

Investigating the effect of active tectonics in the evolution of the alluvial fan, case study: Behbahan-Qaland, Iran

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Abstract

Alluvial fans are geomorphological forms in river systems that are often formed in dry areas and mountain fronts, where rivers meet the plains. They are an erosional and sedimentary system and some factors such as the shape and lithology of the catchment, tectonic activities and climate affect their formation and evolution. In this research, 7 fans were identified in Behbahan-Qaland area. Next, using the Digital Elevation Model (DEM), the map of the drainages network extracted and seven geomorphic indices including the sinusoidal index of the mountain front (Smf), the width of the valley to the height (VF), the asymmetry of the drainage basin (Af), and hypsometric integral (Hi) were calculated for each of the alluvial fans and their upstream basins. The obtained results showed that the smf index values have a minimum value of 1.08, which indicates active tectonic activity and a maximum value of 1.33 which indicates semi-active tectonic activity. For the VF index, in the north part have high tectonic activity. AF index in watershed number 3 and 4 with a small amount of 15 and 16.5 indicates active tectonic activity and erosion on the right bank. The HC index shows that these basins are in a young stage. The HI index indicates a tectonic active and semi-active state. The values of the Iat index in the region for basins No. 3 and 4 are 1.16 and 1.33, a state of intense tectonic activity, in basins No. 1, 5, and 6 with values of 1.83 activity. High tectonics and basins number 2 and 7 with values of 2.33 and 2.16 show moderate tectonic activity.

Keywords: Active Tectonics, Alluvial Fan, Geomorphic Indices, Behbahan-Qaland

1- Introduction

One of the most important geomorphological phenomena are alluvial fans, which are generally the basis of human activities, they have triangular shapes and are formed at the place where the rivers enter the flat surfaces of the plain. Alluvial fans are the result of an erosion and sedimentation system that are attractive for establishment of civilizations. The development of these landforms in arid and semi-arid areas reduces the limitations of water and soil resources. So, they play a role in choosing the location of urban and rural settlements. Most of the investigations indicate the formation and evolution of alluvial fans in dry climates (Madadi et al., 2015). Alluvial fans are among the typical landforms of the mountain front, which are formed due to the sudden decrease in the power of the river as a result of the change in the topographic slope (Bull, 1977), and sedimentation takes place, thus the alluvial fan is formed and its structure changes under the influence of many variables. The main factors affecting the processes of alluvial deposits are: the shape of the basin, conditions adjacent to alluvial deposits, lithology of the catchment area, tectonic activities and climate. Meanwhile, tectonics and climate establish a relationship between energy input and output (Maghsoudi, 2013). Against various factors of weathering, the resistance of rocks has a direct effect on the amount of sediment. The lithology of the catchment determines the primary processes in the change of alluvial fans. Climate and its effects have very important and extensive effects on alluvial deposits, tectonic activities, having a certain and effective role in changing the structure of alluvial deposits, actually affect the effect of other conditions. Sedimentary fans are transformed into small and short-lived forms without the constant activity of tectonics. In most cases, the surface slope of

alluvial deposits is controlled by tectonics (Bahrami & Bahrami, 2013).

Tectonic movements change the base level of erosion and affect the active processes on the surface of alluvial fans and their evolution. Based on this, alluvial surfaces can be used to investigate history and movements (Yang, 1985). In general, it can be said that tectonic forces play the main and primary role in the formation of alluvial fans, and they also play a significant role in their evolution. In areas with tectonic activities, landforms are the result of a complex combination of effects of vertical and horizontal movements of earth crust plates and erosion or deposition by surface processes. By changing the base level, tectonics changes the active processes on the surface of alluvial deposits and affects the evolutionary process of alluvial deposits (Salehpour-Jam et al., 2017). The occurrence of tectonic events, faulting, folding, and subsidence or uplift, have resulted in the reaction of the alluvial fan, in such a way that this reaction can be recorded in the type, size, shape of the sediment and the morphology of the alluvial fan. Also, tectonic activities play a significant role in the change of alluvial (García-Tortosa et al., 2008).

In the folded mountains of tectonic active areas, quantitative-qualitative analysis of drainage systems is effective for investigating the development of landscapes and the impact of tectonic activities on geomorphic processes (Nosrati et al., 2017). (Maghsoudi, 2013) used geological maps, topography, satellite images and field visits. The present study investigates the effect of active tectonics of Zagros on Behbahan and Qaland alluvial fans. This area is home to a large number of people and extensive agricultural activities take place there. Knowing these effects is necessary for better interaction of people with this phenomenon and crisis management.

2- Study area

Behbahan district with an area of 3195 Km² is located in the southwest of Iran (Figure 1) in geographical coordinates of 16°31'50" to 35°03'50" east longitude and 35°33'30" to 22°51'30" north latitude. Its highest elevation is 1628 meters above sea level, the lowest elevation is 239 meters above sea level.

The studied area, which includes two parts of the plain and the mountains. In the north of the

Khayiz mountain range, the highest point of which is 1628 meters, most of the elevations and watersheds leading to the plains are included, and the sediments of these elevations have formed its fans and plains. The Maroon River, which originates from the relatively high mountains of Kohgiluyeh (Sadat region), after a long journey, enters the Behbahan Plain and the study area through Tang Takab. The irrigation and drainage network in the lower reaches of the Maroon dam supplies the majority of water needed for agriculture, industry and drinking in the region.

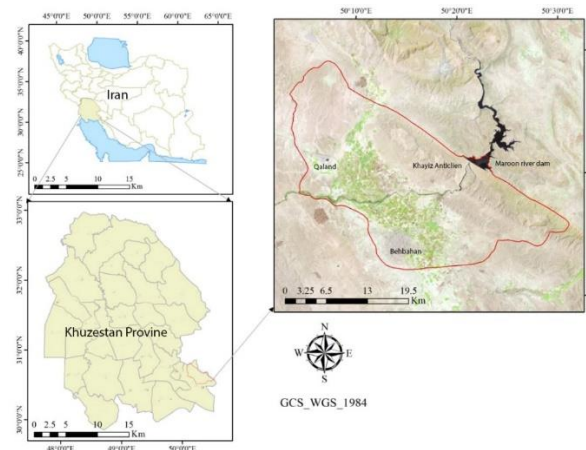


Figure 1- Study area location

3- Material and Methods

In this research, the digital elevation model (DEM) prepared from ASTER GDEM with accuracy of 30 meters, along with the use of Google Earth software and geological maps with a scale of 1:100,000 (Behbahan-W20836) and Landsat satellite images have been used. The studied area is within Behbahan city to Qaland village, the watershed of the area is a part of the Maroon River watershed. The alluvial fans are

spread along the Khayiz anticline and with a northwest-southeast trend (Fig. 2).

After collecting descriptive information by interpreting geological and topographical maps and satellite images (Fig. 3), the studied area was determined, and active tectonic indices were used to evaluate the relation of the alluvial fan to tectonic processes by using tectonic indices. ArcGIS and Google Earth software were used for processing data.

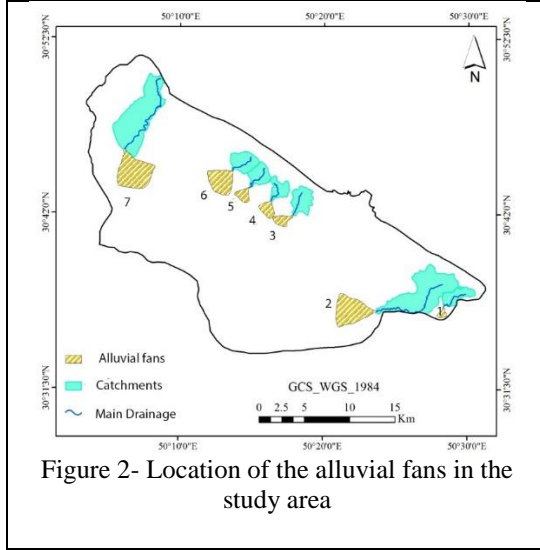


Figure 2- Location of the alluvial fans in the study area

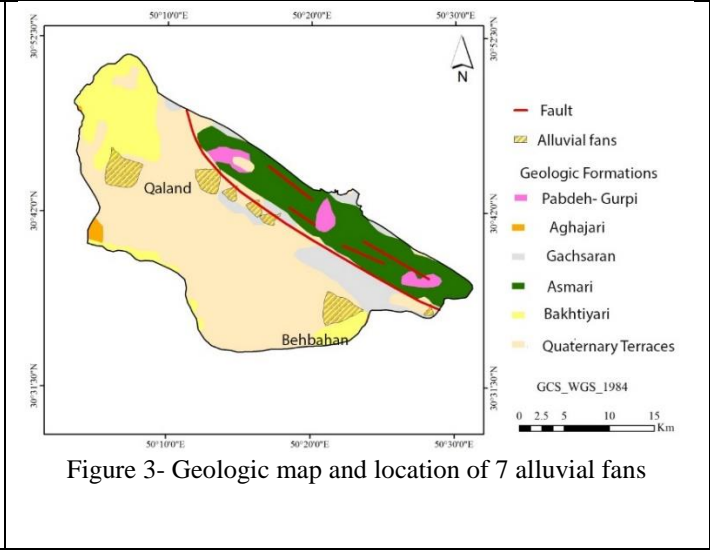


Figure 3- Geologic map and location of 7 alluvial fans

3-1- Quantitative indices

The use of morphological parameters and signs on a regional scale along with geological studies and other methods is done in order to determine the tectonic setting. The type of morphological phenomenon depends on the deformation process and the speed of influence of the deformation factors. The shapes of the front of the mountains and the resulting cliffs have a direct relationship with tectonic activities.

In this research, firstly, the influence of tectonics on the morphology and shape of alluvial deposits of the region has been investigated. In the following, in order to estimate the amount of tectonic activities on the desired alluvial fan, some quantitative indices were used (Keller & Pinter, 2002).

3-1-1- Ratio of the width of the valley to its height (VF)

The following formula was used to study this index:

$$VF = 2V_{fw} / ((E_{1d} - E_{sc}) + (E_{rd} - E_{sc})) \quad (1)$$

Witch VF= is the ratio of the width of the valley to its height, V_{fw} = valley floor width in meters,

E_{1d} = the height of the dividing line between the two valleys on the left side above sea level in meters, E_{rd} = height of the valley floor above sea level in meters. Valleys with a wide bed have higher values of vf index and deep and V-shaped valleys have smaller values of VF index.

3-1-2- Sinusoidal index of the mountain front (Smf)

Measuring the sinuosity of the mountain front is also a quantitative method that can be used to evaluate new tectonic activities in a region. In this method, by measuring the twists and turns created by the drainages on the mountain front and dividing it by the horizontal length along the mountain front, the status of an area can be determined in terms of tectonic activity. This index is expressed as the following equation (Keller, 1996).

$$Smf = L_{mf} / L_s \quad (2)$$

In this regard Smf: It is the mountain front meandering index, L_s : is the length of the sinuosity of the mountain front, L_{mf} is the horizontal length in the direction of mountains in the area.

In this method, the smaller the Smf value, the more tectonic activity.

3-1-3- The asymmetry index of catchment

In areas with active erosion, usually due to the manifestation of topographical effects resulting from erosion on one side of the area and, as a result, subsidence on the other side, the length of the subsidiary drainages and, as a result, the area covered by these drainages on the eroded side of the area is more than this length on the other side. Therefore, the index (AF) is defined as follows:

$$AF = 100 (Ar/At) \quad (3)$$

In this regard AF: asymmetry index of drainages, Ar: Basin area on the right bank of the main waterway (in square kilometers), At: the total area of the catchment area (in square kilometers). If the values of this index are around 50, it will indicate the symmetry of the secondary drains compared to the main drainage and as a result, the absence of tilting due to erosion.

4- Results

In this part, according to the results obtained in the previous stages, the data obtained from the geomorphological indices in the study area were analyzed. Based on this, the effect of active tectonics on the creation and formation of alluvial fans in the southern slopes of Zagros was recognized, and finally, a field visit was made to complete and apply the obtained information.

In the studied area, the Tashan fault has had the greatest impact on the formation of alluvial fans and has caused the formation of a fault abyss and created the necessary conditions for the deposition of alluvium of Khayiz anticline in its downstream and the formation of alluvial fans number 1, 3, 4, 5 and 6. Figure 4 shows the effect of the Tashan fault on the formation of alluvial fans No. 3 to 6.

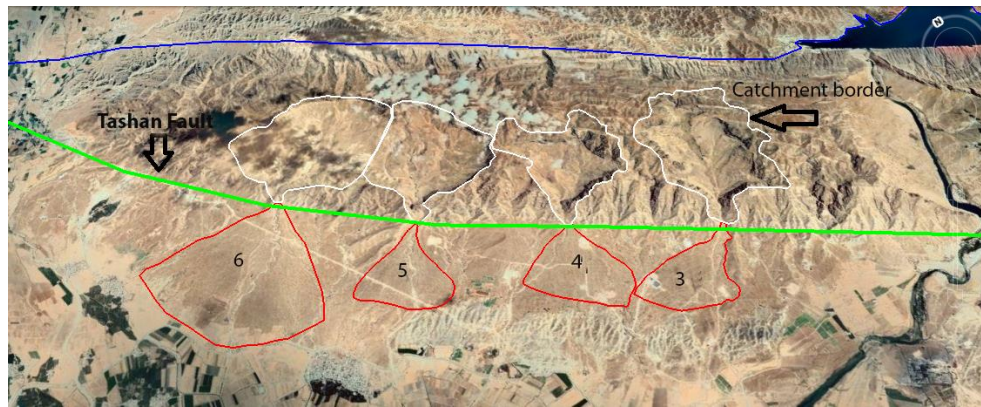


Figure 4- effect of the Tashan fault on the formation of alluvial fans No. 3 to 6.

4-1- Tectonic influence on the drainage pattern of alluvial deposits

In areas that tectonic movements is active, the deformations will cause the drainage network of the area to respond to these changes. One of the most important indices for differentiating old and new alluvial deposits is the drainage pattern.

Drainage networks spread out at the mountain-plain interface due to the decrease in slope and form a distributed or divergent drainage pattern in active alluvial fans.

In general, in new alluvial fans, the drainage pattern is distributed or branched and in some cases intersected, but the old and inactive parts of

alluvial fans have undergone retrograde erosion due to being spared from surface currents (Bahrami & Bahrami, 2013).

4-2- Mountain front sinuosity index (smf)

The sinuosity index or mountain front sinuosity is one of the geomorphic indices for evaluating active tectonics. This index shows the balance between erosion and tectonic (Silva et al., 2003). Erosion processes usually tend to excavate mountain fronts and create an irregular mountain front, while tectonic forces work to create a continuous and straight mountain front. In this

method, by measuring the twists and turns created by the drainages on the mountain front and dividing it by the horizontal length in the direction of the fault and the mountain front, it is possible to determine the state of an area in terms of tectonic activity (Karami, 2018). In general, in tectonically active areas that are associated with uplift, the mountain front is relatively straight, and when the uplift decreases or the area is tectonically calm, erosion processes come into action and cause irregularity and meandering. The table 2 show two types of divisions to evaluate the tectonic activities of the regions based on the Smf index.

Table 2- Smf index values

Fan No.	Lmf (m)	Ls (m)	Smf
1	203	180	1.13
2	1460	1100	1.33
3	450	340	1.32
4	420	390	1.08
5	520	430	1.21
6	1150	1020	1.13
7	870	790	1.10

4-3- Valley width to its height index (VF)

The VF index is usually measured at a certain distance from the mountain front, towards the upstream side of the river (Sorriso-Valvo et al., 1998). By calculating the VF index for the parts of the valley closer to the mountain front, it is

possible to judge whether the mountain front is in active or inactive tectonic setting. Valleys with a wide bed have high VF values and deep and V-shaped valleys show lower values. In fact, the formation of V-shaped valleys is in response to tectonic movements. The VF index measurement areas are shown in Table 3.

Table 3- Tectonic activity classification of study area based on VF index

Fan No.	Vfw	Esc	Eld	Erd	VF
1	15	720	761	787	0.28
2	140	472	494	509	3.5
3	30	484	549	547	0.47
4	18	500	623	618	0.15
5	15	470	524	515	0.3
6	20	466	575	526	0.24
7	190	448	458	456	21

The values obtained from the VF index in the study area can be analyzed. According to the classification of (Keller & Pinter, 2002), mountain fronts in the north of fans No. 1, 3, 4, 5 and 6 have high activity. The mountain front north of fans No. 2 and 7 were identified as inactive areas. Also, in the classification provided by (El Hamdouni et al., 2008), the mountain front in the north of alluvial fans No. 1, 3, 4, 5 and 6 is part of class one and very active, so these valleys are V-shaped, which were created in response to vertical movements. Also, alluvial conifers number 2 and 7 were identified as class 3 and semi-active areas.

4-4- Asymmetry index of the catchment (AF)

If the values of this index are around 50, it will indicate the symmetry of the secondary drains compared to the main waterway and, as a result, the absence of tilting due to erosion. Numerical values greater than 50 indicate erosion on the right bank and a value less than 50 indicates erosion on the left bank. When using this index, it is assumed that the geological controlling factors such as the type of rocks, the slope of the stratifications, and the climate and vegetation factors, none of them had an effect on the asymmetry of the basin (Keller & Pinter, 2002). Table 5 shows the division of regions is observed based on the Af index.

Table 5- Af measurements of the study area

Alluvial fan No.	At (Ha)	Ar (Ha)	Af	Af- 50
1	426	100	23.5	-26.5
2	2235	645	28.8	-21.2
3	569	370	65	15
4	361	240	66.5	16.5
5	439	180	41	-9
6	552	240	43.5	-6.5
7	2369	500	21	-29

From the obtained results, it is inferred that in watershed number 3 and 4, erosion continues on the right bank, while in watershed number 1, 2, 5, 6, and 7, erosion continues on the left bank. Also, according to the classification provided by (El Hamdouni et al., 2008), watershed No. 4 is in the active class, watershed No. 3 is semi-active, and the rest of the watersheds are in the inactive class.

4-5- hypsometric curve index

Hypsometric curves evaluate and describe the distribution of elevation levels of an area. The

hypsometric curve of the basin is drawn by plotting the total height (relative height) against the total area (relative area) of the basin. The total area of the basin (A) is equal to the sum of the total levels between the adjacent level lines in the drainage basin. The surface (a) includes an area of the basin that is above the height (h). It is possible to use topographical maps in large and small scales that are available and available in sufficient quantities. In this case, the difference in area and scale has no effect on hypsometric evaluations (Madadi et al., 2015).

Table 8- Hypsometric integral of the drainage basin of the study area

Basin No.	Hi index	Max Elevation	Min Elevation	Mean Elevation	Class
1	0.56	1600	720	1220	2
2	0.46	1580	470	980	3
3	0.59	1055	475	820	1
4	0.57	1060	470	810	2
5	0.55	1070	440	790	2
6	0.54	1065	445	780	2
7	0.39	750	436	560	3

One of the easiest ways to describe the shape of the hypsometric curve of a certain drainage basin is to calculate the hypsometric integral of that basin. Hypsometric integral of the basin is determined by the area under the hypsometric curve. A way to quickly estimate the hypsometric integral is the following relationship.

$Hi = (\text{average height} - \text{minimum height} / \text{maximum height} - \text{minimum height})$

In this case, the three values of the mentioned formula, which are easily obtained from topographic maps, are necessary to calculate the hypsometric integral of the drainage basin. The maximum and minimum height are directly read from the topographical map (Madadi et al., 2015).

5- Conclusions

In the studied area, 7 alluvial fans were identified and the desired indices were evaluated for each of them. The results of the evaluation of geomorphological parameters used to analyze tectonic activities in 7 watersheds and their downstream alluvial fans have been presented. When several indices are examined simultaneously to evaluate the tectonic activities in a region, the obtained results will be more justified for geomorphic interpretations. Each of these indices provides a relative classification of the tectonic activities of the region, which are useful for the identification and preliminary investigation of such activities.

The values of Smf index have a minimum value of 1.08, which indicates active tectonic activity in basin No. 4, and a maximum value of 1.33 in basin No. 2, which indicates semi-active tectonic activity. In other basins, this index shows a semi-active situation. Therefore, based on this index, the research area has active to semi-active tectonic activity and the mountain fronts have erosion rates. The values obtained from the Vf index are at least 0.15 to 0.47 in the north of fans No. 1, 3, 4, 5, and 6 with high tectonic activity status. Also, the mountain front north of fans No. 2 and 7 with values of 3.5 and 21 were identified as inactive areas.

AF index in watershed number 3 and 4 with a small value of 15.5 and 16.5 indicates active

tectonic on the right bank, while in watershed number 1, 2, 5, 6 and 7 with values less than 7 show more erosion activity. Also, according to the classification provided by (El Hamdouni et al., 2008), watershed No. 4 is in the active class, watershed No. 3 is semi-active, and the rest of the area are in the inactive class.

According to the convexity in the dimensionless hypsometric curves drawn in the watersheds of the studied area, this curve shows that these basins are in a young stage. Also, the convexity in the dimensionless curve indicates the predominance of the tectonic activity of the basins' neo-tectonics over the erosion activities, and from the point of view of the neo-tectonics, it has an active state. Hypsometric integral index values in basin No. 3 with a numerical value of 0.59 indicate a tectonic active state and in basins No. 1, 4, 5 and 6 with values less than 0.57 indicate a semi-active state, also HI index with values of 0.46 and 0.39 in watersheds No. 2 and 7 indicate inactive status. Values of the Iat index in the studied area for basins No. 3 and 4 with values of 1.16 and 1.33 indicate a state of intense tectonic activity, in basins No. 1, 5 and 6 with values of 1.83 high tectonic activity and in basins No. 2 and 7 with values of A number of 2.33 and 2.16 shows the state of moderate tectonic activity.

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