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## Neotectonic Activity of Segmented Alluvial Fans Along Hemr in South Anticline, East Iraq

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### Abstract

A quantitative analysis of geomorphic indices was carried out to understand the impacts of tectonics on the geomorphological relief of drainage basins and alluvial fans. Based on field work, satellite images and aerial photographs interpretation, five stages of alluvial fans were recognized within the study area. They are of a coalesced type, forming continuous belt of Bajada, and covering vast areas which extend along the southwestern limb of Hemr anticline. The alluvial fans' sediments lie unconformably over pre-Quaternary sediments represented by angular unconformity. The earlier stages of the fans were developed during the Plio-Pleistocene age, whereas the later stage represents the sediments of the Holocene age. Four distinct segmented alluvial fans were considered under this study, located within Torsaq and Shosharin basins. They are developed in the first, second and third stages of alluvial fans. Some morphotectonic parameters were calculated in order to understand the tectonic dynamics of these fans, including mountain front sinuosity (Smf), ratio of valley floor's width to height (Vf), fan tilting ( $\beta$ ), and drainage basin asymmetry (FA). The results showed less active mountain front and low uplift, according to the acquired high values of Vf. The fans are tilted towards the west direction, indicating uplift of their eastern parts, while the main streams are shifted downstream to the right.

**Keywords:** Geomorphic indices, Fan segments, Mountain front, Fan tilting, Asymmetry factor.

## النشاط التكتوني الحديث لمراوح فيضية مقطعة على امتداد الطية المحدبة لحميرين الجنوبي، شرق العراق

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### الخلاصة

تم دراسة التحليل الكمي للمؤشرات الجيومورفولوجية لفهم التأثير التكتوني على أحواض التصريف والمراوح الفيضية بالاعتماد على العمل الحقلية، وتفسير الصور الفضائية و الصور الجوية حيث تم تمييز خمسة مراحل للمراوح الفيضية والمتصلة مع بعضها مكونة حزام من البجادا على امتداد الجناح الجنوبي الغربي لطية حميرين المحدبة. تمثل ترسبات المراوح الفيضية عدم توافق زاوي مع

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ترسبات ما قبل العصر الرباعي. تطورت المرحلة الاقدم من المراوح الفيضية في عمر البلايو-لايستوسين بينما تكونت المراحل الحديثة في عمر الهولوسين. تم التركيز على اربعة مراوح فيضية مقطعة تقع في حوضي ترساق و شوشارين تطورت ضمن المراحل الاولى، الثانية والثالثة للمراوح الفيضية وتم حساب بعض المعاملات المورفوتكتونية مثل دالة التعرج، عرض قاع الوادي نسبة الى ارتفاعه، ميل المروحة و تماثل حوض التصريف. اثبتت النتائج وجود نشاط قليل ونهوض قليل اعتمادا على دالة التعرج، اعتمادا على عرض قاع الوادي نسبة الى ارتفاعه فان المراوح الفيضية تميل باتجاه الغرب مشيرة الى وجود نهوض لاجزائها الشرقية وانحراف الوديان الرئيسية باتجاه مجرى النهر نحو الجزء الايمن من الحوض.

## INTRODUCTION

Alluvial fans are a conspicuous conical and depositional landform deposited by a river when its flow is suddenly slowed [1,2]. They are formed at the base of foothills due to the material accumulation, where the load, consisting of fine and coarse size, is coming from upstream and deposited at the point of break in slope.

The size of the accumulation of sediments decreases outward from the apex toward the outer margins of the fans [3]. Their transverse profile is arched and the longitudinal profile is slightly concave, with slopes are usually less than  $10^{\circ}$ [4].

The geometry and development of fans are mainly controlled by the relating factors such as relief, slope, climate, lithology and tectonic activity [2,5]. The sources of the flows are from a single point located at the apex of the fan, which over time move to occupy different positions on the fan surface[6]. A canyon draining from mountainous terrain emerges out into a flatter plain, then alluvial fans are formed. A Bajada or a compound alluvial fan is formed when alluvial fans converge with neighboring alluvial fans into a single apron of deposits against a slope.

The fan shape can be explained as the system which includes the accumulated sediments at the apex of the fan will tend to a state minimizing the sum of the transport energy that is involved in moving the sediment and the gravitational potential of material in the fan. Iso-transport energy lines will be formed in the form of concentric arcs radiating from the discharge point at the apex of the fan. Therefore, the material will tend to be deposited equally about these lines, giving the sediments the characteristic fan shape.

### Location of the Study Area

The study area represents the eastern part of Wasit Governorate, near the Iraqi- Iranian international borders. It occupies an area of about  $2000 \text{ km}^2$  (Figure-1). Zurbatiyatownis within the study area, which contains Torsaq and Shosharin drainages as the main basins. The area is limited by the following coordinates:

Longitude  $45^{\circ}05'00''$ ,  $46^{\circ}00'00''$  Latitude  $32^{\circ}75'00''$ ,  $33^{\circ}06'00''$ .

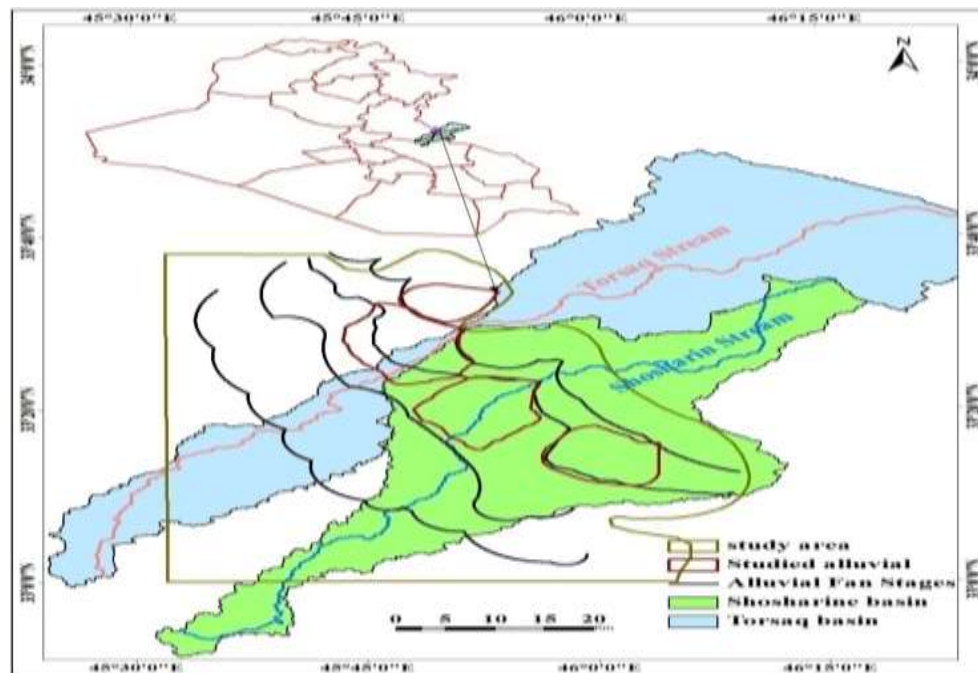


Figure 1- Location map of the study area

### Geological Setting

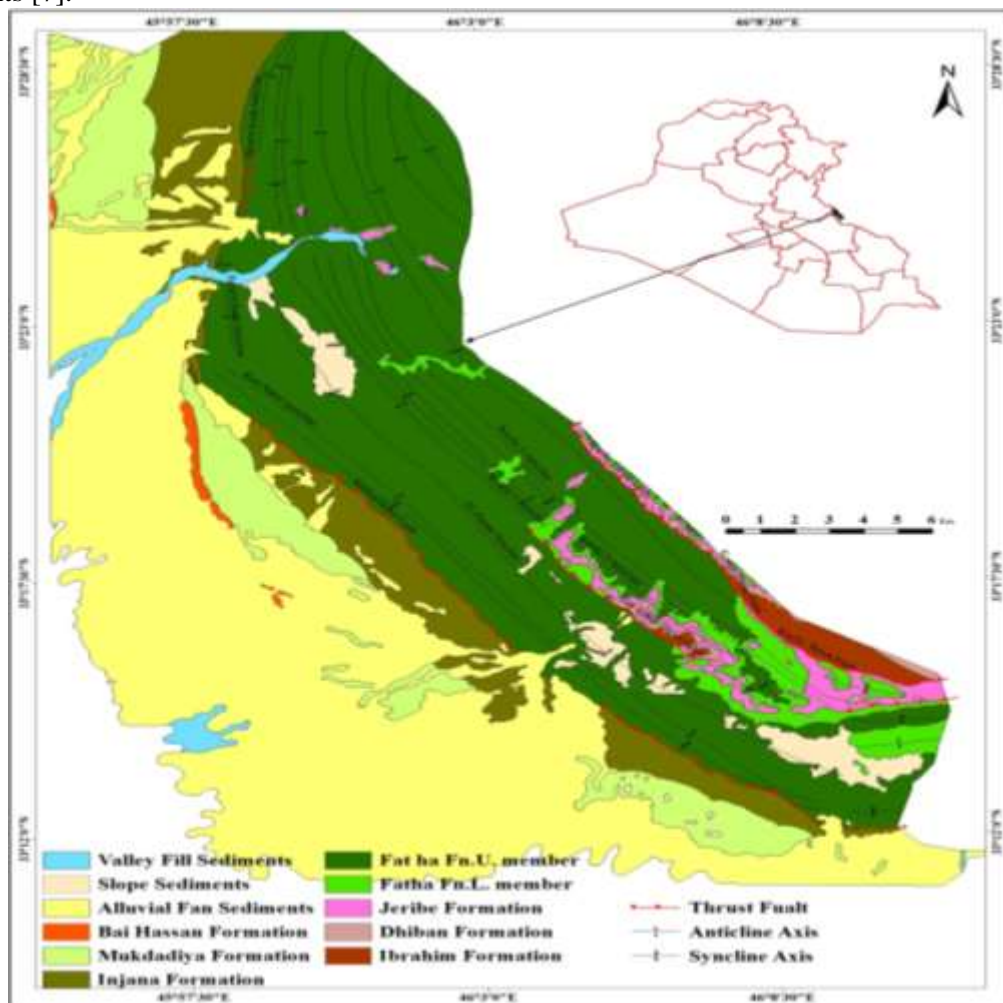
Stratigraphically, different sedimentary formations of different lithological constituents and ages (Oligocene- Pliocene) are exposed within the study area, in addition to various types of Quaternary sediments (Figure-2). A brief description of the lithological units is mentioned hereinafter (from older to younger).

- **Ibrahim Formation (Late Oligocene):** This formation represents the oldest rock unit within the hanging wall of Koolic thrust fault, which is thrust on Dhiban and Jeribe formations (foot wall). It is exposed within the eastern part of the study area. It comprises 130m of alternation of marl and marly limestone. The upper part of the formation is dominated by marl with thin beds of limestone, while the middle part is composed of thick bed of marly limestone. The lower part consists of an alternation of marly limestone and marl [7].
  - **Serikagni Formation (Early Miocene):** It is exposed in the eastern parts of the study area, consisting of 22 m of marl, marly limestone and limestone.
  - **Dhiban Formation (Early Miocene):** It is exposed within in the eastern parts of the study area, consisting of 30 m of white, nodular textured and massive gypsum.
  - **Jeribe Formation (Middle Miocene):** It is exposed as relics along the thrust fault and in the core of Koolic anticline. It comprises of 70 m of massive dolomitic limestone.
  - **Fatha Formation (Middle Miocene):** The formation consists of cyclic an alternation of calcareous claystone, limestone and gypsum. It is divided into two members [8]; both upper and lower members of this formation are exposed in the study area. Its maximum exposed thickness is 330 m. Fatha Formation is thrust over Injana Formation along the major thrust fault.
  - **Injana Formation (Late Miocene):** The formation is exposed only within the southwestern limb of Hemrin South anticline. Injana formation consists of an alternation of claystone, siltstone and sandstone. The uppermost part is characterized by very thick (up to 30 m) claystone and thin sandstone beds. The total thickness is 350 m.
  - **Mukdadiyah Formation (Late Miocene-Pliocene):** It consists of 110 m of rhythmic clastic cycles of sandstone and claystone, which are lenticular as a mode of the deposition, with many lateral changes to each other.
  - **Bai Hassan Formation (Pliocene – Pleistocene):** The formation consists of thick and coarse conglomerates that contain lenses of sandstone. The total exposed thickness is 25 m [7].
- Tectonically, the Zagros Fold- Thrust Belt within Iraq is divided into several NW-SE trending longitudinal tectonic zones [9, 10]. The Low Folded Zone represents a part of the Outer Platform of the Arabian plate [11], where the study area lies. The main structures within the study area are:

**Hemrin South anticline.** It is the major anticline within the study area. It is a NNW-SSE trending anticline, 33 km in length and its width ranges from 0.7 km up to 7 km. The NE limb of Hemrin South anticline is thrust over its SW limb [12].

**Kani Sakht anticline.** It is a narrow asymmetrical anticline, located along the northeastern limb of Hemrin South anticline, with a length of about 30 km and variable widths of up to 1.5 km. It has a NWN – SES trend. The dip of the southwestern limb ranges  $40^{\circ}$  –  $65^{\circ}$ , whereas the dip of the northeastern limb ranges  $47^{\circ}$  –  $52^{\circ}$ . The study area is characterized by the existence of three large scale thrust faults of a NW – SE trend; these are Kachaa Fault which extends over 25 km in length, Cea Koran Fault which extends of 25 km in length, and Koolic Fault which runs parallel to the Iraqi – Iranian international borders and extends over 12 km in length [7].

The study area represents the extreme margin of the Low Folded Zone, which is physiographically known as the Foothill Zone, located between High Amplitude Mountainous and Mesopotamian Plain provinces of Iraq [13]. From the topographic point of view, the study area descends in relief from its northeastern part, where the mountainous area exists, towards W and SW parts, where alluvial fans and sheet run off sediments are well developed. Geomorphologically, the area is dissected by three main streams which have similar characters and behaviors. They are characterized by narrow and deep courses after leaving the alluvial fans and drain within the Tigris River and Hore Al-Shuwaicha depression. The main geomorphological units in the study area are: 1- Units of Structural – Denudational origin, which include fault escarpments, hogbacks and cuestas. 2- Units of Fluvial origin, developed as numerous alluvial fans, which are divided into three types depending on the lithological composition of the sources; the first consists of alluvial fans composed of conglomerate, the second consists of carbonate conglomerate, and the last consists of gypcrete mixed with gravels and rock fragments [7].



**Figure 2-** Geological map of the study area [7]

## Methodology

This study is based on intensive field work and interpretation of 30 m and 12.5 m resolution digital elevation model (DEM), Landsat image (14 m), aerial photographs of scale 1:35000 and topographical maps of scale 1:25000. These data were used for deducing the geomorphological and morphotectonic analyses of the alluvial fans. The morphological parameters of the alluvial fans, such as length, width, area and slope angle were calculated by GIS program.

Four different morphotectonic indices are indicated to evaluate comparative degrees of tectonic activity in the study area; These are: 1) mountain front sinuosity ( $S_{mf}$ ), 2) 'ratio of valley floor width to height (Vf), 3) drainage basin asymmetry (FA), 4) the tectonic tilt of the fans (Table-1), which were calculated according to the methodology proposed earlier [14].

**Table 1-** Geomorphic indices used in this study [14]

Index	Equation
Mountain front sinuosity ( $S_{mf}$ ),	$S_{mf} = L_{mf}/L_s$
Ratio of valley floor width to height (Vf)	$V_f = 2V_{fw}/[(E_{id} - E_{sc}) + (E_{rd} - E_{sc})]$
Fan tilting ( $\beta$ )	$\beta = \arccos ((b/a)^2 \sin^2 \alpha + \cos^2 \alpha)^{0.5}$
Drainage basin asymmetry (AF)	$AF = 100 (A_r / A_t)$

## Alluvial Fans in the Study Area

Two large fans can be recognized in the study area; these are: 1) Torsaqa Alluvial Fan which is developed from Torsaqa stream, and 2) ShoSharin Alluvial Fan which is developed from Shosharin stream. Five stages of alluvial fan can be recognized within the study area (Figure-3). They lie unconformably over the pre-Quaternary sediments with angular unconformity. The fan shapes are unified, represented by delta shape and typical concave tops. The earliest stage (first stage) was developed during the Plio-Pleistocene age, whereas the later stage (fifth stage) represents the sediments of the Holocene age [15]. The alluvial fan sediments are composed of unsorted rock fragments cemented by calcareous materials. The fragments are rounded to sub-rounded with different sizes which range from few centimeters up to large boulders. They are mainly of carbonate rocks covered by secondary gypsum forms in gypcrete crust. The exposed thickness ranges from 20 m in Shosharin alluvial fan to 25 m in Torsaqa alluvial fan [7]. The five stages were differentiated according to their geomorphic positions, lithological variations, and weathering rate and intensity.

Shosharin 1 and Shosharin 2 segments are developed in Shosharin basin and located in the second and third stages of alluvial fans. They have different extensions and sizes, their area ranges 55 – 150 km<sup>2</sup>, with a maximum width of up to 16 km and a length of 9 – 14 km. Their slopes have a gentle surface that ranges 8 – 15° towards southwest (Table-2).

## Geomorphic Indices

### Mountain Front Sinuosity Index ( $S_{mf}$ )

Mountain front sinuosity ( $S_{mf}$ ) is defined by the equation:

$$S_{mf} = L_{mf} / L_s$$

where  $S_{mf}$  is the mountain front sinuosity,  $L_{mf}$  is the length of mountain front along the foot of the mountain along a contour line, and  $L_s$  is the straight-line length of the mountain front along the same contour line. This index reflects the balance between erosion and active vertical tectonic. Active fronts show straight profiles and low values of  $S_{mf}$ , whereas inactive or less active fronts show irregular profiles and high values of  $S_{mf}$ . Generally, the majority of the straight mountain fronts are bounded by major faults [16]. According to a previous work [17],  $S_{mf}$  is classified into three classes; the first ranges 1.0-1.6 and associated with the most active mountain front, the second ranges 1.6-3.0 and is less active, and the third ranges 3.0- 5.0 and indicates inactive mountain fronts.

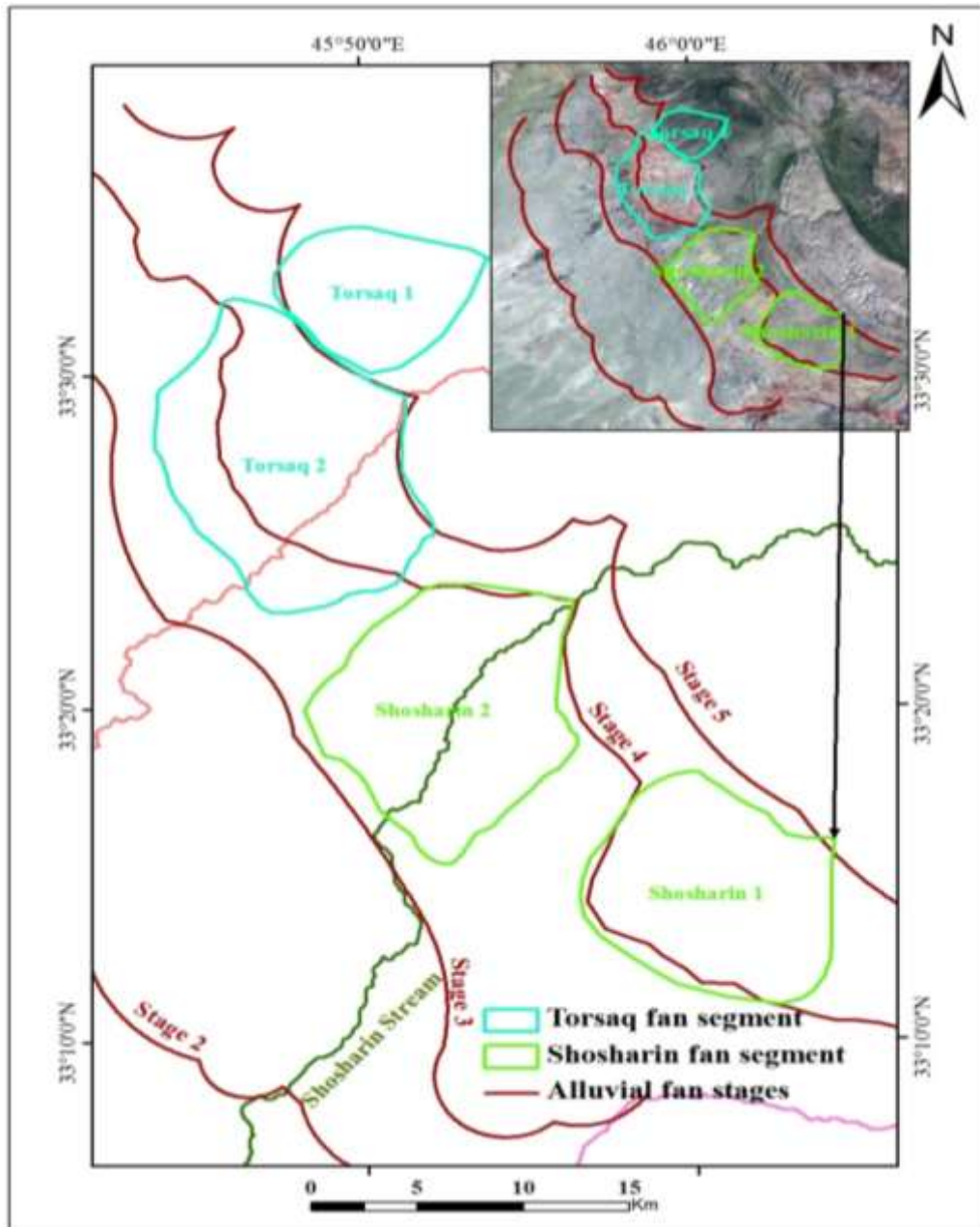
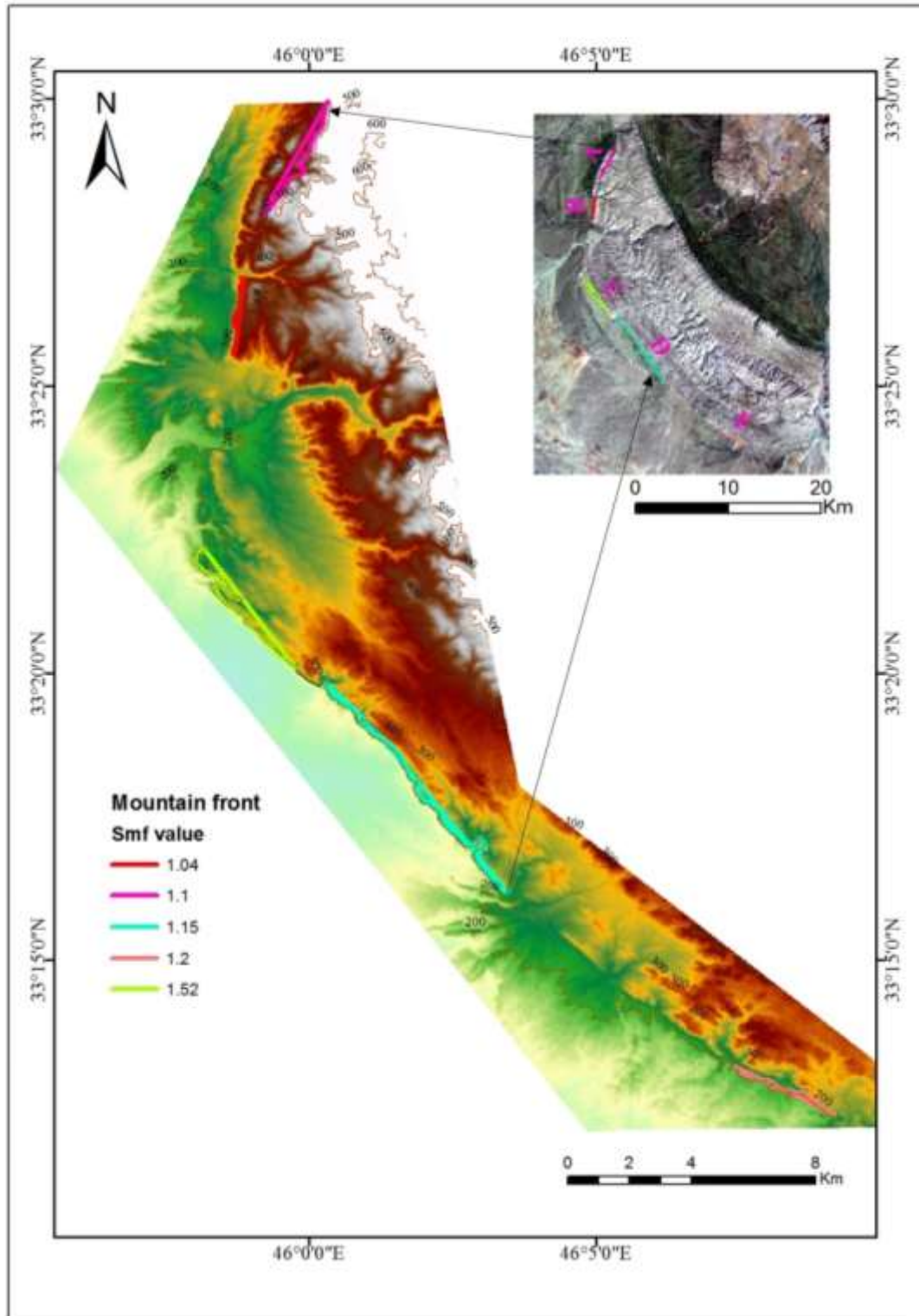


Figure 3-The studied alluvial fans.

Table 2- Geometry of the studied alluvial fans.

Fan Segment	Fan Stage	Total Area(Km <sup>2</sup> )	Width (Km)	Length (Km)	Slope
Torsaq1	Stage 1	55	8	9	10-15°
Torsaq2	Stage 2	150	16	12	8-12°
Shosharin1	Stage 2	110	13	11	8-10°
Shosharin2	Stage 3	130	12	14	9-11°

In the study area, five mountain front segments are drawn along the main Katchaa thrust fault (Figure-4). Their values range 1.04 - 1.52 which reflects an active tectonic mountain front (Table-3).



**Figure 4-** Mountain front segments in the study area.

**Table 3-** Measured mountain front sinuosity values within the study area.

Segment	$L_{mf}$	$L_s$	$S_{mf}$ ( km )	Tectonic activity
A	4.484	4.045	1.11	Active
B	2.594	2.480	1.04	Active
C	6.940	4.574	1.52	Active
D	9.626	8.357	1.15	Active
E	3.716	3.127	1.19	Active

### Ratio of Valley Floor Width to Valley Height Index ( $V_f$ )

Valley floor width to valley height ratio is calculated by the following equation:

$$V_f = 2V_{fw} / (E_{ld} - E_{sc}) + (E_{rd} - E_{sc})$$

where  $V_{fw}$  is the width of the valley floor,  $E_{rd}$  and  $E_{ld}$  are the elevations of the right and left valley divides facing downstream, and  $E_{sc}$  is the elevation of the valley floor. This index differentiates between the U-shaped valleys (broad floored) and the V-shaped valleys. Thus  $V_f$  can be classified as V-shaped valleys which has  $V_f$  values  $<1.0$ , with an active stream incision associated with high uplift rates. Values between 1.0 and 1.5 reflect moderately active tectonics, and values  $>1.5$  are classified as U-shaped valleys associated with low uplift rates [17, 15]. Values of  $V_{fw} > 1.5$  also mark lateral erosion due to the stability of base level or tectonic quiescence [18].  $V_f$  values vary depending on stream discharge, catchments sizes, and rock type [19].

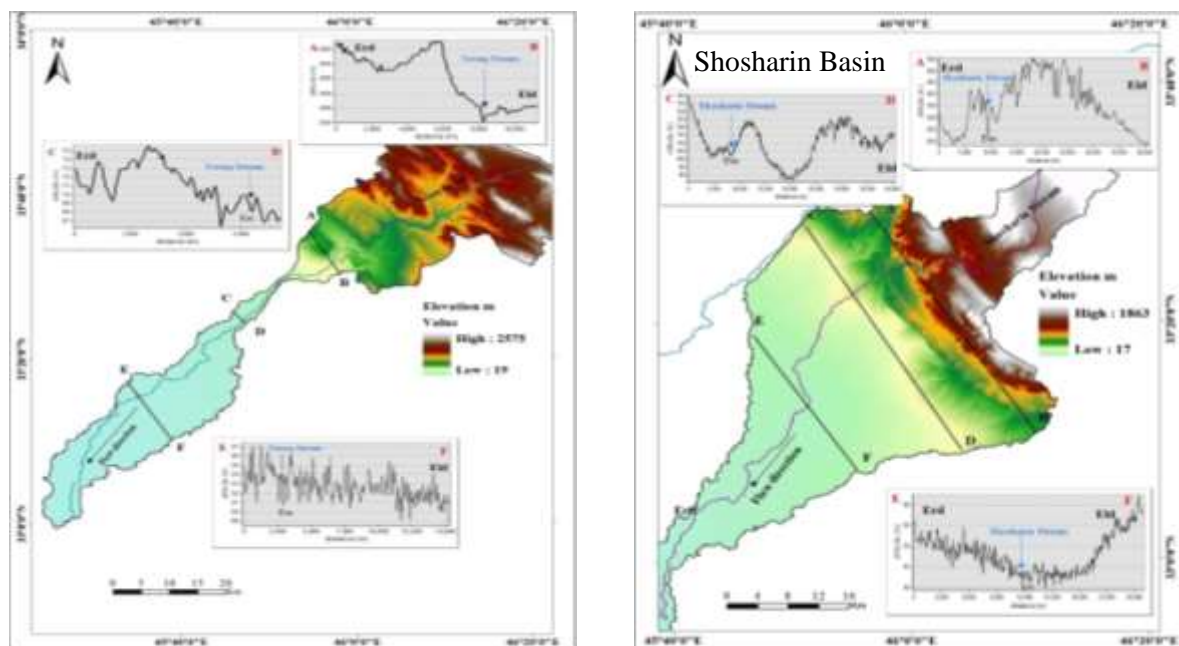
Three different transverse profiles across the main course of Shosharin and Torsaqa basins were calculated, namely A-B, C-D, and E-F (Table-4 and Figure-5). The localities of the profiles were selected according to the distance to the main thrust, where A-B is near the thrust, whereas the other two profiles are located in the alluvial fan area.

The ratio of valley floor's width-to-height of the three profiles in Shosharin basin showed high values of 2.4, 27.2 and 28.5, which indicate that all the tributaries in Shosharin basin reflect growth of U-shaped valleys associated with low uplift [15].

The calculated values of  $V_f$  in Torsaqa basin are variable, being 1.4 in the profile A-B, which reflects the growth of deep or V-shaped valley associated with uplift, whereas the values in C-D and E-F profiles are 26.3 and 17.24, respectively, which indicate U-shaped valleys associated with low uplift rates.

**Table 4-** Measured values of valley floor width to valley height within the study area.

Basin	Profile	$V_{fw}$ (m)	$E_{sc}$ (m)	$E_{ld}$ (m)	$E_{rd}$ (m)	$V_f$	Tectonic activity
Torsaqa	A- B	200	260	300	500	1.4	Moderate
	C- D	50	68	69.8	70	26.3	Low
	E- F	100	30.7	36	37	17.2	Low
Shosharin	A- B	500	280	550	420	2.4	Low
	C- D	750	105	140	125	27.2	Low
	E- F	100	40	45	42	28.5	Low



**Figure 5-** Transverse profiles of Torsaqa and Shosharin basins.



### Fan Tilting

Simple alluvial fans are symmetrical half cones with approximately circular topographic contour lines in the absence of tilting, whereas in case of tectonic tilt, the contour lines across the fan represent segments of ellipses with long axes parallel to the tilt direction. The amount of the tilt can be measured by the following equation[15]:

$$\beta = \arccos \{ (b/a)^2 \sin^2 \alpha + \cos^2 \alpha \}^{0.5}$$

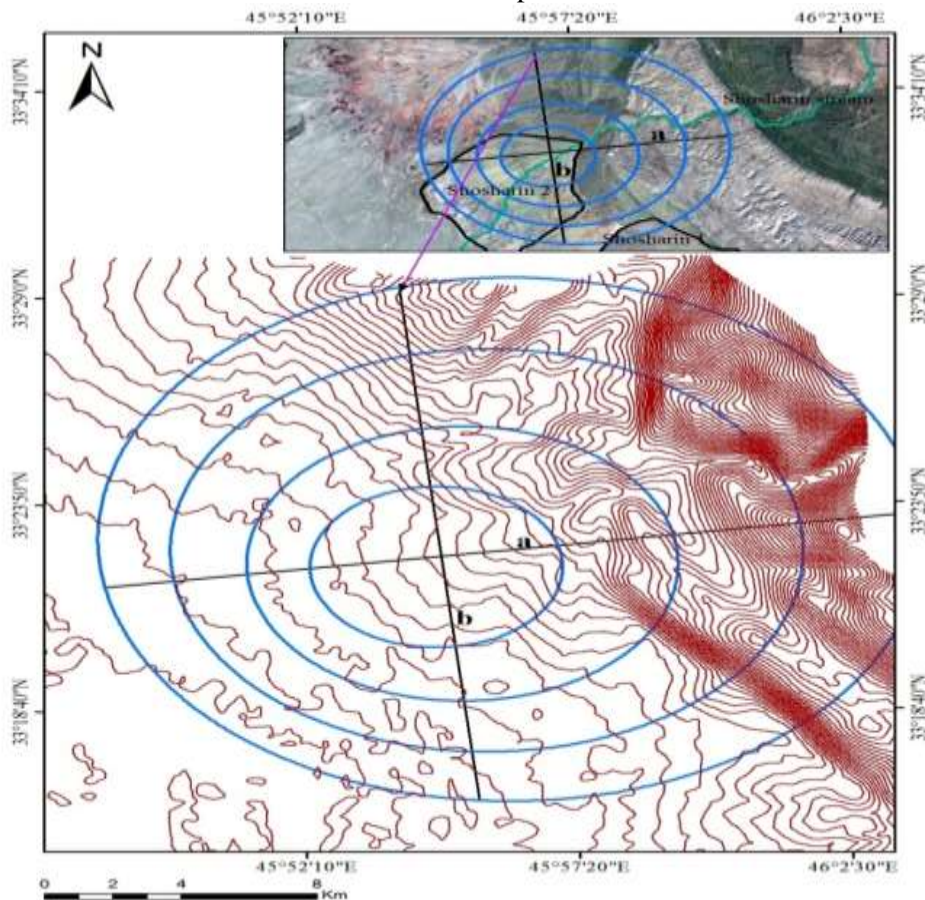
where  $\alpha$  is the original depositional slope, which is derived by measuring the slope along the minor axis of the ellipse,  $b$  is the half of the length of the minor axis of the ellipse, and  $a$  is the half of the length of the major axis of the ellipse.

In the study area, the tilting was calculated for the four alluvial segments. The results of fans tilting are shown in Table-5.

**Table 5-** The data of fan tilt in the studied alluvial fans within the study area.

Fan name	b (m)	a (m)	$\alpha$	$\beta$ (degree)
Torsaq1	17.246	17.331	1.03	0.57°
Torsaq2	21.942	22.520	0.25	0.77°
Shosharin1	23.710	24.177	0.23	0.85°
Shosharin2	19.440	19.627	0.35	0.73°

The angle of tilting in Shosharin 1 and 2 fan is 0.85° and 0.73, whereas it is 0.57° in Torsaq 1 and 0.77° in Torsaq 2. The tilting in all fans is towards the west direction (Figure-7), indicating uplift of their eastern parts. This uplift can be attributed to the neotectonics of the thrusting uplift along Katchaa thrust fault, due to the collision of the Arabian- Iranian plates.



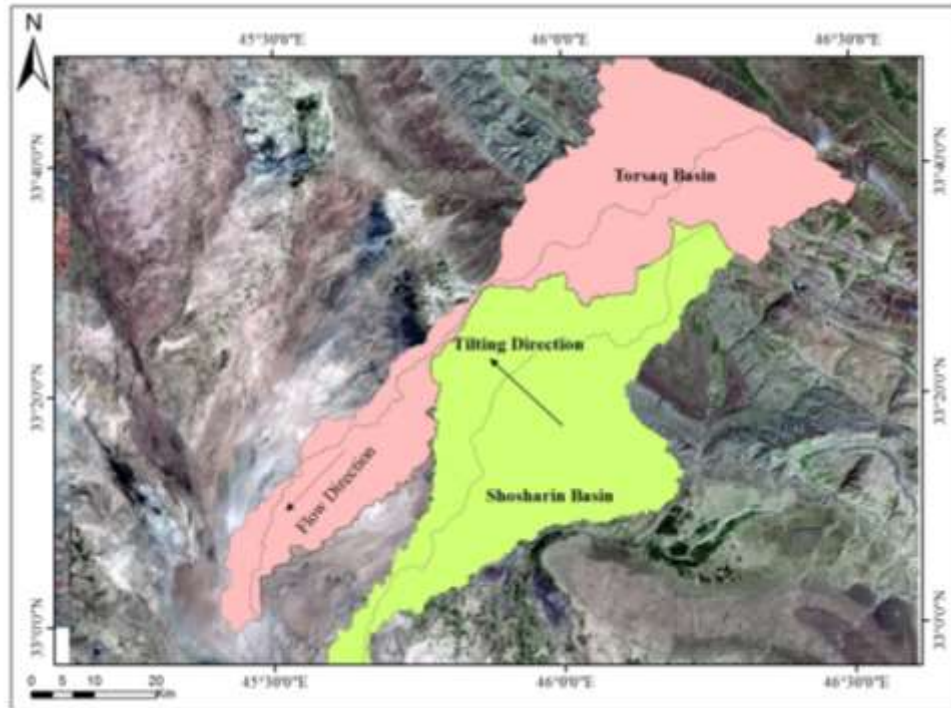
**Figure 7-** Fit ellipses on elevation contours of the Shosharin 2 fan;  $a$  and  $b$  are the major and minor axes of the ellipse.

### Drainage Basin Asymmetry Factor (AF)

This factor is used to identify tectonic tilting of the basin [15, 20]. This factor is defined as  $AF = 100(A_r/A_t)$

where  $A_r$  is the drainage basin area to the right of the trunk stream (facing downstream) and  $A_t$  is the total area of the drainage basin. Values of AF close to or equal to 50 indicate little or no tilting, i.e. a symmetric basin. AF values greater or lower than 50 may reflect asymmetry resulting from lithological control, tectonic tilting, or differential erosion [15].

Two basins were analyzed in the present study, namely Shosharin and Torsaq. The calculated values of AF of Torsaq and Shosharin basins are equal to 46.33 and 38.28, respectively, which indicate that the main streams are shifted downstream to the right and tilted towards northwest (Figure-8).



**Figure 8-**Drainage Basin asymmetry of Torsaq and Shosharin basins.

### CONCLUSIONS

The study area is located within two tectonic zones; i- Low Folded Zone which extends along the northern and northeastern parts and characterized by the existence of several regional folds, faults, and tectonic activity. ii- The majority of the study area is located within the Mesopotamian Zone which is characterized by thick Quaternary sediments and low tectonic activity. The existence of very narrow areas in the middle part of each basin is due to the formation of a very deep gorge. Tectonically, the area is active due to the Smf values of five marked mountain front segments drawn along the main Katchaa thrust fault, which have the range of 1.04 - 1.52. Most of the valley floors have a wide range of 50 - 200 m in Torsaq basin and 150 - 750 m in Shosharin basin. It is notable that Vf values are high and they are increased with the flow direction away from the main thrust. Thus, the valley floor's width-to-depth ratio in the Shosharin and Torsaq basins show high values, which reflect the growth of U-shape valleys which is a clear indication of low uplift. An exception is one profile (A- B in Torsaq basin) which reflects the growth of deep or V-shaped valley associated with uplift, which is due to the close distance to the main thrust.

There is an inverse proportionality relationship between area and slope of the fans; Torsaq 1 is the smallest and steepest segment fan, whereas Torsaq 2 is the largest and gentlest. The fans are tilted towards the west direction, indicating uplift of their eastern parts. The values of drainage basin asymmetry (AF) in the studied basins are equal to 46.33 and 38.28, which indicate that the main streams are shifted downstream to the right and tilted towards northwest. According to the values of

drainage basin asymmetry and the fan tilting, it is concluded that there is an uplifted zone with West and Northwest directions.

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