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Assessment of geomorphological indices in the basins of Boz Qoosh area (Southeast of Tabriz - Northwest of Iran)

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Abstract: Geomorphic indices are useful tools for studying relative active tectonics of a specific area. In this study, the relative active tectonics of Bozgoush region (NW of Iran) has been investigated based on geomorphic indices. The studied indexes include: the stream lengthgradient (SL), hypsometric integral (Hi), the ratio of valley floor width to valley height (Vf), the shape of the drainage basin (Bs), the sinuosity of mountai front (Smf), asymmetric factor of drainage basin (Af) and transverse topographic symmetry factor (T). In the present study, gathered data from various morphometric indexes of six basins are aggregated, and their obtained result is provided as relative active tectonics of the region or Iat index that shows a proper illustration of the relative active tectonics of the mentioned region. In order to develop a correct analysis of the mentioned area, the AHP (analytic hierarchy process) model with a studied weight, the final overlapped layer of relative tectonics is prepared with applying coefficients. With the comprehensive field studies, evidences like deep valleys, river bed immigration, landslides, sudden change in river cycles and surfaces of faults were found that are in good consistence with obtained data of relative active tectonics of the region. After measuring these indexes, it was found that Aydoghmush and OujanChay basins have a high relative active tectonics. With regard to the obtained results of present study, it seems that Tabriz fault has the most seismic and motional potential in northern basins of the region. In addition, in Aydoghmush basin, in southern part of the region, Qeynarjehchartagh fault has a highactive tectonics that according to the estimated values has been identified as an active young structure in the region.

Keywords: Geomorphic Indexes, Active Tectonics, Bozgoush Region, Iran.

1- Introduction

The studied region is located in the north western of Iran and as a mountain range with east-west direction with an approximate length of 90 km and width of 30 km. According to the global model of plate tectonics, active tectonics of Iran is due to convergence of Eurasia and Arabia continental crusts. This con- vergence makes the movement of the Arabian shield to the north side of Eurasia shield, and as a result, leads to compression of the Iran plateau between the two crusts. Studied region is divided into 6 basins that are interrupted by extended branches of Tabriz fault; thereby their structural position and tectonics regime will be determined in Quaternary period. Southeast part of Tabriz fault passes from the northern and southern slopes of Bozghoush Mountain. In this region the trend of faults is east-west and northwest-southeast that their most important faults are northern and southern faults of this mountain which lead to sub- sidence of both sides of Bozghoush mountain from Sarab plain in north and Myaneh plain in south and uplifting of its central part. The mechanism of these faults has determined strike-slip with reverse dip-slip component [1].

Geomorphologic indexes are useful to identify the specific characteristics of an area, for example, to determine the level of active tectonics. These indexes are useful for identification of areas that undergo rapid tectonics deformation. Each of these indexes provides a relative classification of the intensity of active tec- tonics. For a specific area, using the several indexes rather than an index pro- vides more meaningful results [2].

Geomorphologic indexes have been used in different areas by numerous scientists and the result has been approved, for ex- ample, in Costa Rica’s Pacific coast [3], the Mediterranean coast of Spain [4] and the southern Sierra Nevada Mountains of California [5].

In this study, many morphometric parameters have been evaluated and by determination of I at index and conducting analytic hierarchy process, relative tectonics of the region has been examined. To achieve this goal, the indexes were measured and finally by averaging all of them relative active tectonics (Iat) of each basin has been determined. According to the field studies in the region, impact factor of each index was calculated with Expert Choice software based on its effect on the active tectonics of the region; and final result of the integrated AHP model with raster data has been provided for determining the relative active tectonics of each basin in the mentioned region.

2- Regional Setting of Study Area

The studied area is located in northwest of Iran and south of the Sabalan volcanic rocks at coordinates of 45˚37' - 48˚00' east longitude and 36˚30' - 38˚30' north latitude (Figure 1). The dominant lithology of the studied region is recent alluviums, marl,

sandstone, siltstone and volcanic and igneous rocks that are scattered in different parts of the region (Figure 2).

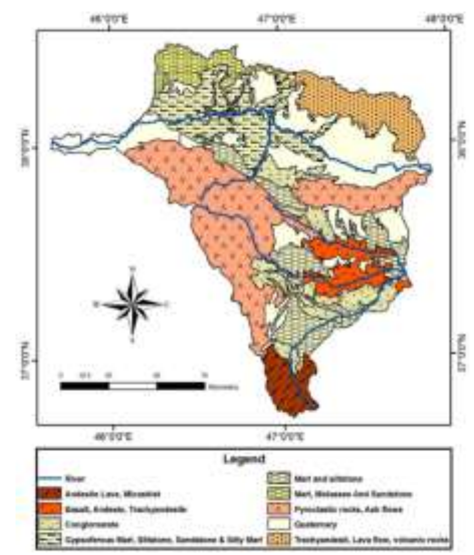

Figure 2) Geological map of the studied area

In western Alborz, oldest rocks are metamorphic rocks around Zanjan which belongs to Precambrian that are covered by Kahar formation with a little metamorphic rocks of late Precambrian. During the Eocene under-marine volcanic activities in Azerbaijan (Western Alborz) had been dominated so that the intensity of these activities are increased to the West. During the Pyrenees orogeny and alongside extensive magmatic activity that mainly are made of granite and syenite, the produced magma had been injected into the green tuffite [6].

According to [7] the movement of Saudi Arabia headland to the North in the middle Pliocene, leads to the moving and activity of Caucasus and Talysh transverse faults, and thus a gap created between the Black Sea and southern basin of the Caspian Sea. If this assumption be accepted, we have to conclude that the Azeri Plateau continues to move in the direction of the N-NE and probably Plio-Quaternary volcanism of Sabalan, Sahand and earthquakes of the region are results of these displacements [6].

3. Materials and Methods

Geomorphology is a powerful tool for examining relative tectonics. Description of different forms and topography of the earth surfaces is defined with relations of size, height (maximum, minimum and average) and their dips. In this study, all related indexes with the change of the river channel and watershed basins have been studied and relative tectonics of the region has been evaluated by the use of a single index, i.e. Iat index, which is the result of estimating 7 geomorphic features [12]. Finally, with the regard to the priority of the effect of the each index in the region and give the deserving weight to each of the Geomorphic in- dices and implementing AHP model, relative active tectonics of each basin was estimated in the region, separately.

3.1. Stream-Length Gradient Index (SL)

Change the dip of the river channel that is a factor in the change of the dip of water level is under the effect of rocks type and active tectonics [2]. Stream- Length gradient index (SL) is an indication of compromise between erosive processes such as river streams and tectonics activities [13] [14] and [15]. This index is defined as follows [14]:

$SL = (\Delta h \;\; \Delta l)\ l$

where, l is the length of the river channel form the upstream to the point that the

SL index (Stream-Length gradient) is calculated and

$\Delta h \ \Delta l$

is the dip of that Section of the river channel. This index is under the influence of uplifting in the area. Therefore, motional components with horizontal displacements like strike- slip faults don't have a strong effect on this index.

The calculated values of this index in the studied area were estimated by digital elevation model and GIS system that their values are shown in Figure 3. The thresholds of this index shows that the effected channels by tectonics movements have calculated values more than 500 meters; and values less than 300 meters represents those basins that are more affected by erosive processes of river streams. In order to find the SL index (Stream-Length gradient) anomaly that depends on the rock strength, at first a simple map of lithological units was prepared from geology map of northwest of the Iran, then various levels of relative rock strength based on the rock type and field observations was defined and suggested as a map of lithological units with different relative strength (Figure4).

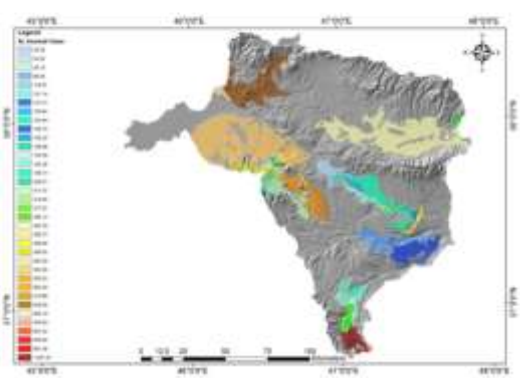

Figure 4) Spatial distribution of SL index anomaly values by color

Different levels of rocks strength are defined as follows:

1. Very low strength: Marl, silt, Quaternary sediments and young alluvial terraces
2. Low strength: gypsum marl, sandy Marland siltstone
3. Moderate strength: conglomerate, sandstone and molasse deposits
4. High strength: pyroclastic rocks and volcanic ash
5. Very high strength: ignimbrites, basalts, andesites, tracky andesite and volcanic rocks

After preparing the map of relative rocks strength, SL values plotted on this map (Figure 4) and their relationship with rock strength was analyzed. SL index was analyzed based on relative rock strength in different basins and its anomalies were found as follows.

1) In Western AjiChay River, the maximum value of SL index is in the north- east of the Tabriz city and located in Marl sediments. With the regard to soft bed of this river, high valued of SL index can be associated with the activities of the North Tabriz Fault; the graph of SL values along the river longitudinal profile shows that the highest SL index value pertain to the location of Tabriz fault (Figure 6).

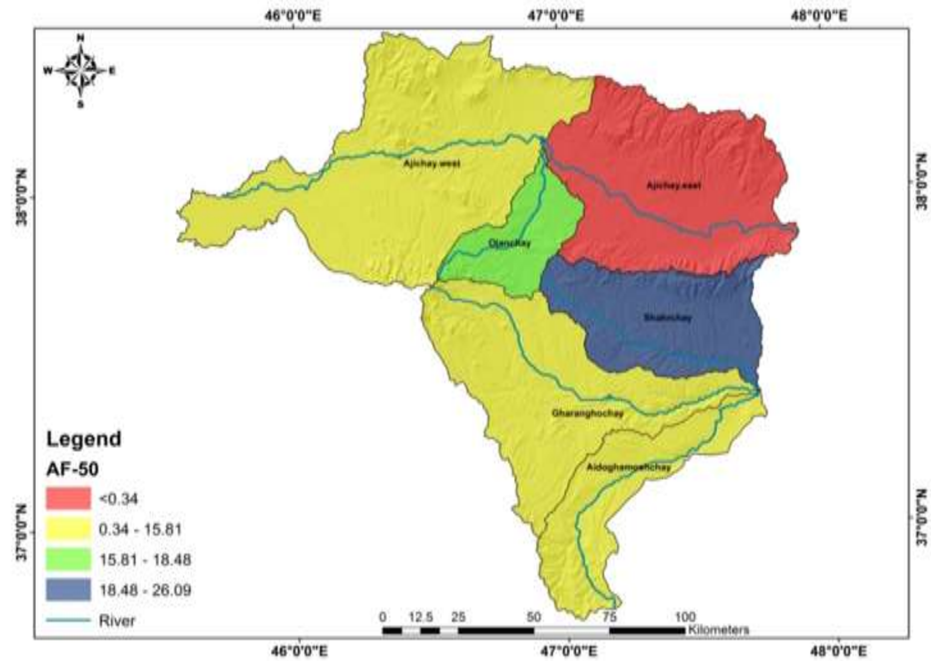

Figure 6) Spatial distribution of AF index values

2) OujanChay River with a length of 76 kilometers originates from the Sahand mountain, has anomaly in two points; the range of SL index value of this river is between 127 and 629. Tabriz fault nearly intersect this river in Bostanabad city perpendicularly (Figure 5), from this point towards southeast, river bed is composed of the pyroclastic and volcanic ash and SL index value is increased when the river passes the dacite and andesite domes, in which, this value of SL index is explained by high value of river bedrock strength in this area.

3) The values of SL index along the AjiChay River are mainly low and less than 300. The riverbed of Eastern AjiChay is composed of soft marl and siltstone sediments that their low SL index values reflect low tectonic activity of this basin. But in upstream of the river and in northeastern of the Bozghush mountain range, values of SL index suggested a high anomaly (Figure 5 & Figure 6). With the regard to the field observation of riverbed composition that is young alluvial terraces, the high value of index in this area could be in association to uplifting these alluvial sediments as a result of reverse faults activities in the north of Bozghush mountain.

4) SL index value along ShahrChay River differs from 25 to 1024. Roughly, the northern half section of the river has SL index value less than 300 that with the regard to the high relative bedrock strength of this section, unlike what is expected the index value of this area is less than 300. The low value of this index necessarily is not a result of domination of erosive forces over tectonics ones, because in this area ShahrChay River is parallel to Tabriz fault and in somewhere riverbed located on the strike of the Tabriz fault (Figure 5).

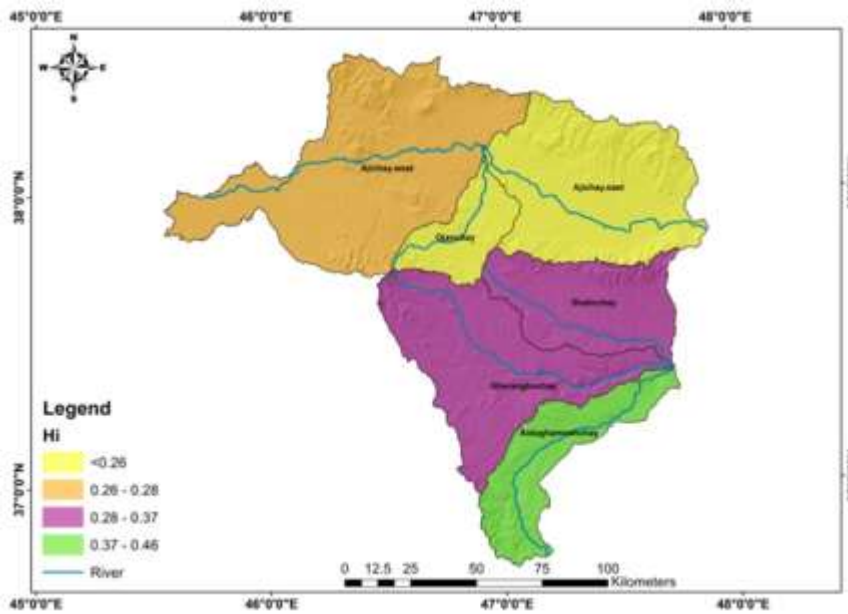

Figure 5) Spatial distribution of Hi index values

In lower half of the ShahrChay River, the high value of SL index to some extend could be a result of very high strength of riverbed rocks and to somewhat a result of tectonics uplift, because in spite of the fact that bedrock of the end section of the river composed of very low strength sediments, SL index value is greater than 500 that reflects the active tectonics of this area (Figure 5).

5) SL index value of the GharanghuChay River differs in its two halves like the SharhChay. From the mid-river towards its upstream, SL index value is low and in the downstream of it SL value is high (Figure 5 & Figure 6). In the downstream of the river SL values reach 2965 which is associated with riverbed lithology of this section of the river that passes the relative high strength rocks (including ignimbrites, basalt, andesite and tracky andesite), however, in the end section of the river in spite of sediments with very low strength, SL index is greater than 500 that reflects high active tectonics in this section of the river, consequently, both factors of tectonics and high strength of the lithology caused the index value approaches up to nearly 3000 (Figure 6).

6) In Aydougmush river, SL index value differs from 86 at the upstream to 8041 in the downstream section of the river. A severe anomaly of SL index is seen along the river in two points (Figure 6). The first anomaly is seen where the SL value reached 1947 and bedrock of the river is formed by conglomerate and molasse sediments with moderate strength, therefore, high value of index in this area could be explained by high active tectonics. In this part of basin, old folds of marl sediments and Miocene sandstone are refolded by recent tectonics and created fantastic forms. The second anomaly is seen in the end section of the river where SL value reached 8041 that bedrock is composed of ignimbrites and acidic tuffs and due to very high strength of these sediments, this value of SL index is not unexpected.

3.2. Hypsometric Integral (Hi)

Hypsometric integral (Hi) shows height distribution in a specific area. Hypsometric curve involves drawing height ratio versus area ratio and calculating the area under the curve. Hypsometric integral is independent of the size and height of the basin [16]. The beneficial use of hypsometric curve is that the drainage basins with different sizes can be compared with each other [2] [17] [18]. High values of this index suggest the active and young areas and low values show the old areas that the erosive processes are dominant and less affected by the active tectonics of the region [12]. In the studied region, this index was obtained by plotting the curve by digital elevation model and calculating the area under the curve which represents the value of hypsometric integral index. The values of Hypsometric integral (Hi) are classified into three categories: $Hi < 0.4$, $0.4 < Hi < 0.5$ and $Hi > 0.5$. With the exception of Aydogmush basin, all other basins have a hypsometric integral index less than 0.4 that could be due to the effects of sediments compaction with low strength and their faster erosion against erosive agents in the mentioned region (Figure 7).

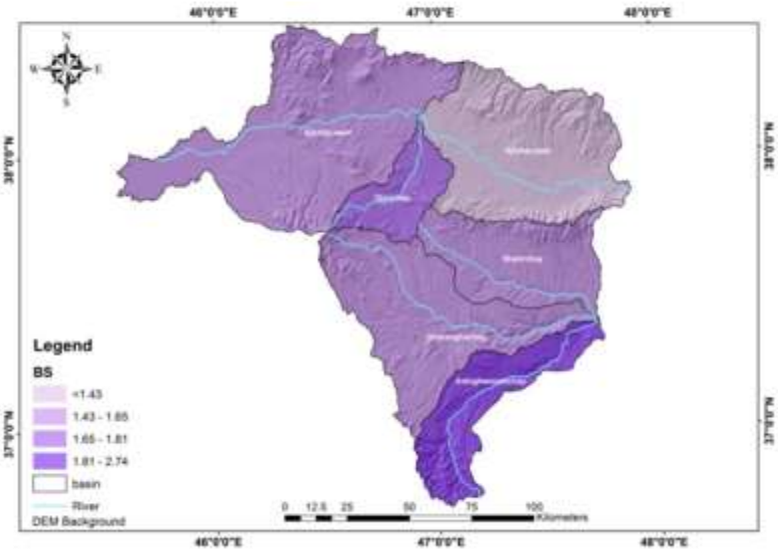

Figure 7) Spatial distribution of Bs index values

3.3. Asymmetry Factor (Af)

The asymmetric factor (Af) is a way to evaluate the existence of tectonic tilting at the scale of a drainage basin. The method may be applied over a relatively large area [2] [19]. This index is defined as follows:

$Af = 100 (Ar \; At)$

where, Ar is the area of basin in righthand of the main channel (facing down- stream) and At is the total area of the drainage basin. Numerical values of Asymmetry factor (Af) near 50, indicates the symmetry of basin, and thus the lack of tilting as a result of uplift, but numerical values more or less than 50 indicates a tilted basin that can be a result of active tectonics or lithologic structural control.

The values of this index are measured for basins of the region that their results are shown in Table 1. Index values are classified into three categories: Af-50 > 15,
15 > Af-50 > 7 and Af-50 < 7. Obtained values reflect that most of the basins are tilted towards the west that can be attributed to tectonics structures. In some sections of AjiChay basin, immigration of river bed can be observed due to basin tilting in silts and marl bedrocks (Figure 8).

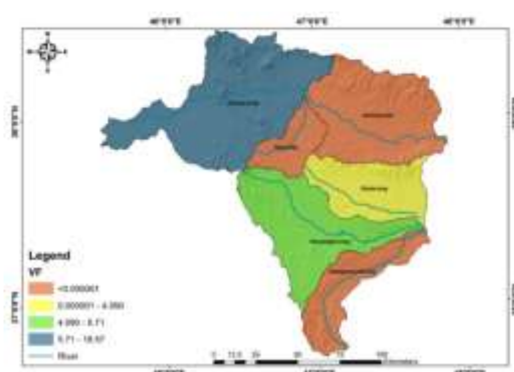

Figure 8) Spatial distribution of VF index values

3.4. Index of Drainage Basin Shape (Bs)

Relatively young drainage basins tend to be elongated in shape. With continued evolution or less active tectonic processes, the elongated shape tends to evolve to a circular shape [20]. Horizontal projection of basin shape may be described by the elongation ratio. The Index of drainage basin shape (Bs) [21] [22], expressed by the equation:

BS = Bl Bw

where, Bl as the basin length is the distance between the lowest basin height and farthest point of it and Bw as a basin width is measured in the widest section of basin. High value of this index represents elongated basins that are more seen in younger area of basin and more associated with frontal mountain fronts due to fast uplifting of relevant structures [23]. The values of index divided into three classifications: Bs > 4, 4 > Bs > 3; and <3. Values of the Bs index over the study area, are calculated (Table 2).

3.5. Ratio of Valley Floor Width to Valley Height (Vf)

This ratio represents the relation between tectonic activity and valley formation that is defined as follows:

Vf = 2Vfw (Ald + Ard − 2Asc)

Vfw is the width of the valley floor; Eld is the elevation of the left side of the valley; Erd is the elevation on the right side; and Esc is the average elevation of the valley floor. V shape and narrow valleys are associated with active mountain front and represent fast uplift and riverbed erosion occurred along the valley path. With the decrease of tectonics activities, erosive agents leading to the more increase of valley floor width and U shaped valleys are formed [2]. Silva et al. [4] believed that this index should be measured in a specific distance of mountain front (1 - 1/5 km). In the studied region, index values for main valleys that intersect faults front are calculated. Low value of Vf (Ratio of valley floor width to valley height) shows more basin uplift [2]. The Vf index values are classified into three categories: Vf ≤ 0.5; 1 > Vf > 0.5; and Vf > 1.

The lowest value of Vf in the region is found in western AjiChay basin at F point (Figure 9). According to the bedrock lithology of this point that are composed of sandstones and Miocene red marls, low value of this index reflects high tectonic activity that is associated with active Tabriz fault.

3.6. Transverse Topographic Symmetry Factor (T)

Calculation of this index is a method for evaluating a river inside a basin and in- tensity of asymmetry change in different part of the valley.

T = Da Dd

where Da is the distance basin midline to active meander belt (main active stream) and Dd is the distance from the basin midline to the basin divider [23]. When there is no change in the basin asymmetry, transverse topographic symmetry factor (T) is close to zero; as the asymmetry increases, T values approach

1. In perfectly symmetric basin T index is equal to. The index values are classified into three classes: class 1 (T ≥ 0.4), class 2 (0.4 < T < 0.2) and class 3 (T ≤0.2).

Calculated values for this index are in good consistency with values of AF index, in other words, it represent tilting and symmetry of transverse topography of the rivers in most basins of the region. Obtained values of symmetry of transverse topography are shown in Table 3.

3.7. Sinuosity of Mountain Front Index (Smf)

The sinuosity of mountain front index (Smf) is defined as below [16] [19]:

Smf = Lmf Ls

where, Lmf is the length of the mountain front along foot of the mountain where a change in slope from the mountain to the piedmont occurs; and Ls is the straight line length of mountain front. The sinuosity index of the mountain front reflects the balance between the tendency of river to create an irregular moun- tain front and vertical active tectonics that tends to create direct and prominent front [20]. Therefore, tectonics activities tend to create a smooth and direct mountain front that is coincided with boundary of an active fault, whereas ero- sive processes make the mountain front indirect. Sinuosity of mountain front index (Smf) is divided into the three classes [12]: class 1 (Smf ≤ 1.1), class 2 (1.1 ≤ Smf < 1.5) and class 3 (1.5 ≤ Smf). In the studied area, calculation of the si- nuosity of mountain front index was evaluated by topographic map with the scale of 1:50000 in GIS system. Mountain front segments that has been measured shown in Figure 10 and also obtained results are shown in Table 4.

4. Results and Discussion

4.1. Relative Tectonic Activity Classification (Iat)

In present study, relative tectonic activity of a region has been evaluated by use of geomorphic variables. Relative tectonic activity index (Iat) is obtained by average of the different classes of geomorphic indices, which is used for evaluation of relative active tectonics in a desired region that has four different classes [12].

Where, class 1 is a region with very high activity that $1 < Iat \leq 1.5$, class 2 has high activity with $1.5 < Iat \leq 2$, class 3 has a moderate activity with range of $2 < Iat \leq 2.5$, and finally class 4 is a region with low tectonic with values of the Iat index greater than or equal to 2.5 ($2.5 \leq Iat$). Relative active tectonics classes (Iat) are acquired by collecting all seven geomorphologic indexes of the studied area. Based on the obtained values of each class of Geomorphic indices for each basin and taking the average of them (S/n), the studied area is divided into three tectonic zones. The first group shows an area with high active tectonics with values of $1.5 < S/n \leq 2$, the second group with a moderate active tectonics with values of $2 < S/n \leq 2.5$ and the third group an area with low active tectonics with values of $2.5 \leq S/n$ (Table 5).

4.2. Analytical Hierarchy Process (AHP)

AHP that stands for Analytical Hierarchy Process is one of most known multi- purpose decision making techniques, which is based on binary comparisons and decision maker makes the decision by providing hierarchical tree, and then conducts a series of binary comparisons. These comparison determine the weight of each factor versus other competing alternatives in decision making. Finally, the logic of analytical hierarchy process emerges resulting matrixes of binary comparisons with each other in such a manner that optimum decision could be made [24].

It seem that one could determine weight and priority of each abovementioned indexes by examining affluent factors on each index and by using data and results of indexes' estimation, in order to, instead of relying merely on average of each index in Iat method, weight and significance of each index compared to other indexes be the basis of active tectonics of studied region.

In the determination of Iat index, index weighting have not been per- formed and all indexes have an equal significance, therefore, regarding to the fact that some indexes are directly and some other indirectly associated with active tectonics of the region, it seems reasonable that some indexes has more weight than the other indexes. Consequently, with the purpose of analysis this sort of system, the resulted maps of classified indexes were prepared in the form of valued and raster layers in GIS. Then, with the aim of identifying priorities and integrating resulted maps, Geomorphic indices were prioritized using decision-making rules, so that by maintaining the rank of these indexes, all of them could be integrated and finally impact factors were applied by the use of Expert Choice and ArcGIS software's and output raster was obtained. Applied coefficients for the indexes were determined as follows: Hi = 1, SL = 1.5, BS = 0.9, Smf= 1.4, Vf = 1.3, Af = 1.1 and T = 1.2.

The overlapped final layer of relative active tectonics has been prepared by applying mentioned coefficients that according to which only Oujan Chay and Aydoghmush basins lie in the class 1 with high relative active tectonics (Figure 11 & Table 1). With regard to earthquake epi- center maps of recent year and 110 past years, the most stress focus is along the Tabriz fault and studied region lie in the pre-seismic stage (Figure 11).

Based on previous work on the salt and muddiapirism [25]-[41] and neo tectonicregi mein Iran [42]-[51], Zagros in south Iran is the most active zone [52]-[93]. Then, Alborz [94]-[151] and Central Iran [152]-[169] have been situated in the next orders. Thus, the study areas have not been affected by strong regional shortening. It means that, there is disperse seismicity along major faults such as the Tabriz, Daman Jan and Benaravan faults (Figure 11).

Figure 11) relative tectonic activity classes (Iat) by color

5. Conclusions

Geomorphic indices provide useful tools for studying intensity of tectonic activity. Geomorphologic topography, indexes calculation and classes of the relative tectonic activity have a good consistency with the significant structures of the region. After studying the geomorphologic indexes and their calculation in the region, it was found that a district with the area of 2895.7 km^2 has been identified as high active tectonics (class 1), an area of 5808.4 km2 as moderate (class 2) and finally an area of 9385.6 km^2 (class 3) as low active tectonics. A comparison of field observations of active tectonics like deep valleys, river bed immigration, landslides, sudden change in river cycles and surfaces of faults clearly coincide with the values and classes of relative tectonic activity.

By estimating this index, it was found that low active tectonics (class 3) mainly occurs in the upper part of the region's basins, while moderate and high active tectonics (classes 1, 2) occur in the middle and lower parts of the basins.

Channels displacing is the best way to detect subsurface structures and is also one of the most important morphological evidences. In the case of OujanChay and Aydoghmush River, one could observe the effect of tectonics on river dis- placement in the end section of the river. In this section, the existence of various faults like Tabriz caused deep valleys and meandering of the river path. River path displacement is observed in several parts of the basin that the most path deviation is more evident at the end section of the river.

Alluvial terraces of studied region are tectonics terraces that have a multilevel and one could found tilting and fault-derived deformation in them like Oujan- Chay basin that as a result of Tabriz fault with NW-SE direction leads to river terraces with high active tectonics in this basin. Areas with relative high active tectonics mainly located in locations that rocky sediments have many deep fractures and create significant folding in these areas. The existence of narrow val- leys was confirmed by field observations of faults and tectonics features that is an evidence of active tectonics and uplifting in this region. Active structures were identified by estimating SL anomaly index such as Qeynarjeh Chartagh re- verse fault in the south part of Aydogmush basin that based on available evidences shows a high active tectonics.

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