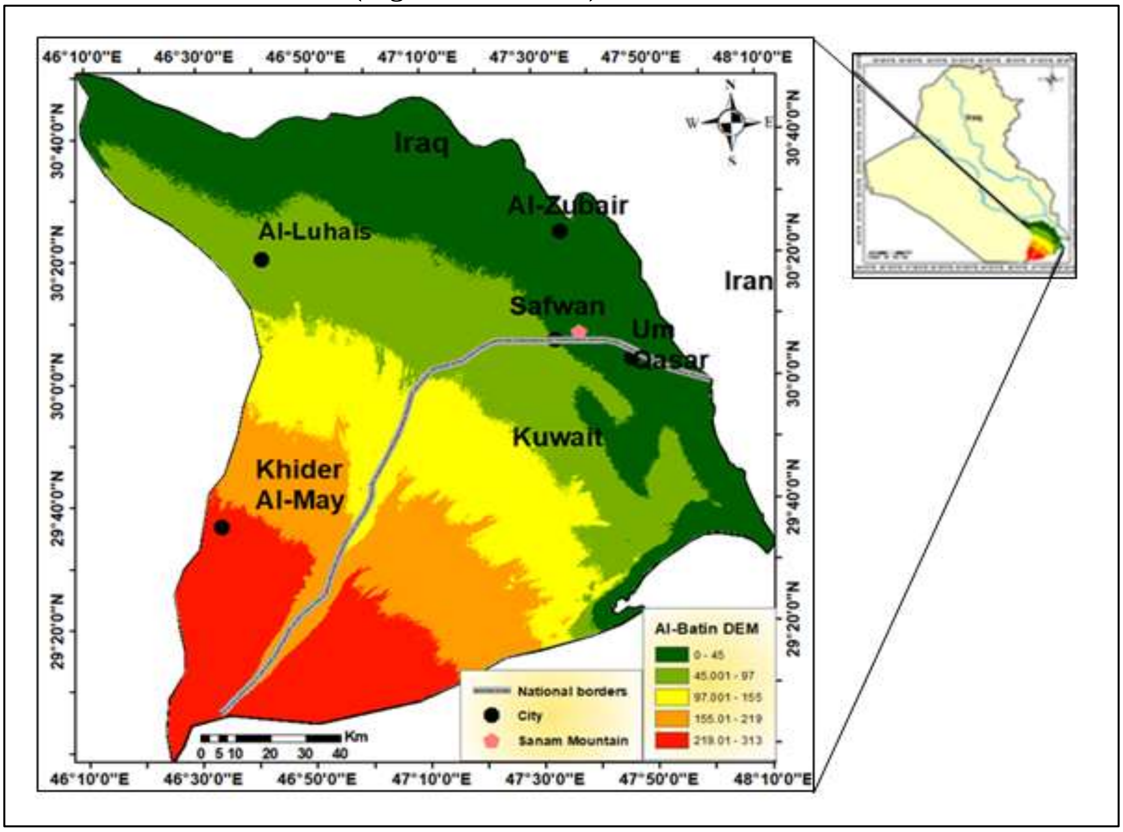
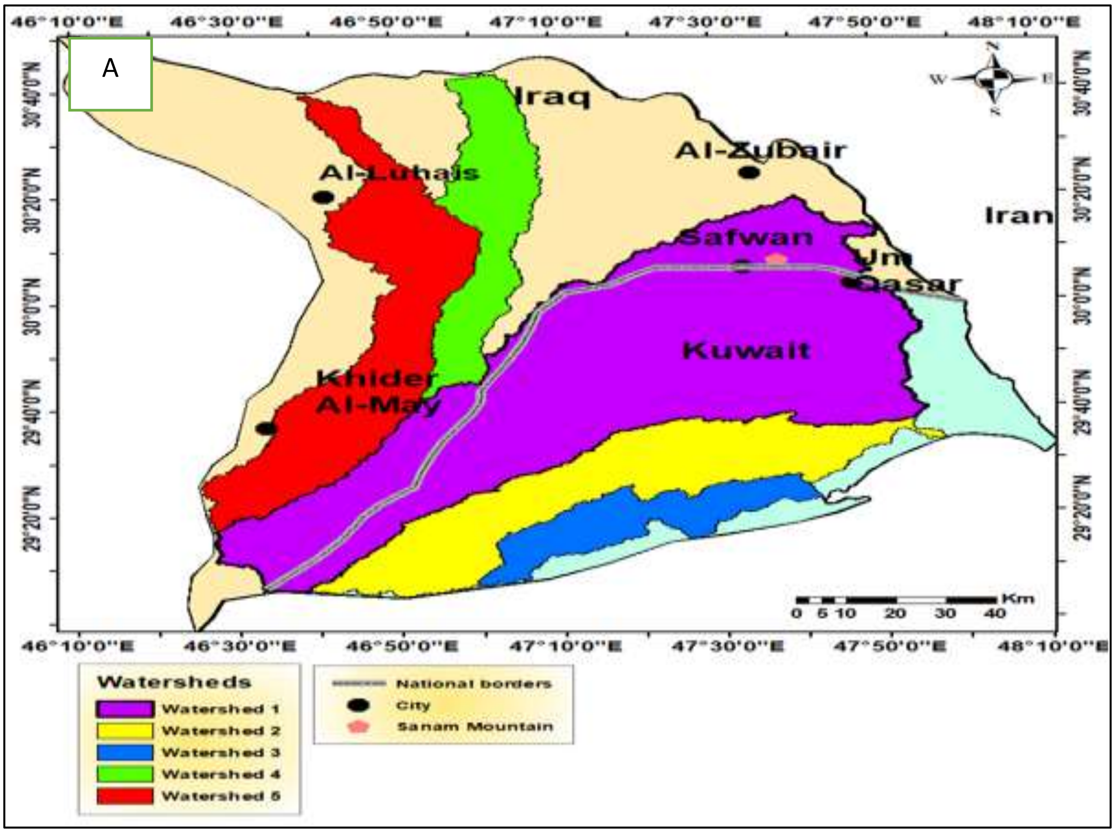


Figure 1: location map of the study area.



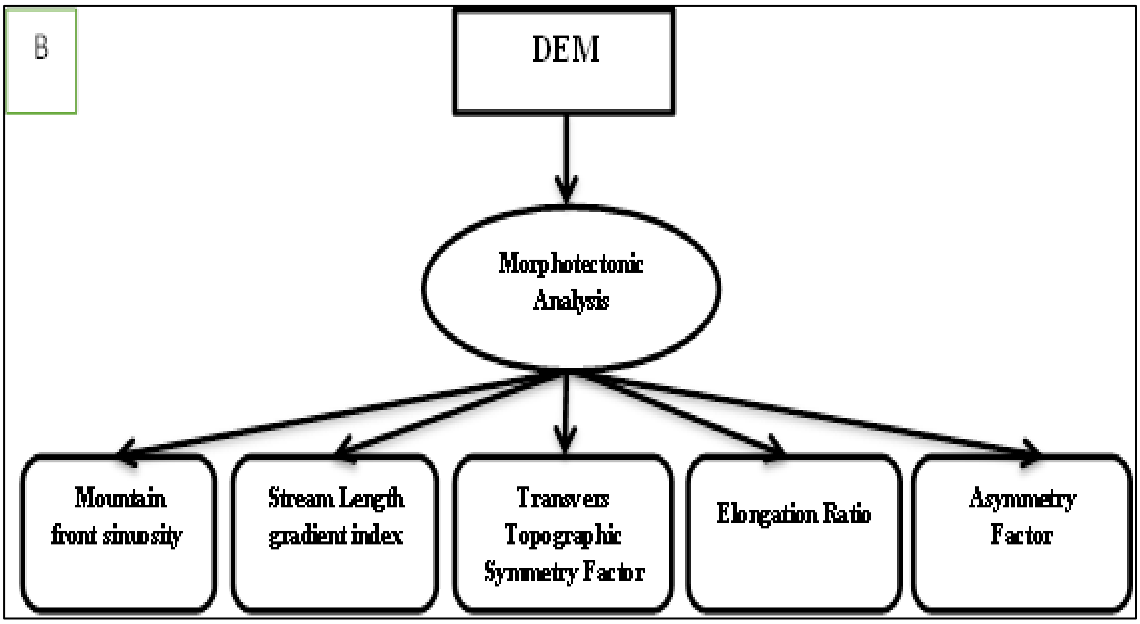


Figure 2: A, Five watersheds; B, Flowchart of the Morphotectonic Analysis.

2.2 Geological and Tectonic setting

The Dibdibba Formation is exposed in the study area with thickness ranging from 3-8 m [12]. It consists of poorly sorted sand and sandstone with gravel. The sand and sandstone consist of 84.2% quartz grains of mono-crystalline type, with around 8.5% of rock fragments and 7.3% of feldspar. The age of the Dibdibba Formation is a matter of argument; it is assumed to be Late Miocene-Pliocene to Early Pleistocene [13] (Figure 3). In Kuwait, the Dibdibba Formation covers most of the northern area, divided into upper and lower members. The upper member of the Dibdibba Formation underlies the extensive undulating plain of north and northeast Kuwait and extends towards the southwest as capping to the sinuous ridges characteristics of the northwest area of Kuwait. It is mainly composed of very coarse-grained sand with plenty of scattered pebbles, cobbles and boulders. The lower member of the Dibdibba Formation is exposed in the west and north-central Kuwait, including the escarpment zone of Wadi Al-Batin. It is formed of weathered brown medium to coarse-grained gritty and pebbly sandstone. Holocene sediments cover the most ancient rocks in Kuwait, consisting of inland deposits, including alluvial sediments, windblown sand, playa sediment and coastal deposits, desert floor deposits and marine sand [14] and [15].

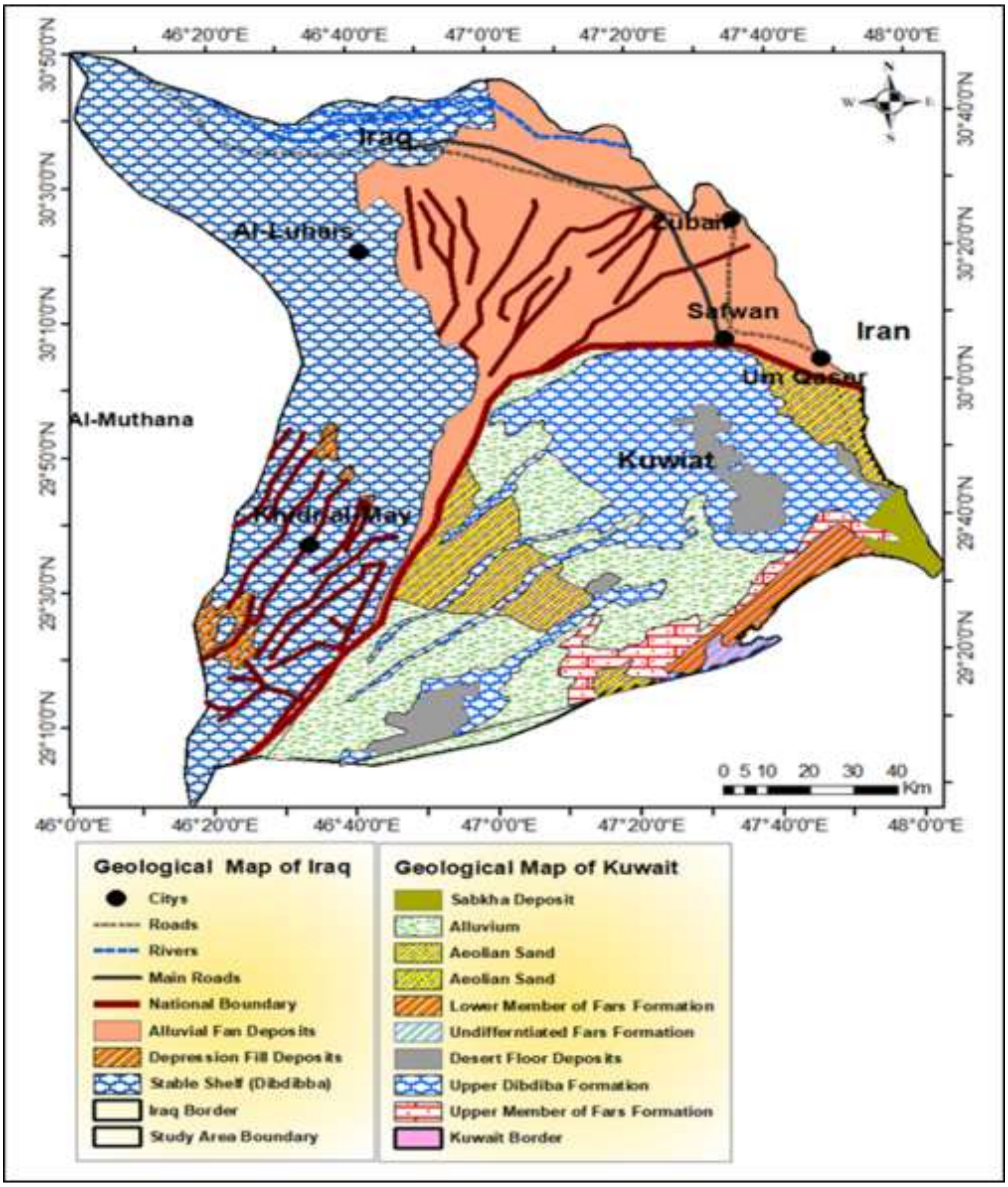


Figure 3: Geological map of the study area [14] and [10].

3. Materials and Methods

3.1 Morphotectonic Indices

Several geomorphological indices have been developed to determine the geologic features of active tectonics and relative tectonic activity to obtain valuable information regarding tectonic processes and periods of recurrence of seismic events. Stream channels may witness offset, marine terraces may be faulted, uplifted, tilted, or folded, and alluvial fans also faulted or folded. Deformation can be measured in the field or from topographic maps.

3.2 Morphotectonic Parameters

The morphotectonic analysis was described by many morphotectonic parameters, which are indicated by the interaction between surficial and tectonic operations that produce geomorphic features. All the morphotectonic parameters are calculated by the various formulas (Table 1):

Table 1: The morphotectonic parameters were computed using the following methodology.

Morphometric parameters	Formula	References
Elongation ratio (Re)	Re = 2 √((Ba /π)) / Lb.; Ba = Area of the basin (km2); Lb. = Basin length in Km	[16]
Asymmetry factor (AF)	AF=100(Ar/At): Ar: is the basin area to the right of the watershed facing downstream . At: is the total area of the drainage basin.	[17]
Transverse topographic symmetry factor(T)	T=Da/Dd: Da: is the space from the midline of the drainage watersheds to the midline of the active belt, Dd: is the space from the midline to the basin limit.	[18]
Stream length gradient index (SL)	SL=(ΔH/ΔL)L: Where SL: is Stream Length- Gradient Index, L : is the total channel length from the midpoint of the reach to the highest point on the channel, ΔH : is the change of elevation, ΔL : length of the reach (local change in channel slope)	[19]
Mountain-front sinuosity (Smf)	Smf=Lmf/Ls: Lmf : is the length of the mountain front piedmont, Ls : is the straight line length of the whole mountain front.	[20]

4. Result and Discussion

4.1 The most critical morphotectonic indices applied in the present study can be described as follows:

4.1.1 Longitudinal profiles

Streams have witnessed periods of tectonic uplift, climate changes, and watershed developments. The longitudinal profiles of streams provide different data for concluding the structure and tectonic information of the area.

The longitudinal profiles within the Al-Batin streams (wadies) have the following characteristic:

1. Figure 4A shows the cross-section X-X ´ that represents the main channel of Wadi Al-Batin. The section has several knick points, the most noticeable of which are located in the middle of the section intersecting the main valley with the Euphrates - Abu Jir Fault, and another when the valley runs within some subsurface structures.
2. The longitudinal profile at the end of Figure (5) shows the shape (bay of Kuwait), with steep breaks at the two-end marking the faults scarp in Jal-Al-Zor fault, it is displaying the deformation in the region caused by the growth of the subsurface structure of the oil filed and the fault effects, as the anticline reflects active tectonics.
3. Generally, the figure clearly shows the successive sedimentation stages of the Al-Batin alluvial fan. The cross-section profile (y –y') in Figure 4B depicts subsurface features of oil fields (Rumaila, Al-Zubair, and Ratawi structures) that suggest a continuous uplift process reflecting tectonic activity. They gradually rise and are higher than their surroundings in the north and east regions due to the various uplifting tectonic activities, fault activity and the activity of Abu-Jir –Euphrates and Jal-Zor faults.

4. The longitudinal profiles show that the slope of the Al-Batin fan is steep from apex to toe (Figure 5A and B). The slope has four breaks that may reflect the different rates of the tectonic process, the activity of the subsurface structures such as anticlines (oil fields), and faults.

5. From Figure 5A, the main channel of Wadi Al-Batin has been affected by the transverse fault (Al-Batin Fault) and some valleys branching from the main channels in the north and west. In addition, the subsurface folds control the deviation of the paths of some valleys of the alluvial fan.

6. In Figure 5B, a sudden slope appears at the end of the longitudinal section of one of the valleys branching from the main fan channel due to its impact on the transverse Jal Al-Zor Fault in the far southeast. The longitudinal profile shows a clear knick point that resembles a clear cliff, which is the cliff of Jal Al-Zor overlooking the Gulf of Kuwait.

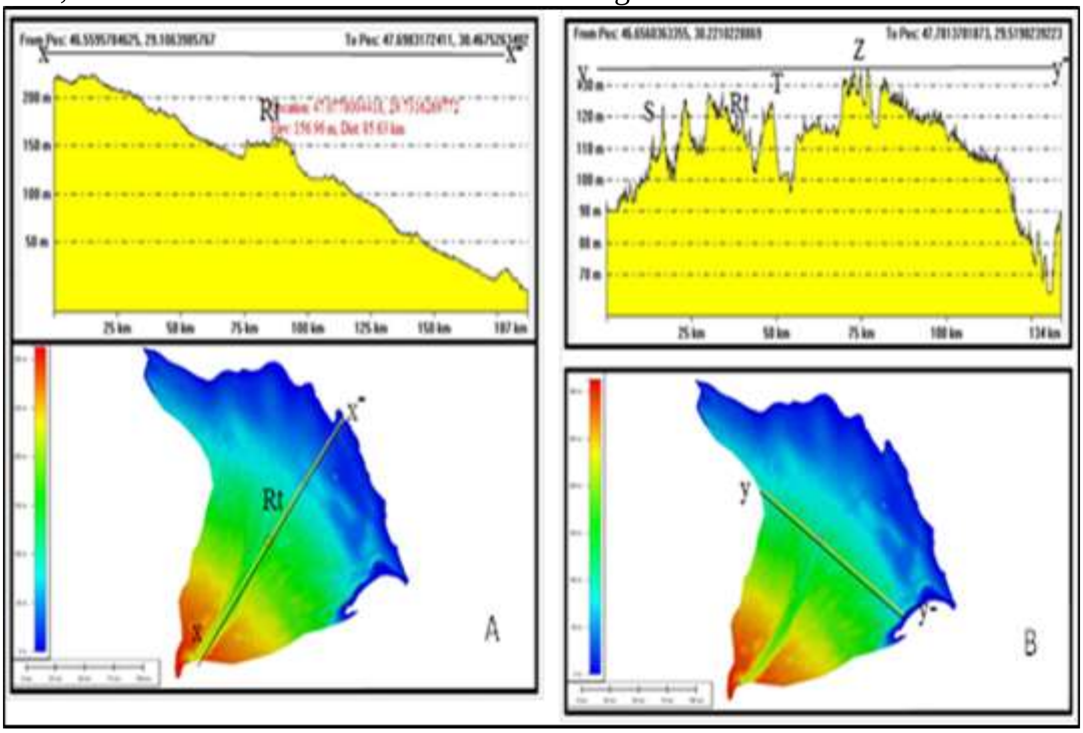


Figure 4: A: Crosses Section profile (X – X⁻): Rt: Ratawi oil field, B: Crosses Section profile (Y – Y⁻) from North to South: Rt: Ratawi oil field, S: Suba oil field, T: Tuba oil field, Z: Zubair Oil field.

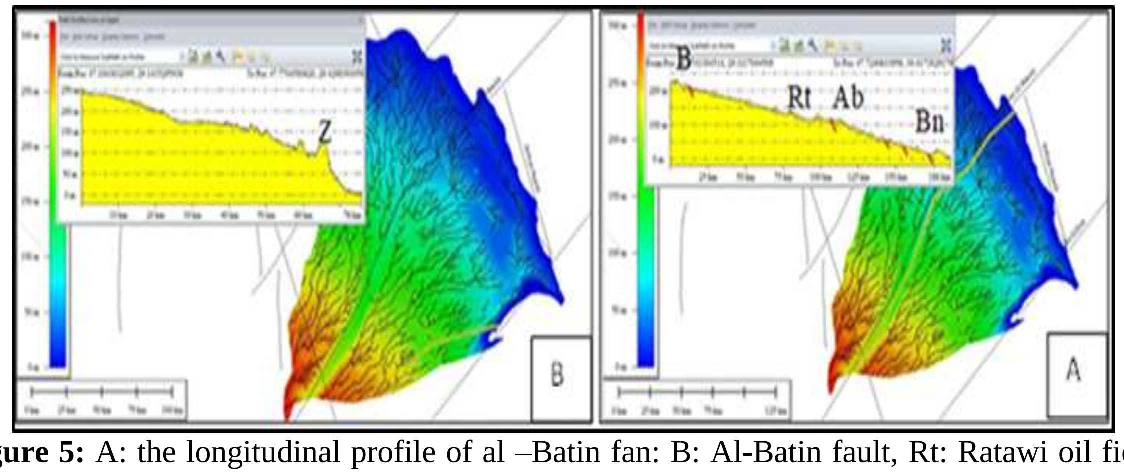


Figure 5: A: the longitudinal profile of al –Batin fan: B: Al-Batin fault, Rt: Ratawi oil field, Ab: Abu -Jir fault, Bn: Nahran- Bin Umar oil field, B: the longitudinal profile of channel branching from the general channel in the far southeast.

4.2 The morphotectonic parameter result shows:

4.2.1 Elongation Ratio (Re)

The diameter of a circle with the same area as the basin divided by the maximum basin length is the elongation ratio (Schumm, 1956). The result can be summed up as follows: (Table 2). According to [21] this ratio varies between 0.6 and 1 over geology and climatic types. With the use of the reindex, the various slopes of the watersheds can be classified into (0.9-0.10), (0.8-0.9), (0.7-0.8), (0.5-0.7), and (0.5 as round, oval, less elongated, elongated, and more elongated [22]. Table 2 shows watersheds in the Wadi Al-Batin alluvial fan are elongated. [23] suggested that the directing influence of thrusting and faulting in the basins is responsible for the diversity of the elongated forms of the basins. According to [24], the elongation ratio values for all watersheds of the al-Batin alluvial fan suggested a neotectonic activity, except Wsh1, that has a lower tectonic activity than other watersheds, associated with relief and steep ground slopes. The type of lithology is one of the most critical factors that affect infiltration capacity and runoff intensity. The region consists of poorly sorted sand, sandstone, and gravel. The sand and sandstone are mainly quartz. The high Re value indicates a high infiltration capacity in the area and thus will not have a lot of discharge runoff [9], except in periods of high rain and water flow in the form of temporary torrents.

Table 2: Elongation ratio value for five watersheds

Watersheds	Elongation Ratio (Re)	Shape of Basin	Activity Tectonic
Wsh1	0.54	Elongated	Slightly Active
Wsh2	0.40	More elongated	Tectonically Active
Wsh3	0.45	More elongated	Tectonically Active
Wsh4	0.35	More elongated	Tectonically Active
Wsh5	0.37	More elongated	Tectonically Active

4.2.2 Asymmetry factor (AF)

The area of the right side of the stream facing downstream divided by the entire area of the drainage basin is defined as the asymmetry factor. This factor was created to detect tectonic tilting of drainage basins on both large and small scales. AF factor was significantly affected by tectonic activity. Figure (6) shows the asymmetry factor results for the five watersheds of the Wadi Al-Batin basin calculated according to (Hare and Gardner, 1985). The results of AF indicate continued tectonic activity as all watersheds were tectonically active, which caused watershed imbalance (Table 3). AF values are affected by the lithology and climate type, where the region had a desert climate, poorly sorted sand, sandstone, and gravel. The sand and sandstone are mainly quartz, and the drainage direction and sloping mainly to the east and northeast (Figure 6).

Table 3: Asymmetry factor value for Five watersheds

Watersheds	Asymmetry Factor (AF)	Activity Tectonics
Wsh1	20.64	Tectonically Active
Wsh2	35.59	Tectonically Active
Wsh3	37.84	Tectonically Active
Wsh4	50.71	Tectonically Active
Wsh5	44.17	Tectonically Active

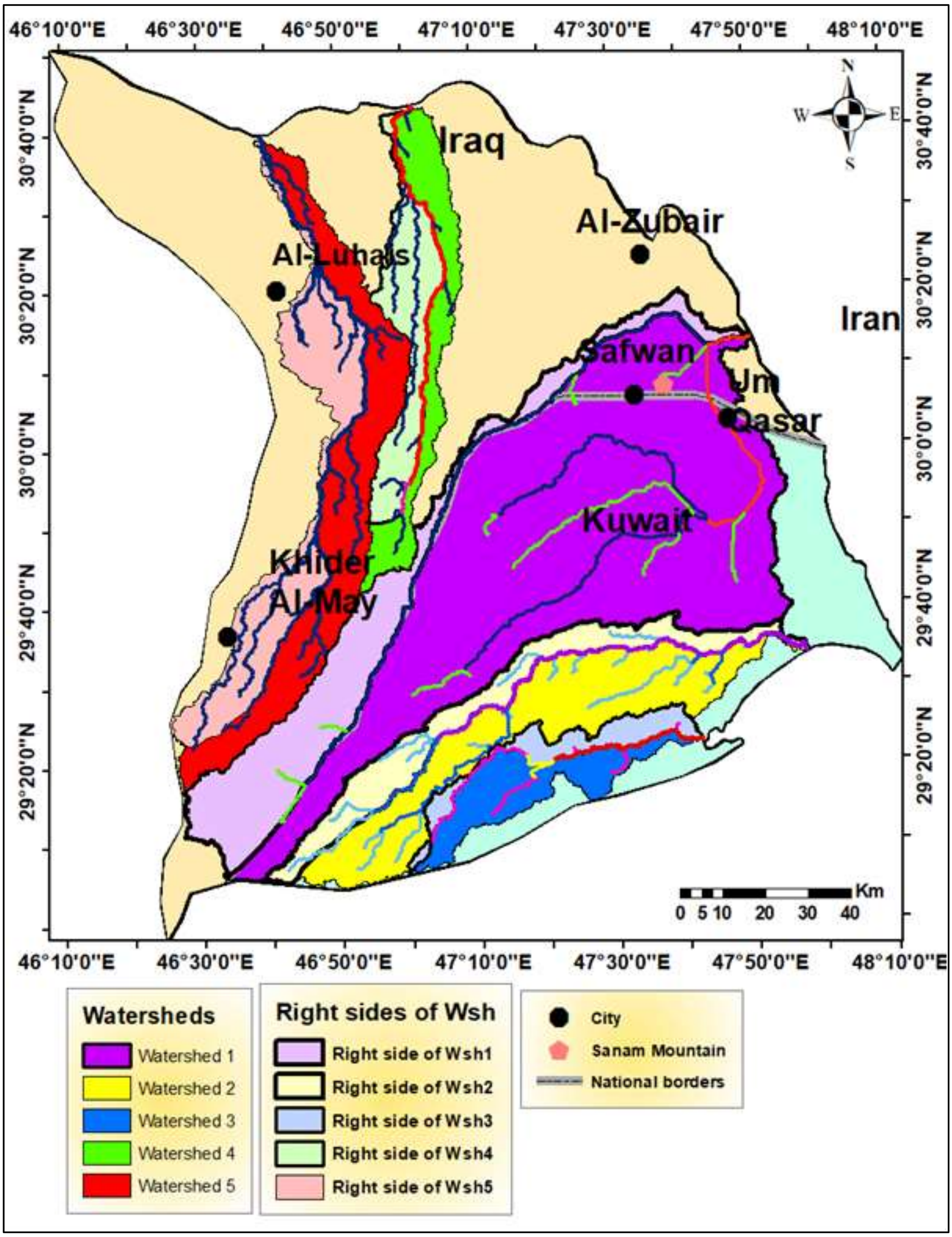


Figure 6: Right side for each watershed in Al-Batin Alluvial fan

4.2.3 Transverse Topographic Symmetry Factor (T)

The transverse topographic symmetry factor is one of the most important indices for assessing basin asymmetry [25] The T value range between 0 in the symmetric basin and 1 in the asymmetry basin. Figure 7 shows how to calculate the Da and Dd used to determine the T index. Table 4 shows the results of the T index indicating two phases of the tectonics activity in the Wadi Al-Batin alluvial fan watersheds, moderate activities in the watersheds Wsh2, Wsh4, and high activities in watersheds Wsh1, Wsh3, Wsh5.

Table 4: Transverse topographic symmetry factor value for Five watersheds.

Watersheds	Da	Dd	T	Shape of watersheds	Active Tectonics
Wsh1	28.38	32.59	0.87	Asymmetric	High tectonically active
Wsh2	6.57	11.71	0.56	Asymmetric	Moderate active
Wsh3	4.01	4.87	0.82	Asymmetric	High tectonically active
Wsh4	5.59	9.39	0.59	Asymmetric	Moderate active
Wsh5	7.51	11.73	0.64	Asymmetric	High tectonically active

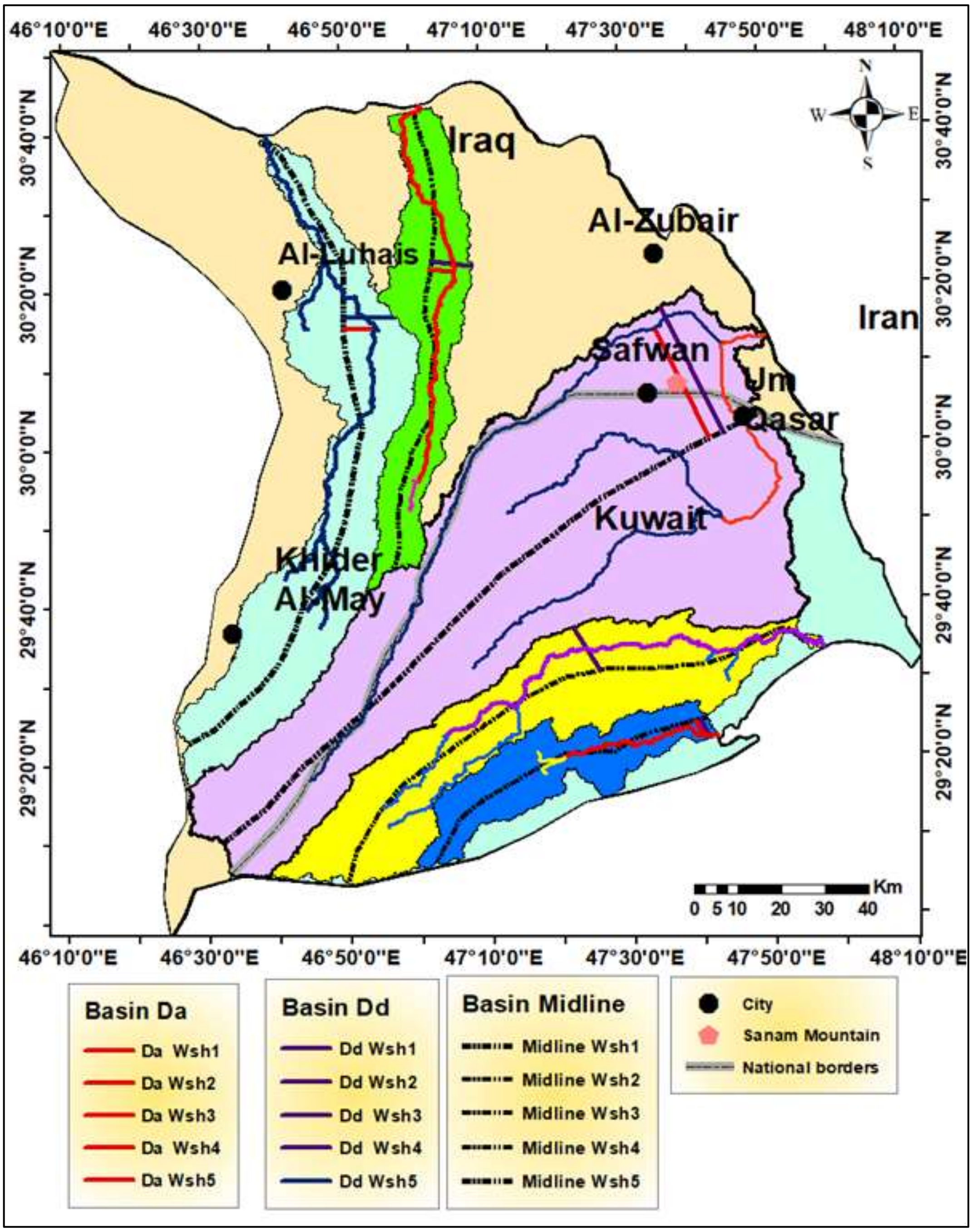


Figure 7: the T index for each watershed in Al-Batin Alluvial fan

4.2.4 Stream Length Gradient Index

Stream Length Gradient Index (SL) was used to determine if the lithological or tectonics are controlled in the region [9]. It is significant for estimating stream gradient conditions and determining the relationship between rock resistance, topography, prospective tectonic activity, and stream length [26]. SL was estimated using a contour map, a digital elevation map (DEM) of the region and the length of the main channel Figure (8).

The Stream length gradient index is divided into three categories based on tectonic activity, high (SL >500), moderate (300> SL< 500), and low (SL <300). The SL value is low when the river passes through fragile rocks such as limestone and alluvial clay, while it is high when the river passes through hard rocks. Areas show tectonic activity with higher SL values on hard rocks and lower values on soft rocks (Table 5).

The SL gradient index outputs suggested that the Wadi Al-Batin alluvial fan watersheds have two levels of active tectonics, moderate relative tectonic activities in the watersheds (Wsh1) and low relative tectonic activities of watersheds (Wsh2, Wsh3, Wsh4, Wsh5). So, the region has low tectonic activity (Table 5).

Table 5: SL index value for Five watersheds

Watersheds	L	ΔH	ΔL	SL	Type of rocks	Active Tectonics
Wsh1	177.91	90	33.49	478.10	soft rock Gravels sands	moderate tectonic active
Wsh2	107.86	40	20.28	212.74	soft rock	low tectonic active
Wsh3	41.83	40	27.07	61.81	Soft rock	low tectonic active
Wsh4	102.43	60	41.26	148.95	Soft rock	low tectonic active
Wsh5	132.05	50	40.98	161.15	Soft rock	Low tectonic active

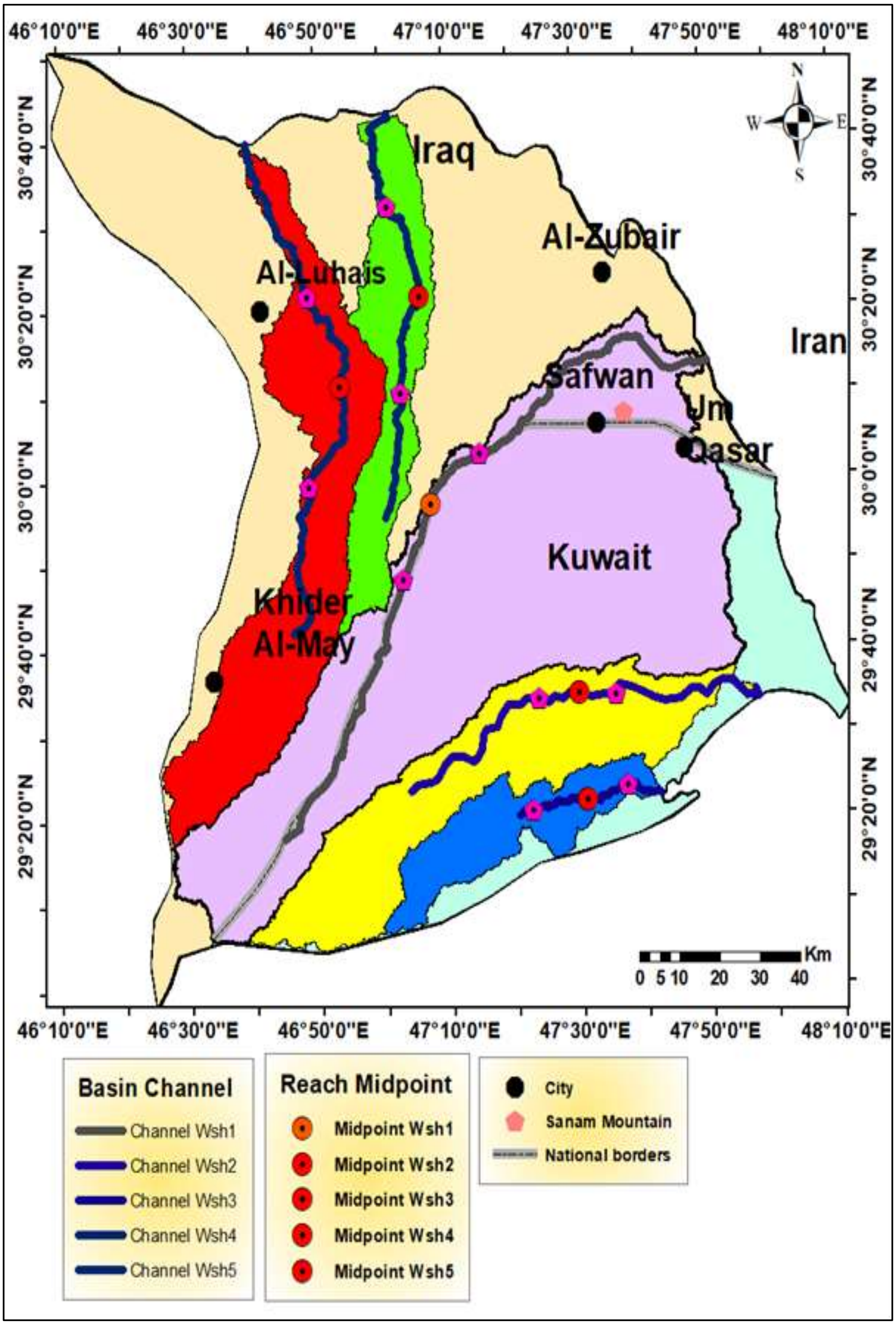


Figure 8: SL index for each watershed in Al-Batin Alluvial fan

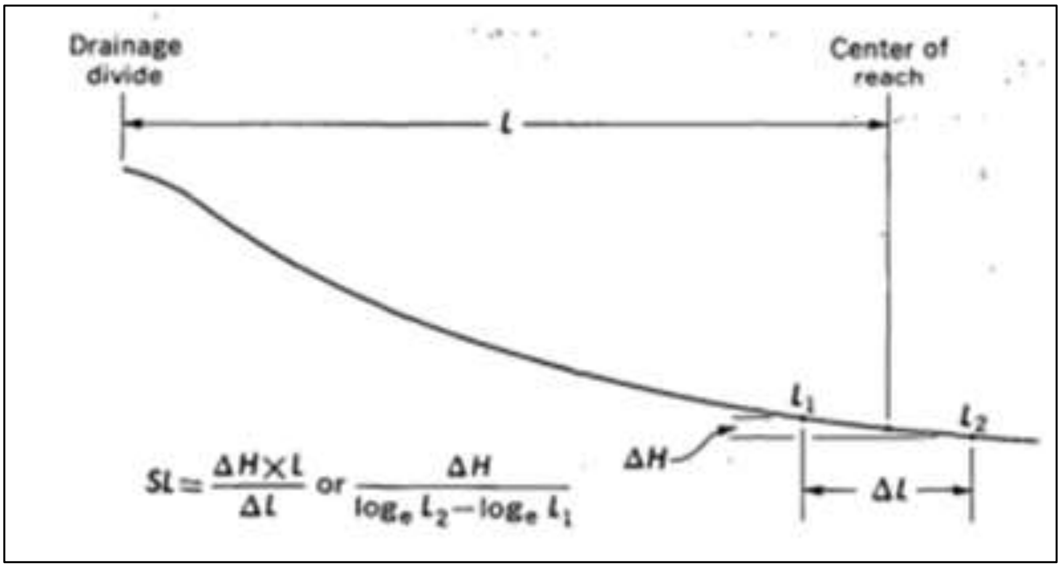


Figure 9: After Hack, 1973.

4.2.5 Mountain front sinuosity

The ratio of the length of the mountain front piedmont (Lmf) to the straight-line distance of the entire mountain front (Ls) is defined as Smf (Table 1). The equilibrium between tectonic forces that tend to build a linear mountain front and erosion forces that prefer to cut measures into a mountain front is depicted by Smf [27], which was calculated by using remote sensing and digital elevation map DEM to generate a contour map in the GIS environment (Figure 9).

The Smf is divided into high (1-1.5), moderate (1.5-2.5), and low (>2.5) categories [28]. Table 6 shows the Smf results of the Wadi Al-Batin alluvial fan watersheds indicating three active tectonics classes, high for Wsh5, moderate for Wsh2, Wsh3, and low for Wsh1 and Wsh4, which confirm that the region is moderate to high tectonic activity[29] (Figure 10).

Table 6: Smf value for Five watersheds

watersheds	Segment	Lmf	Ls	Smf	Smf mean	Active Tectonics
Watershed Wsh1	1	105.51	21.94	4.80	3.95	Low active tectonically
	2	134.93	35.11	3.84		
	3	136.70	42.54	3.21		
Watershed Wsh2	1	54.59	22.54	2.42	2.26	Moderate active tectonically
	2	31.09	13.82	2.24		
	3	54.15	25.24	2.14		
Watershed Wsh3	1	20.66	13.66	1.51	1.75	Moderate active tectonically
	2	18.61	16.05	1.15		
	3	39.62	15.28	2.59		
Watershed Wsh4	1	31.11	18.55	1.67	2.87	Low active tectonically
	2	45.72	12.21	3.74		
	3	34.12	10.65	3.20		
Watershed Wsh5	1	20.97	22.34	0.93	1.46	High active tectonically
	2	33.00	14.67	2.24		
	3	23.21	18.92	1.22		

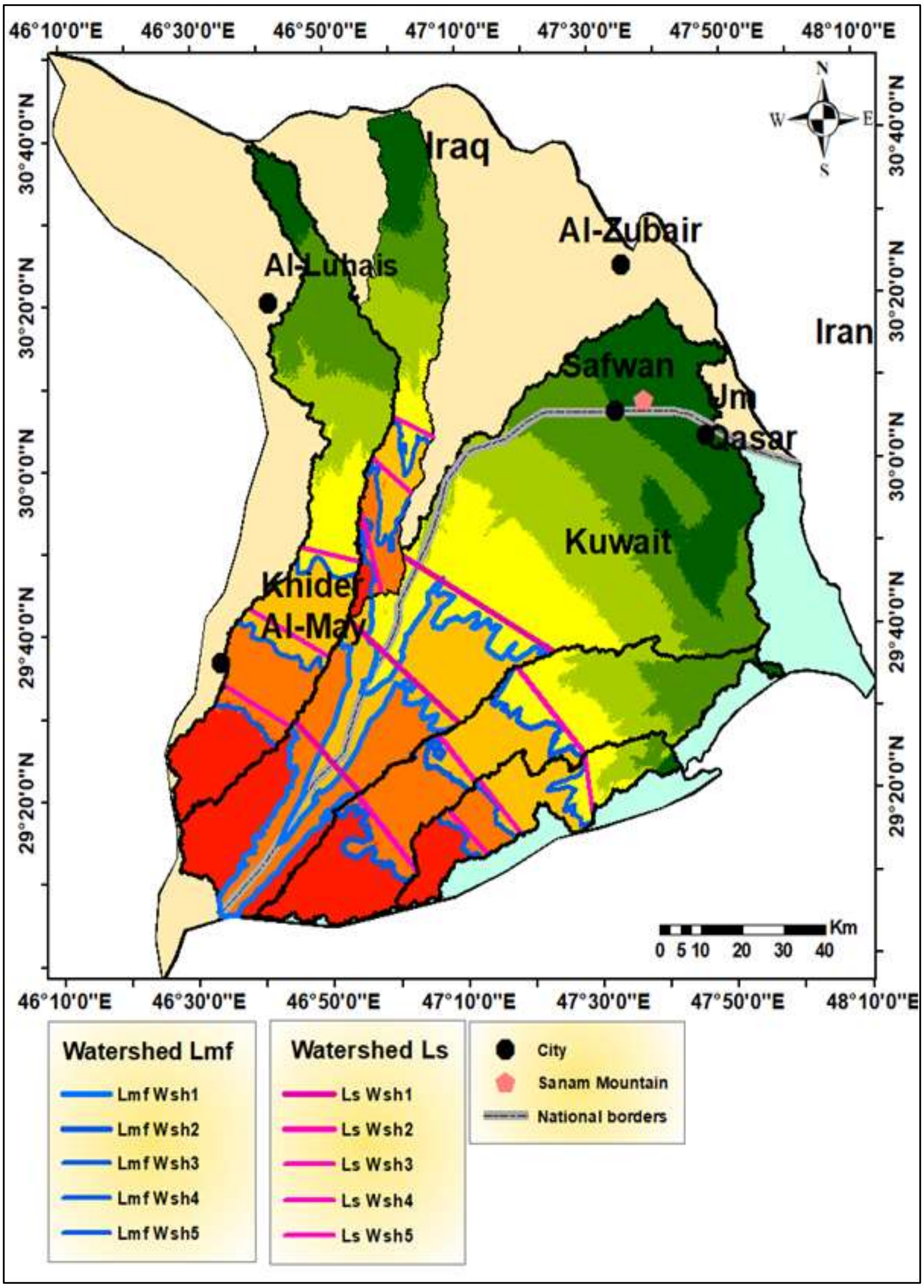


Figure 10: Smf index for each watershed in Al-Batin Alluvial fan

4.3 Lineaments Extraction of Wadi Al-Batin alluvial fan

According to [14] and [13] Al-Batin lies within two different zones. Its upper half part is located within the stable shelf, while the lower half part is situated within the unstable half. It is situated in the Mesopotamian Zone (Zubair Subzone), bounded in the north by the Takhadid Al-Qurna Transversal Fault [30] Figure 11 represents the lineaments map of the Wadi Al-Batin alluvial fan and reflects the presence of the subsurface structure through their effect on the alluvial sediments.

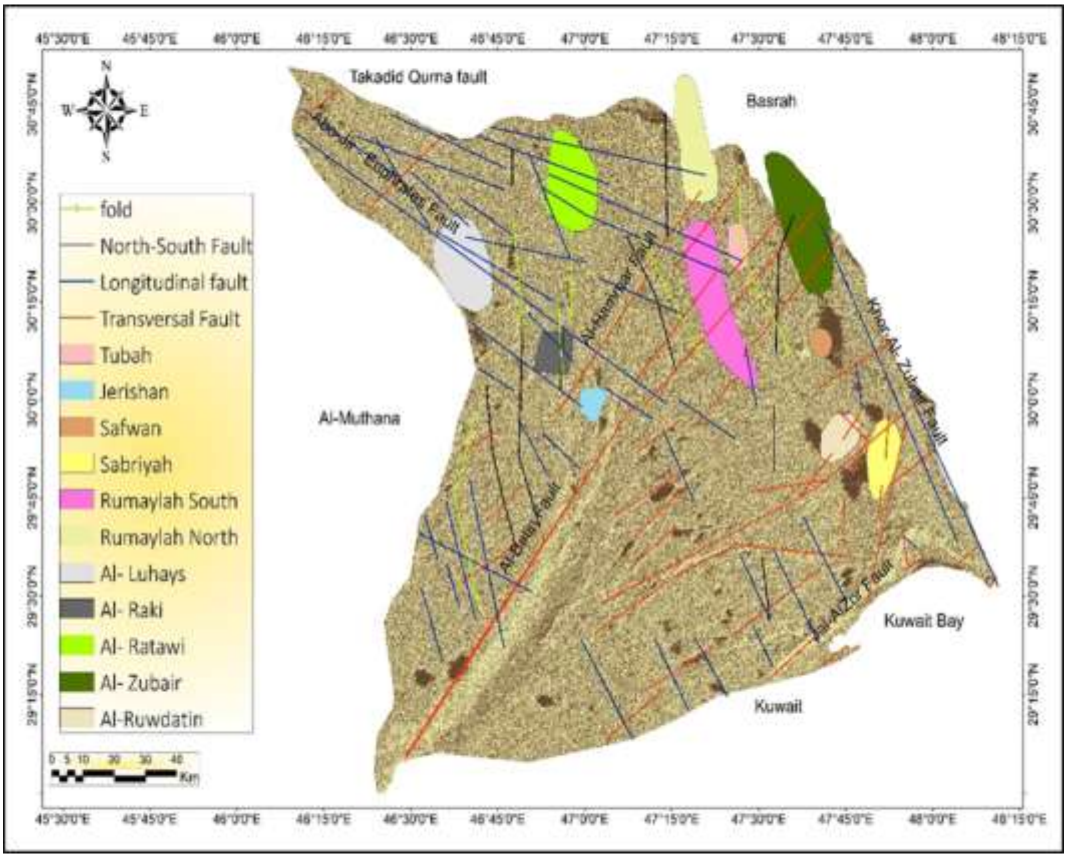


Figure 11: Oil fields related with lineaments Extraction of Wadi Al-Batin alluvial fan.

The map of the linear structures and other geologic structural phenomena of the study area includes the following facts:

1. A network of patterns developed in different directions in the alluvial fan of the Batin and through it large and small linear patterns, often consistent with the direction of the oil fields (Figure 12).
2. The Al-Batin alluvial fan is structurally influenced by many significant regional faults that run in the NE-SW and NW-SE directions, as evidenced by DEM data analysis.
3. The NE-SE transversal fault running through the fan body from the NE to the SW represents lineaments that reach 150 km extend along the Iraq-Kuwait border and 250 km in the Saudi Arabia territory.
4. The Khor Al-Zubair runs through the fan body in the far SE direction, and the Takhadid Al-Qurna fault (NE-SW) crosses through the fan body in the far northeast.
5. Abu Jir- Euphrates fault with NW-SE direction has a course through the fan body at northwestern part. In addition to Al-Hammar fault and Basrah Zubair faults with NE-SW direction.
6. The oil fields (Al-Zubair, Al- Ratawi, Al-Ruwdatin, Al- Luhays, Al-Rumaylah south, Al-Rumaylah north, Safwan, Sabriyah, Jerishan, and Tuba) are distributed in different localities of the fan (Figure 12). It increases in the lower part from Al- Batin alluvial fan at north and northwest because the longitudinal and transversal fault increase in this part like the Takhadid Al-Qurna fault and Abu Jir – Euphrates fault zone (NW-SE), Al- Hammar fault and Basra-Zubair faults (NE-SW), and other faults and subsurface structure formed in the region

5. Conclusions

- Al-Batin alluvial fan is influenced by multiple significant regional faults that run in the NE – SW and NW – SE directions, as evidenced by DEM data analysis.

- Longitudinal and cross-section explain the main channel and the oil field in the region like Al-Zubair, Al- Ratawi, Al-Ruwdatin, Luhais, Rumayla South, Rumayla North, Safwan, Sabriyah, Jerishan, and Tuba.
- Morphotectonic analysis explains the interaction between the tectonic and surface process resulting in the formation of geomorphological features; it was extracted using remote sensing (ASTER GDEM) data and GIS techniques which reveal a very useful tool.
- Al-Batin alluvial fan comprises five watersheds based on the local structural and topographical situation.
- The watersheds are of elongated shapes and tectonically active, except Wsh1, which has low tectonic activity.
- The asymmetry factor values show all watersheds were tectonically active; the transverse topographic symmetry factor indicates that the Wadi Al-Batin alluvial fan watersheds have two phases of the tectonic activity, moderate activates in the watersheds Wsh2 and Wsh4, and high activities in watersheds Wsh1, Wsh3, and Wsh5.
- Stream length gradient index confirms that the watersheds have two levels of active tectonics, moderate for watershed Wsh1 and Low for watersheds Wsh2, Wsh3, Wsh4, and Wsh5. Eventually, the area is considered to have low tectonic activity.
- The results of Mountain front sinuosity show three classes of active tectonics in the study area, the high for Wsh5, moderate for Wsh2, Wsh3, and low for watersheds Wsh1 and Wsh4. This indicates that the Smf are active with moderate to low tectonically active because the region is not a mountainous area.

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