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ACTIVE TECTONIC ASSESSMENT OF MANDILI WATERSHED USING GIS TECHNIQUE

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Key words: Dem, GIS, Hypsometric Integral, Mandili, Stream, Drainage basin, watershed

ABSTRACT

Geomorphic indices such as Asymmetry Factor (*Af*), Stream Length Gradient ratio (*Sl*), Hypsometric integral (*Hi*), Valley floor width to height ratio (*Vf*), Basin shape factor (*Bs*) and Mountain front sinuosity (*Smf*), are particularly useful in tectonic studies, because they can be used for rapid tectonic evaluation of large areas, and the necessary data often can be obtained easily from topographic maps and aerial photographs.

Geographic Information system (ArcGIS V-9.3) and Digital Elevation Model (DEM) with resolution of 30 m have been used to extract the stream network watersheds of Mandili Quadrangle, sheet No. NI-38-11, scale of 1: 250 000, east of Iraq.

Mandili Quadrangle is chosen to analyze the relationships between the morphometric characteristics and the active tectonics. The area concerned is located at the western edge of the well-known Zagros mountainous belt, which is a well-known tectonically active area.

Ten sub-basins were extracted by DEM and the above mentioned morphometric indices. In addition relative active tectonics were calculated to evaluate the tectonic history of the area.

The results show that the active tectonic effects on Mandili area range between inactive (low) to moderately active, which may be due to the soft and weakly resistant sediments that cover almost all the area concerned or due to prevailing climatic conditions in a tectonic quiescence.

تقييم النشاط التكتوني لحوض تصريف مندلي باستخدام تقنية نظام المعلومات الجغرافية

لؤي داود يوسف

المستخلص

بعض الأدلة والشواهد الجيومورفولوجية، مثل دالة نسبة طول المجرى المائي الى انحداره (*Sl*)، ونسبة عرض ارضية الوادي الى ارتفاعه (*Vf*)، ومعامل التماثل (*Af*) ، والمعامل الهبسومتري (*Hi*) ، ومعامل شكل الحوض (*Bs*)، و دالة التواء واجهة الجبل (*Smf*)، تكون ذات فائدة في دراسة النشاط البنيوي لأي منطقة لامكانية استخدامها في التقييم البنيوي السريع لمساحات كبيرة، والبيانات اللازمة يمكن الحصول عليها بسهولة من الخرائط الطوبوغرافية والصور الجوية والمرئيات الفضائية.

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استخدمت خاصية Hydrology ضمن ادوات Spatial Analyst Tools في برنامج Arc GIS V-9.3 ونموذج الأرتفاعات الرقمية DEM بدقة 30 متر، لأستنباط شبكة الأودية والمجاري المائية لتحديد مناطق تغذية احواض التصريف في لوحة مندلي رقم (NI-38-11) ذات المقياس 1: 250000 الواقعة شرق العراق.

وقد اختيرت لوحة مندلي NI-38-11 بمقياس 1: 250000، لتحليل العلاقة بين الخصائص المورفومترية والفعاليات البنيوية لها لكونها تقع على الحافة الغربية لما يعرف بحزام جبال زاكروس والمعروف بانة فعال بنيويا.

وتم استنباط (10) احواض ثانوية في المنطقة من نموذج الارتفاع الرقمي و الدالات المورفوميترية المذكورة اعلاه. بالاضافة الى حساب النشاط البنيوي النسبي لتقييم النشاط البنيوي للمنطقة.

واظهرت النتائج ان النشاط البنيوي المؤثر على حوض التصريف في لوحة مندلي يتراوح مابين المتوسط و قليل (عديم) الفعالية، وذلك قد يرجع الى ان اغلب المنطقة تغطيها الترسبات النهرية الحديثة ضعيفة المقاومة للتعرية، اوالى احتمالية سيادة الظروف المناخية مقترنة بفترة هدوء بنيوي.

INTRODUCTION

Morphometry is defined as quantitative measurement of landscape shape (Keller and Pinter, 1996). At the simplest level, landforms can be characterized in terms of their size, elevation, and slope. Some geomorphic indices have been developed as basic reconnaissance tools to identify areas experiencing rapid tectonic deformation (Bull and Mc Fadden, 1977; and Keller and Pinter, 1996). Geomorphic indices are particularly useful in tectonic studies because they can be used for rapid evaluation of large areas, and the necessary data often can be obtained easily from topographic maps and aerial photographs. In recent years, Digital Elevation Models (DEM) and Geographical Information Systems (GIS) have been extensively used to determine the morphometric properties of tectonically active regions (Sarp *et al.*, 2010). Some of the geomorphic indices most useful in studies of active tectonics include: Asymmetry Factor (*Af*), Hypsometric curve and Hypsometric Integral (*Hi*), Valley Floor Width to Height Ratio (*Vf*), stream length-gradient (*Sl*), Basin Shape (*Bs*) and Mountain Front Sinuosity (*Smf*).

In mountainous ranges, recent and active tectonics can be viewed as the main factor contributing to rock uplift, their present-day topography being the result of the competition between tectonic and erosional processes (Andermann and Gloaguen, 2009; and Perez-Pena *et al.*, 2009) The drainage patterns in tectonically active regions is very sensitive to active processes such as folding and faulting, which are responsible for accelerated river incision, basin asymmetry, drainage geometry and complexity, and river deflection (Cox, 1994).

In the present study, an attempt has been made to evaluate the geomorphic indicators of active tectonics in Mandili Quadrangle watershed through remote sensing and GIS approachs. This investigation applies quantitative analyses of geomorphic indices of Mandili Quadrangle, Sheet No. NI-38-11, scale of 1: 250 000. This area is located at the western parts of Zagros Thrust Belt, which is well known as tectonically active region due to the Anatolian- Eurasian -Arabian collision.

The main aim of this study is to assess the active tectonics in Mandili drainage basin area, which is a part of the Low folded zone, and the Mesopotamian foredeep. Mandili Quadrangle is located in the middle part of the eastern borders of Iraq between 33° 00' – 34° 00' North, and 45° 00' – 46° 30' East (Fig.1).

Yacoub (1983) described the geology of Mandili area, specially the Quaternary cover of the Mesopotamian Plain. Hasan (1985) described the regional photo-geological and geomorphological maps of Mandili, Badra, Zurbatiya, Sheikh Faris and Al-Teeb areas.

Barwary (1991) described the geology of Mandili Quadrangle, based on the data gained by the aforementioned reports data. Sissakian (2014) updated the report of Barwary (1991) by digitalizing Mandili geological map, using GIS technique. The following rock formations are exposed in the area; Euphrates, Fatha, Injana, Mukdadiya and Bai Hassan in addition to several types of Quaternary sediments. Kadhum (2014) prepared a land use land cover map for Mandili Quadrangle using remote sensing technique.

Lastly, detailed geological mapping of Zurbatiya area were conducted during 2014 (Mahmood *et al*., in press), in which some geological formations were investigated and marked. These are; Ibrahim Formation (Late Oligocene – Early Miocene), Dhiban Formation (Early Miocene), Jeribe Formation (Miocene), in addition to the aforementioned exposed formations.

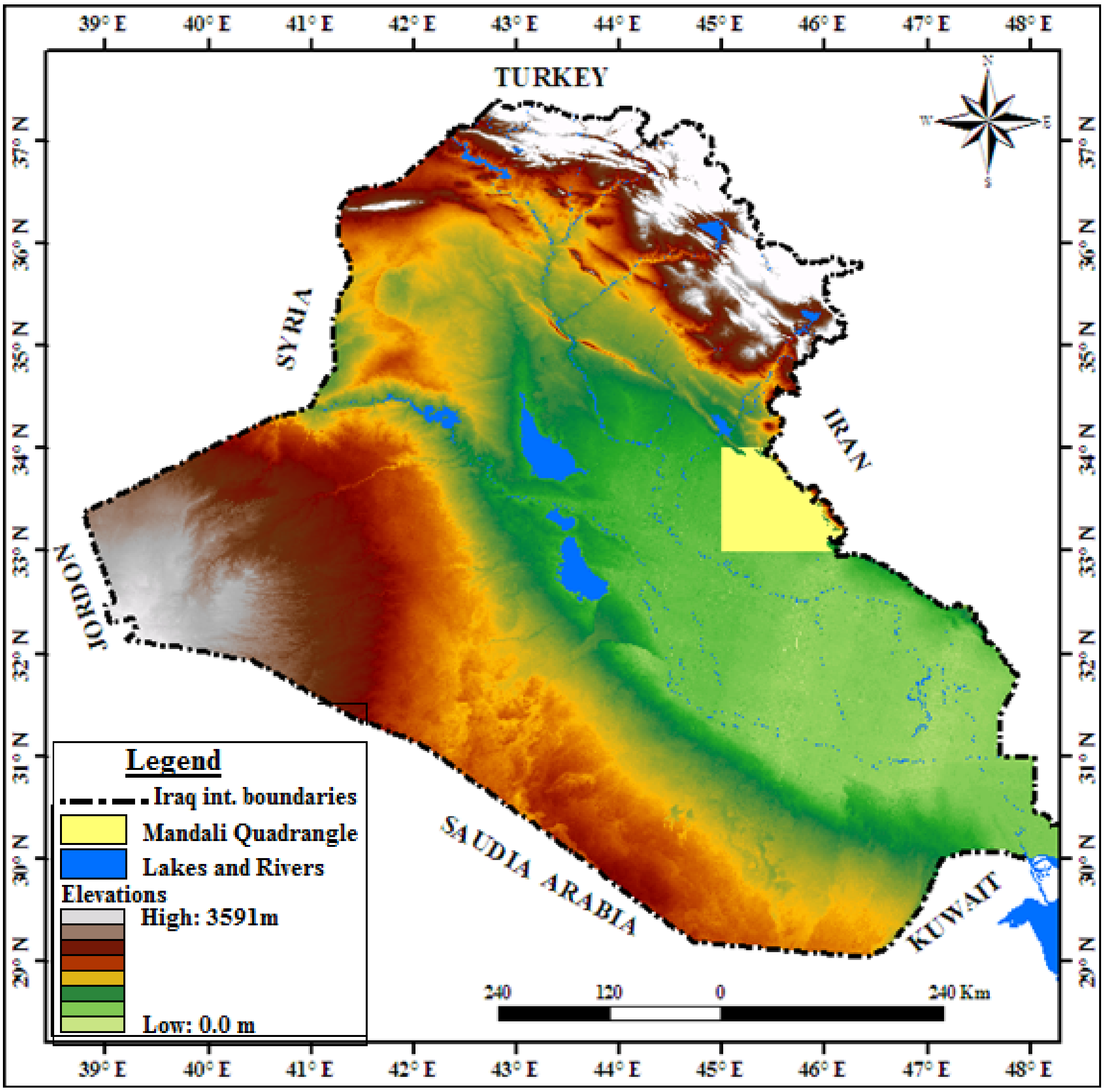

Fig.1: Location map of Mandili Quadrangle,
sheet No. NI-38-11, scale of 1: 250 000

GEOLOGICAL SETTING

The study area reveals a variegated topography due to the combined action of tectonics and erosion. The landforms developed in the drainage basin area are controlled by the climate, structure and lithology of the exposed sediments.

This area occurs to the west of the Zagros Fold – Thrust Belt. In fact it lies partly in the Low Folded and partly in the Mesopotamian Foredeep.

- **Geomorphologically**

About 10% of the area is characterized by hilly terrain that may reach up to 960 m a.s.l., in the east and northeastern parts, and about 90% is gently sloping pediment plain in the central and southwestern parts which may be as low as the sea level (Barwary, 1991). Hence, different geomorphological features were developed, such as:

At the most extreme northeastern part of the drainage basin, the structural-denudational forms are represented by "Himreen South" structure, which shows intense erosion. The discontinuous homoclinal ridge of the southwestern limb of Himreen structure form Cuestas and Hogbacks. Valleys are deep with steep banks and flat floors (U-shaped), whereas V-shaped valleys are short related to early stages of streams.

Almost all other parts of the studied area show geomorphological features, of fluvial origin.

Alluvial fans form a wide belt alongside the southwestern flank of Himreen South structure, reaching in some places 15 Km in width, and consist of many individual fans coalescing to form Bajada. Alluvial fans are composed of sandy gravels with secondary gypsum. In the studied area, the alluvial fans are developed in five stages. Boundaries between them are often marked by a break in the slope. Fine clastics dominate the younger stages and the margins of the fans.

Accumulation Glacis which is accumulation of the clastics is originated from the weathered and eroded materials of the alluvial fans and pre-Quaternary rocks. The surface is gently sloping to the south and southwest. Both erosional (sheet erosion, wind abrasion) and accumulation (sand sheet and small sand dunes), exist.

The studied area comprises two flood plain provinces. The first one is in the southwestern corner, representing the highest stage of the Tigris River and partly of Diyala flood plain characterized by almost flat surface with micro relief made up of ancient irrigation canals and shallow depressions. The second flood plain province is that of the lower foothill streams, includes several separated and independent flood plains. The younger stage of the flood plain is restricted to the main channels which include the recent and sub recent channel fill and point bars.

Aeolian forms also exist. Very shallow depressions, and ponds with commonly cracked surfaces, mantled by very thin salt crust, are common too.

- **Stratigraphically**

The previous geological mapping of Barwary (1991); and Sissakian (2014) suggest that the oldest exposed rock in the extreme eastern part of Mandili Quadrangle belong to the Euphrates Formation of Early Miocene age (Fig.2). However, during 2014, detailed geological mapping in Zurbatiya area, indicates that the Euphrates Formation exposures are considered to be the Jeribe and Dhiban formations of Early Miocene age, which overly the Ibrahim Formation of Late Oligocene – Early Miocene.

– Pre-Quaternary sediments: The exposed succession in Mandili Quadrangle are described hereinafter following Mahmood *et al.*, (in press) for Ibrahim, Dhiban and Jeribe formations and Sissakian (2014) for the youngest formations:

Ibrahim Formation (Late Oligocene – Early Miocene), consists of alternations of marl, limestone and marly limestone. A basinal anhydrite bed of more than 4 – 5 m thick, lies directly on the Ibrahim Formation and is considered as the upper contact of Ibrahim Formation with the overlying Dhiban Formation (Aqrawi and Goff, 2010). Dhiban Formation (Early Miocene) is exposed at the eastern parts and as relics along the thrust faults with total thickness of 70 m. It consists of alternations of gypsum, marl and marly limestone. The upper contact is conformable with Jeribe Formation. Jeribe Formation (Early Miocene) is exposed as relics along the thrust fault in the southeastern part, and consists of thickly bedded dolomitic limestone; grey, tough, fossiliferous, finely crystalline. The total thickness of this formation is 60 m. Fatha Formation (Middle Miocene) is exposed only north of Zurbatiya town, forming continuous steep escarpment. The Fatha Formation consists of two members of cyclic nature, starts with claystone followed by marl, thin limestone and thick gypsum. The upper member contains reddish brown claystone, which does not appear in the lower member. The upper contact with the overlying Injana Formation is conformable, based on the first appearance of thick sandstone beds. Injana (Late Miocene), Mukdadiya (Late Miocene – Pliocene) and Bai Hassan (Pliocene – Pleistocene) formations, respectively follow the Fatha Formation. All these formations are characterized by alternations of clastic sediments and fluvial sediments. These sediments are composed of monotonous alternation of sandstone, claystone and siltstone beds in Injana and Mukdadiya formations, and with conglomerate beds in Bai Hassan Formation.

– Quaternary sediments: All of the studied area are covered with different types of Quaternary sediments.

Due to the abrupt changes in the gradients, the studied area is regarded as typical region in which alluvial fans are developed (Fig.2). Alluvial fans form a continuous belt along the southwestern limb of Himreen structure, and they represent the marginal facies of the Mesopotamian sedimentary basin. They are developed in five stages marked often by sudden break in morphologic relief. They usually consist of cobbles, boulders, with subordinate amounts of sands, silts and clays. Slope sediments usually accumulate on the foot hill slopes, covering the Pre-Quaternary rocks, by combined action of sheet wash and gravity. They mantle the pre-Quaternary strata, or sometimes mixed with the alluvial fan sediments. Slope sediments are composed generally of gypsiferous sand or loam with rock fragments and gravels. The thickness is variable depending on the topographic relief. Sheet runoff sediments occupy wide area between alluvial fans; flood plains and shallow depressions fill units. They are the weathering and erosional product of pre-Quaternary rocks, alluvial fans, etc. This unit is built up by silty clays, silt and sand sediments.

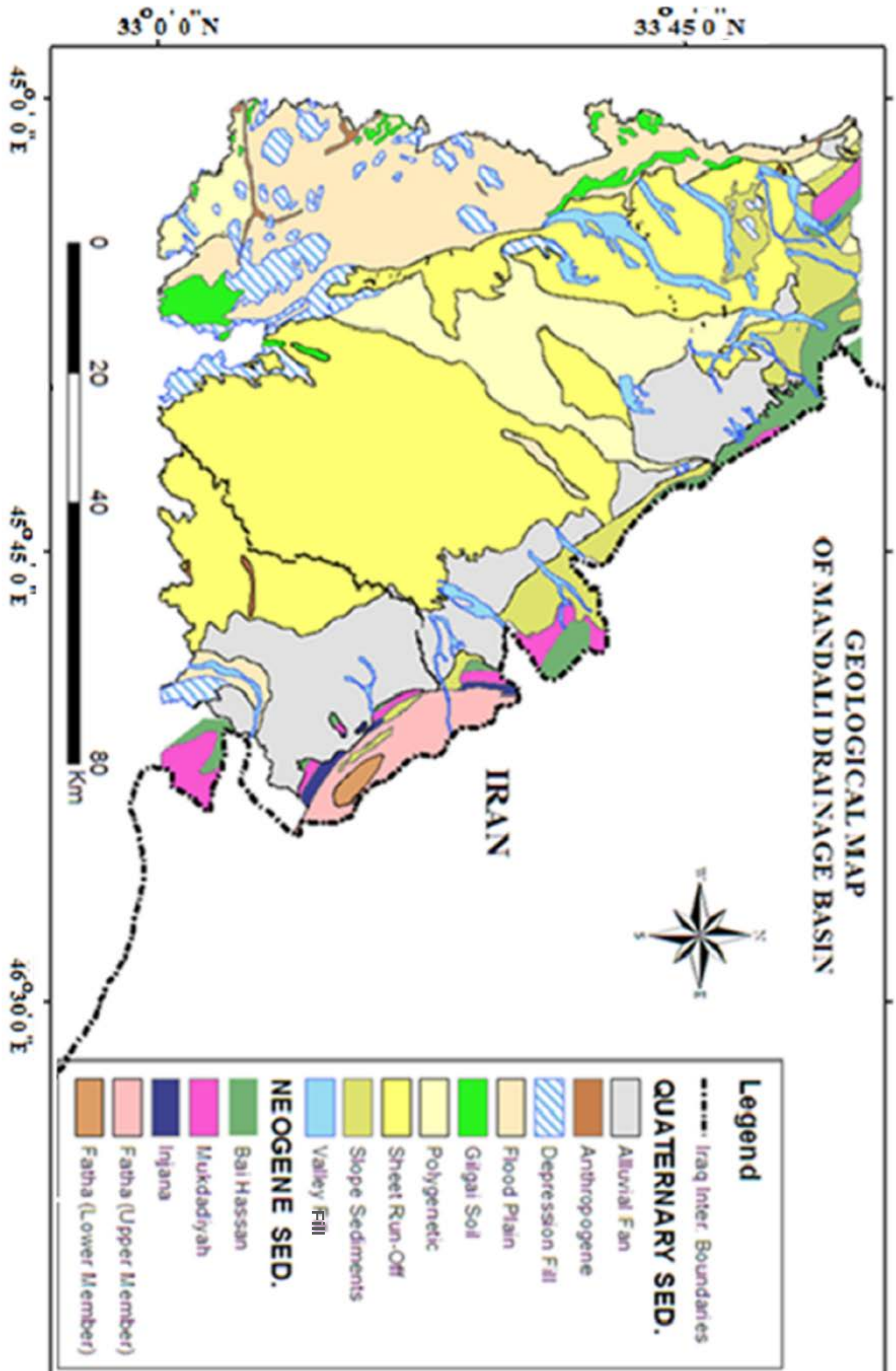

Fig.2: Geological map of Mandili watershed area (Sissakian, 2014)

- **Tectonics**

The studied area is located within the Low Folded Zone and the Mesopotamian Foredeep; both belong to the Outer Platform (Unstable Shelf) of the Arabian Plate (Fouad, 2014), which are affected by the late regional intensive tectonic movements of the Alpine Orogeny (Fouad, 2012; and Ajirlu *et al*., 2016). This tectonic movement caused the uplifting of Himreen structure, in the Low Folded Zone and the development of asymmetrical sinking basin in the Mesopotamian Foredeep, in the Late Pliocene. The influence of this movement is extended to deform the sediments of the Mesopotamian Foredeep. The evidence of this deformation is the uneven paleo-surface of the pre-Quaternary rocks, which is now covered by thick Quaternary sediments.

The Mesopotamian Foredeep is characterized by still active gradual subsidence that can be evidenced by the continuous filling of the basin by recent sediments. Simultaneously, these sediments rose in the adjacent Himreen mountain as indicated by the development of different levels of alluvial fans and river terraces on the southwestern flank.

The Himreen South structure is the only elevated structure within the studied area. Three anticlines occur in the studied area within this structure, the southwestern limb of the anticlines is within the studied area, although many minor anticlines and synclines are developed within the limb, especially north of Zurbatiya; all have the same trend of the main Himreen structure, which shows clear deflection towards the north (from its main NNW – SSE trend). This phenomenon is very clear in the contact between the Injana and Fatha formations (Sissakian, 2014).

During the detailed geological mapping of Zurbatiya area (2014), southeast Mandili Quadrangle, many longitudinal and transversal faults were recorded along the southwestern flank of Himreen South anticline. The longitudinal faults are represented by three major thrust faults with NW – SE trend associated with minor faults, while the transversal faults are relatively short with NE – SW trend (Mahmood *et al*., in press).

- **Hydrology**

Except the sloping range of Himreen Mountain in the extreme northeast part of the studied area, the other parts slope down from the north towards south, and southwest leading to the comparatively flat Mesopotamian Plain. This Plain is dissected by some intermittent major streams, such as Galal Badra, Galal Tersuq, Galal Haran, etc. These streams disappear finally in the flood plain of the Tigris River. The studied area is a part of the Tigris River basin.

The studied area is built up by discontinuous lenticular bodies of fine-coarse grained gravels and sands and silty clay and sandy bodies (alluvial fans), Generally, the sediments have good permeability and high infiltration capacity, so the water seeps into the ground, some remain in the soil, some evaporate and the remainder passes into the zone of saturation. The recharge is restricted almost entirely to the winter and spring seasons, when rain is the only source of feeding the surface water, although, numerous springs are perennial and occur as natural ponds.

METHODOLOGY

Digital Elevation Models data and Geographical Information System techniques have been widely used to determine the geomorphic characteristics of tectonically active regions. Some of the geomorphic indices are most useful in the study of active tectonics (Sarp *et al*., 2010). Indices of active tectonics may detect anomalies in the fluvial system or along mountain fronts. These anomalies may be produced by local changes in tectonic activity such as uplift or subsidence (El Hamdouni *et al*., 2008).

The present study is carried out in order to find the active tectonics of the watershed catchment of Mandili Quadrangle. The main objective of the study is fulfilled by computing the geomorphic indices, using GIS and remote sensing. The digital elevation model (DEM) with 30 m spatial resolution, of Iraq territory, has been used as a base map in Arc GIS 9.3 software, to extract the stream networks and their stream orders according to Strahler (1957). Then the watershed was delineated and ten subbasins were divided, using the Hydrological tools of the GIS system (Fig.3).

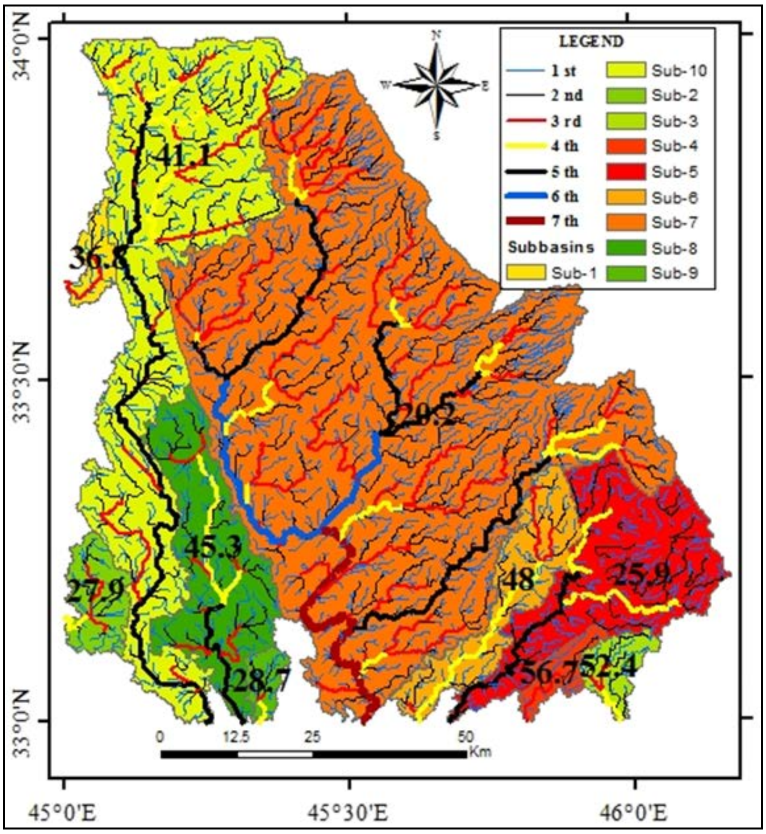

Fig. 3: Stream network and subbasins of Mandili watershed map

- **Morphometric Indices and Results**

The geomorphic indices are based either on analyses of the drainage network or mountain fronts. In order to evaluate rate of tectonic activity, six of the morphometric indices of Mandili watersheds, were analyzed and assigned into different tectonic classes based upon the range of values of individual geomorphic index, as follows:

– Asymmetry Factor (*Af*): This index is related to tectonic and non-tectonic factors. Non-tectonic factors may be related to lithology and rock fabrics. Tectonic factor is a way to evaluate the tectonic tilting at the scale of a drainage basin (Hare and Gardner, 1985; and Keller and Pinter, 2002).

To calculate this index in the area, ***At*** and ***Ar*** are obtained using the subbasins and the master river maps. The index is defined as follows:

$$Af = \frac{Ar}{At} * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1$$

Where, ***Ar***: is the right-side area of the master stream basin (looking downstream), and ***At***: is the total area of the basin.

Af is close to 50% (when symmetry) if there is no or little tilting perpendicular to the direction of the main stream. ***Af*** is significantly greater or smaller than 50 under the effects of active tectonics or strong lithologic control. The values of this index are divided into three categories (El Hamdouni *et al*., 2008).

Class 1 (***Af*** < 35 or ***Af*** ≥ 65), Class 2 (57 < ***Af*** < 65 or 35 < ***Af*** ≤ 43) and Class 3 (43 < ***Af*** < 57)

Values under and over 50% represent rightward and leftward tilting (according to the main stream flow), respectively.

In Mandili watersheds, the minimum value of the ***Af*** values is 20.15 in subbasin 7, while the maximum value is 56.74 in subbasin 4 (Table 1). The subbasins; 2, 5, 7, and 9 are classified as class 1 with high asymmetry (High tectonic tilting), the subbasins; 1 and 10 are within class 2 of moderate active tectonics (close to symmetry), while the subbasins; 3, 4, 6, and 8 are within class 3 (Fig.4) with low or inactive tectonics. These results may be due to the soft lithology prevailing of the studied watersheds.

Table 1: The calculated values of ***Af*** index for Mandili watersheds

Subbasin	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Af	36.8	28.0	52.42	56.7	26.0	48	20.2	45.3	28.7	41.1

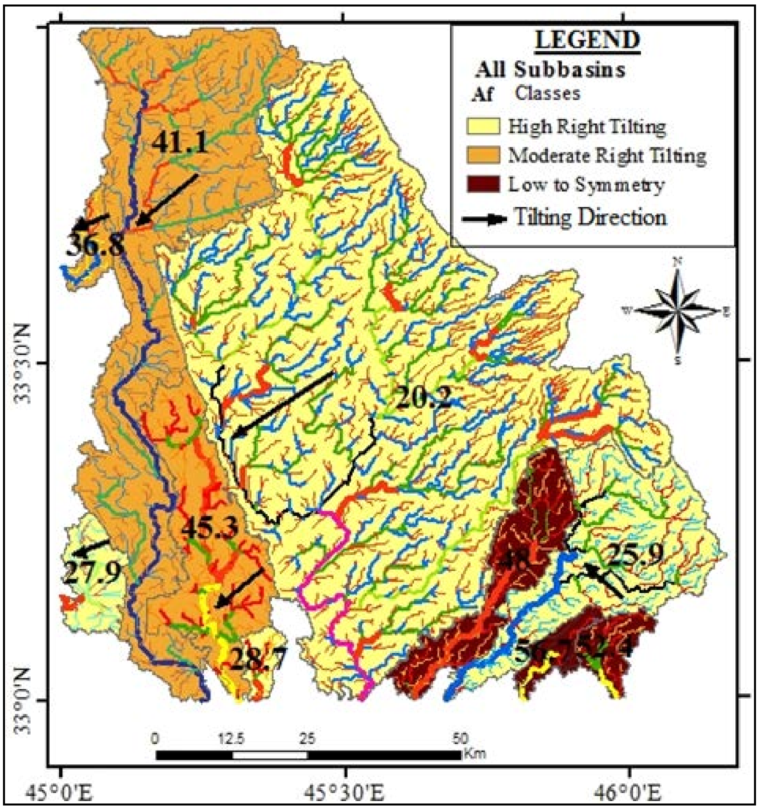

Fig.4: ***Af*** classes and tilting directions in Mandili watershed map

– **Stream Length – Gradient Index (*Sl*):** The rivers flowing over rocks and soils of various strengths tend to reach equilibrium with specific longitudinal profiles and hydraulic geometry (Hack, 1973; and Bull, 2007). Thus, Hack (1957, 1973 and 1982) used ***Sl*** index to test whether stream have reached equilibrium or not. Mathematically, ***Sl*** is given by:

$$Sl = (\Delta H / \Delta L) * L \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2$$

Where, ***ΔH***: is the change in elevations of the reach, ***ΔL***: is the total channel length from the midpoint of the reach of interest upstream to the highest point on the channel, and, (***ΔH/ΔL***): is the channel slope or gradient of the reach (Keller and Pinter, 1996) and ***L***: is the horizontal length of the watershed divide to the midpoint of the reach.

The high values of ***Sl*** index occur where rivers cross the hard rocks and reflect relatively high tectonic activity. Alternatively, low values of ***Sl*** index indicate relatively low tectonic activity and suggest less-resistant and softer underlying rock types (Hack, 1973; and Keller and Pinter, 2002). Also, the anomalous ***Sl*** values that are observed in uniform lithological conditions are due to tectonic activities. The ***Sl*** index value will increase as rivers and streams flow over an active uplift, and may have lesser values when they are flowing parallel to features such as valleys produced by strike-slip faulting.

Sl values are divided into three categories according to El Hamdouni *et al*. (2008):

Class 1 (***Sl*** ≥ 500); Class 2 (300 ≤ ***Sl*** < 500); and Class 3 (***Sl*** < 300)

For the current study, no ***Sl*** values are calculated for the sub-basins 8 and 9, because the values of the contour lines which cut the main stream trunks cannot be used. All the calculated ***Sl*** values are less than 300 i.e. within class 3 (Fig.5), which indicate that most of the streams, cross very low resistant sediments of the young and old alluvial fans. Among the calculated ***Sl*** values, minimum value belongs to subbasin 3, with 31%, and the maximum value belongs to sub-basin 1, with 108.125% (Table 2).

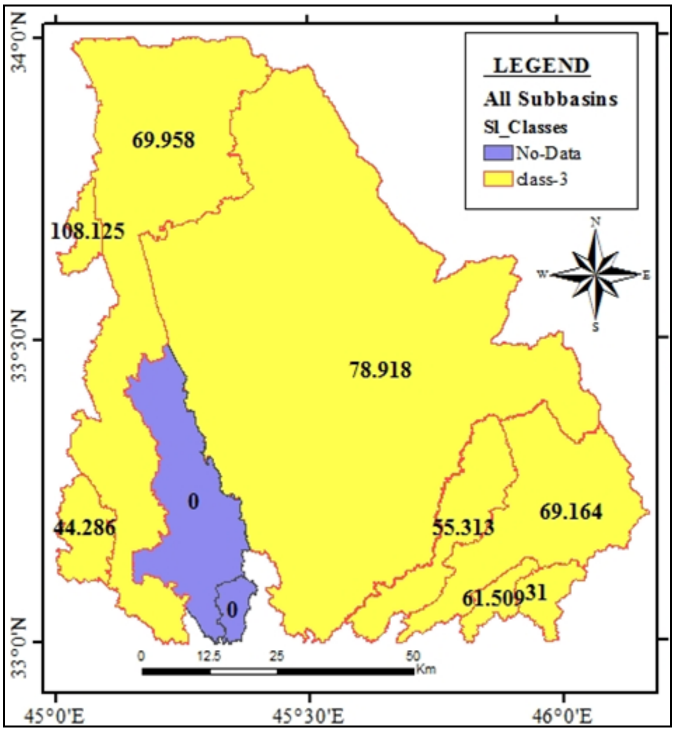

Fig.5: ***Sl*** values and classes of Mandili watershed map

Table 2: The calculated values of ***Sl*** index for Mandili watersheds

Subbasin	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Sl	108.1	44.3	31	61.50	69.2	55.3	79.0	-	-	70.0

– Hypsometric Integral Index (*Hi*): The ***Hi*** describes the relative distribution of elevation in a given area of a landscape, particularly a drainage basin (Strahler, 1952). The hypsometric integral **(*Hi*)** reveals the maturity stages of topography that can, indirectly, be an indicator of active tectonics. This index expresses the volume of a basin that has been eroded.

The hypsometric integral is calculated by the following formula (Keller and Pinter, 2002):

$$Hi = \frac{(H\ mean - H\ min.)}{H\ max. - H\ min.)} \quad \ldots\ldots\ldots\ldots\ldots \quad 3$$

Where; ***H max:*** maximum, ***H min:*** minimum and, ***H mean:*** mean of elevation are calculated from the DEM.

In general, high values of the ***Hi*** are generally greater than 0.5 and mean that not as much of the upland have been eroded, and may propose a younger landscape, possibly produced by active tectonics.

Intermediate values tend to have values between 0.4 and 0.5; lower values (< 0.4) indicate mature or old area that have been much eroded (El Hamdouni *et al*., 2008). The ***Hi*** index like the ***Sl*** index in that rock strength as well as other factors affects the value.

This index is calculated for all subbasins in the area, and the minimum value is 0.085 for subbasin 7, and the maximum value is 0.588 for subbasin 4 (Table 3). Subbasins; 2, 4 and 8 are of high ***Hi*** values (within class 1), subbasins; 1, 3 and 9 are of moderate ***Hi*** values (class 2) and sub-basins; 5, 6, 7 and 10 are of low ***Hi*** values (class 3) that indicate these subbasins have been much eroded due to its closeness to Himreen ridge (Fig.6).

Table 3: The calculated values of ***Hi*** index for Mandili watersheds

Subbasin	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Hi	0.46	0.5	0.45	0.59	0.14	0.39	0.08	0.51	0.49	0.22

– Valley Floor width – Valley Height Ratio (*Vf*): The ***Vf*** is sensitive to tectonic uplift. This index can separate V-shaped valleys from U-shaped valleys. The calculation formula is (Bull, 2007):

$$Vf = 2Vfw\,/\,(Ald + Ard - 2Asc) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 4$$

Where; ***Vfw:*** is the width of the valley floor, and ***Ald***, ***Ard*** and ***Asc***: are the altitudes of the left and right divisions (looking downstream) and the stream channel, respectively.

When rapid stream down cuts in tectonically active mountains, valley floor is narrowed with steep slopes and V-shaped, while in tectonically inactive mountain fronts, streams have U-shaped valley floor (Bull and McFadden, 1977).

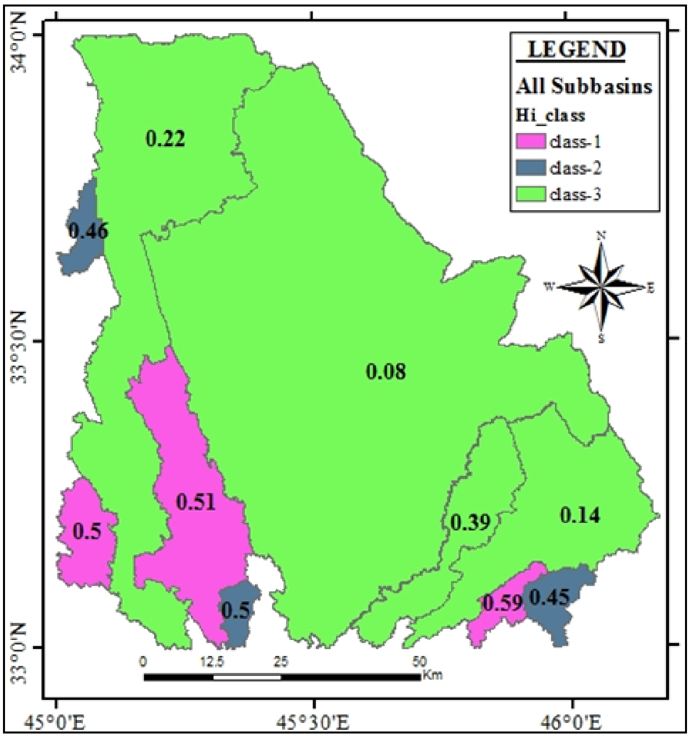

Fig.6: ***Hi*** classes and values of Mandili watershed map

Because uplift is associated with incision, the index is thought to be a proxy for active tectonics where low values of ***Vf*** are associated with higher rates of uplift and incision. Deep V-shaped valleys (***Vf*** < 1) relate to linear, active down cutting streams distinctive of areas subjected to active uplift, while flat floored (U-shaped) valleys (***Vf*** > 1) showing attainment of the base level of erosion mainly in response to relative tectonic quiescence (Keller, 1996; and Keller and Pinter, 2002). Values of ***Vf*** vary depending on; basin size, stream discharge, and rock type encountered. ***Vf*** values are divided into three classes (El Hamdouni *et al*., 2008):

Class 1 (***Vf*** < 0.3), class 2 (0.3 ≤ ***Vf*** ≤ 1), and class 3 (***Vf*** > 1)

This index is calculated for the main valleys of the studied subbasins using cross section drawn from DEM, along three locations (up, mid and downstream) for the main stream trunk in each subbasin and then the average of ***Vf*** values are obtained for each main stream. The calculated ***Vf*** index values are listed in Table (4).

Table 4: ***Vf*** values of Mandili subbasins

Subbasin	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Vf	5.5	5.5	2.7	1.8	3.6	2.4	0.7	2.8	5.6	1.3

Only one ***Vf*** value of subbasin-7 is within class 2 (0.3 < ***Vf*** < 1.0), which indicate moderate to low uplifting rates, whereas, all the other subbasins have high ***Vf*** values within class 3 (> 1.0) which is associated with low uplifting rates and characterize places where the stream cut broad (U-shaped) valley floor (Fig.7).

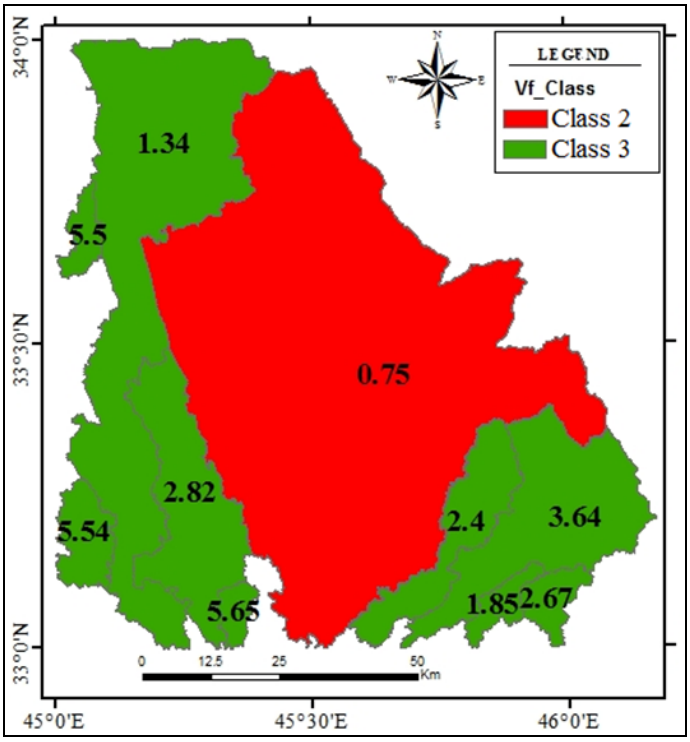

Fig.7: ***Vf*** classes and values map

– **Mountain Front Sinuosity Index (*Smf*): *Smf*** is an index that reflects the balance between erosional forces that tend to cut embayment into mountain front and tectonic forces that tend to produce a straight mountain front coincident with an active range-bounding fault (Bull and McFadden, 1977).

Those mountain fronts associated with active tectonics and uplift are relatively straight, with low values of ***Smf***. If the rate of uplift is reduced or ceased, then erosional processes would carve a more irregular mountain front, and ***Smf*** would increase. Mountain front sinuosity index is defined by Bull (2007) as:

$$Smf = Lmf / Ls \quad \ldots\ldots\ldots\ldots\ldots\ldots \; 5$$

Where; ***Smf***: is the mountain front sinuosity, ***Lmf**:* is the length of the mountain front along the foot of the mountain, and ***Ls**:* is the straight-line length of the mountain front.

The mountain front sinuosity **(*Smf*)** is commonly less than 3, and approaches 1 where steep mountain rise rapidly along a fault or fold (Bull, 2007). Therefore, this index can play an important role in tectonic activity. Because mountain front sites are independent of subbasin places, chances are that some of them have various fronts and that the others have no mountain fronts. The sinuosity of highly active mountain fronts generally has low values that range from 1.0 to 1.5 that indicate uplift prevails over erosional processes, yielding straight mountain fronts. The moderately active fronts range from 1.5 to 3.0, and that of inactive fronts ranges from 3 to more than 10 indicating erosional processes that generate irregular or sinuous mountain fronts (Bull, 2007). A sinuosity greater than 3 describes a highly-embayed front (Bull and McFadden, 1977). The ***Smf*** values are divided into three classes (Keller, 1986):

Class 1 (***Smf*** < 1.5), class 2 (1.5 ≤ ***Smf*** ≤ 3), and class 3 (***Smf*** > 3)

All the calculated ***Smf*** values (except subbasin 5) in Mandili drainage subbasins are within class 3, and only subbasin 5 has ***Smf*** value (1.73) which is within class 2 (1.5 < ***Smf*** < 3) as shown in Fig. (8). Subbasin 2 have no ***Smf*** value because there is no mountain front involved (Table 5). These results suggest relatively low rate of mountain front activity that wears down with time; the front is more eroded and sinuous, and the mountain front valley is wide.

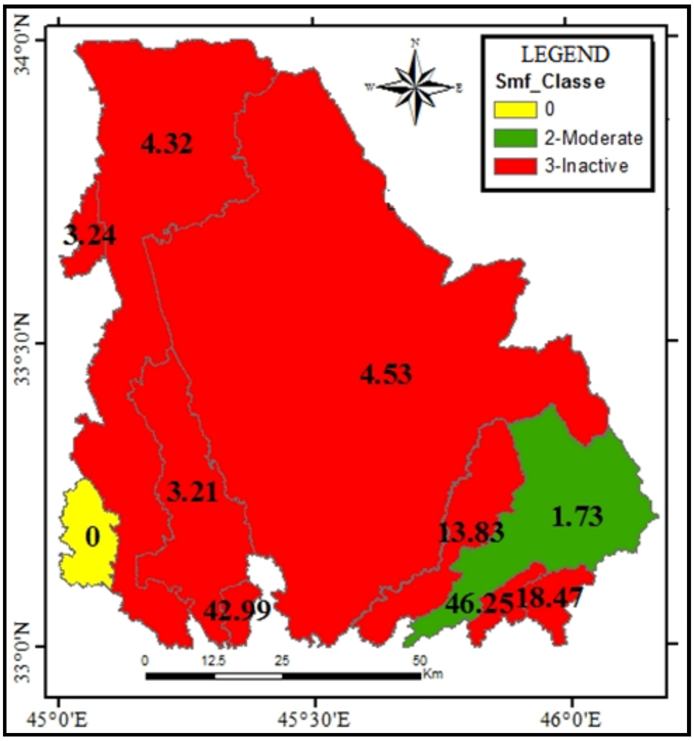

Fig.8: ***Smf*** values and classes

Table 5: ***Smf*** values of Mandili subbasins

Subbasin	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Smf	3.24	-	18.5	46.2	1.7	13.8	3.2	43	4.3	3.5

– **Basin Shape Index (*Bs*):** Relatively young drainage basins in active tectonic areas tend to be more elongated than their normal shape on the topographic slope of a mountain. The elongated shape tends to evolve into a more circular shape (Bull and McFadden, 1977). The horizontal projection of the basin shape may be described by the ***Bs*** or elongation ratio (Cannon, 1976; and Ramirez-Herrera, 1998). The calculation formula is:

$$Bs = Bl \,/\, Bw \quad \ldots\ldots\ldots\ldots\ldots \quad 6$$

Where; ***Bl****:* is the length of the basin measured from the headwater to the mountain, and ***Bw****:* is the basin width at the widest point of the basin.

In the studied area, ***Bl*** and ***Bw*** are obtained using the subbasins and the main river maps; then, the values are divided into three classes: class 1 (***Bs*** > 4), class 2 (3 < ***Bs*** ≤ 4), and class 3 (***Bs*** ≤ 3) (El Hamdouni *et al.*, 2008). The high values of ***Bs*** are associated with elongated basins, generally associated with relatively higher tectonic activity. Low values of ***Bs*** indicate a more circular shaped basin, generally associated with low tectonic activity. Therefore, ***Bs*** may reflect the rate of active tectonics.

Bs results (Table 6) show that; only two subbasins (6 and 10) are within class 1, which is associated with elongated shape basins that reflect the relatively higher tectonic activity (Fig. 9). Whereas, subbasins; 1, 4, 7, 8, and 9 are within class 2 and subbasins; 2, 3, and 5 are within class 3, which indicate a more circular shaped basin, generally associated with low tectonic activity.

Table 6: ***Bs*** values of Mandili subbasins

Subbasin	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Bs	3.2	1.9	2.2	3.1	2.1	4.5	2.5	2	3.4	5.5

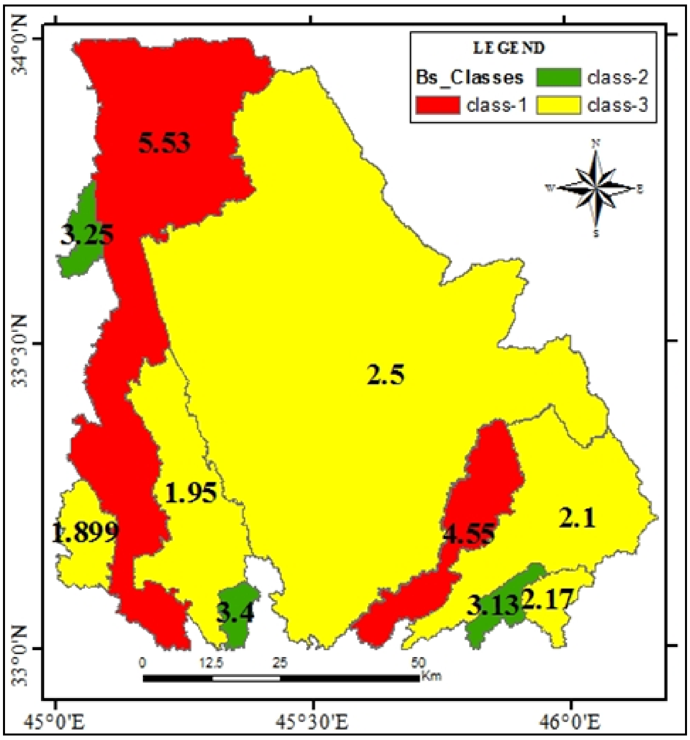

Fig.9: ***Bs*** values and classes

– **Relative Active Tectonic Index (*Iat*):** To calculate the ***Iat*** in the studied area, the average of the six geomorphic indices is used. The average (***Iat***) values are classified into four classes (El Hamdouni *et al*., 2008):

Class 1 (***Iat*** < 1.6 = Very High), Class 2 (1.6 ≤ ***Iat*** ≤ 2 = High), Class 3 (2 < ***Iat*** ≤ 2.5 = Moderate), and Class 4 (***Iat*** > 2.5 = Low)

The calculated ***Iat*** values listed in Table (7) show the subbasins of Mandili Quadrangle drainage basin to be divided between moderate (Class 3) and low (Class 4) relatively active tectonics (Fig.10).

Table 7: Morphotectonic classes of Mandili watersheds

Sub basins	*Af* Class	*Sl* Class	*Vf* Class	*Bs* Class	*Hi* Class	*Smf* Class	*Iat* Values	*Iat* Class	Active Tectonic
1	2-M	3-L	3-L	2-M	2-M	3-L	5	4	Low
2	1-H	3-L	3-L	3-L	1-H	0	3.7	4	Low
3	3-L	3-L	3-L	3-L	2-M	3-L	2.83	4	Low
4	3-L	3-L	3-L	2-M	1-H	3-L	2.5	3	Moderate
5	1-H	3-L	3-L	3-L	3-L	2-M	2.5	3	Moderate
6	3-L	3-L	3-L	1-H	3-L	3-L	2.7	4	Low
7	1-H	3-L	2-M	3-L	3-L	3-L	2.5	3	Moderate
8	3-L	0	3-L	2-M	1-H	3-L	2.6	4	Low
9	1-H	0	3-L	3-L	1-H	3-L	2.2	3	Moderate
10	2-M	3-L	3 L	1-H	3-L	3-L	2.7	4	Low

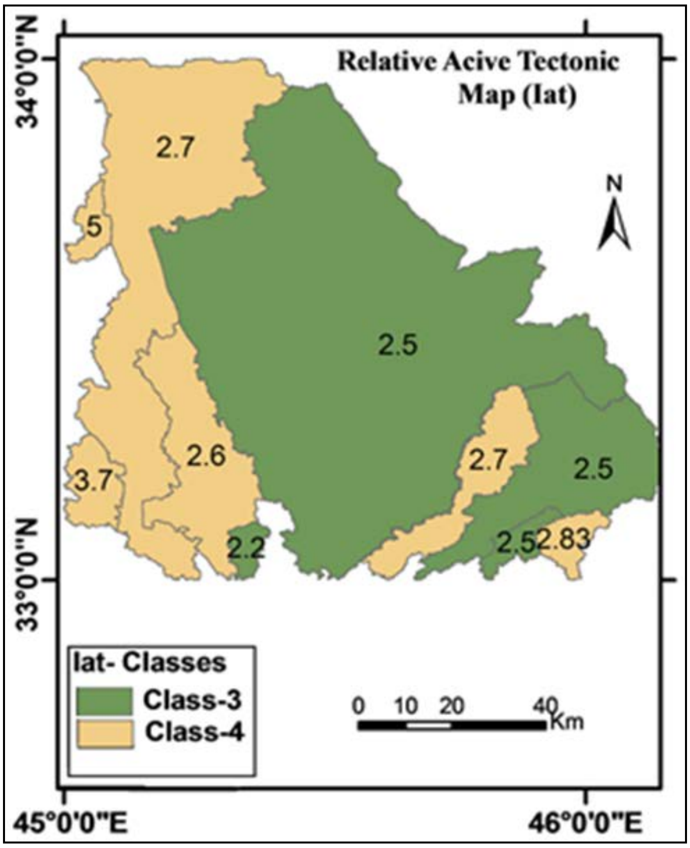

Fig.10: Relative active tectonic (***Iat***) map of Mandili watershed

By reviewing the results in Table (7), it is noted that the values of the moderate ***Iat*** in subbasins; 4, 5 and 7 are so close (***Iat*** = 2.5) to the values of the low relative active tectonics (***Iat*** > 2.5), which support the idea of the low active (inactive) tectonics in the studied area. These are due to the soft and low resistant sediments of the alluvial fans and flood plain prevailing in the studied drainage basin.

DISCUSSION

Three plates; Arabian, Anatolian and Eurasian collided forming the Zagros mountainous region of Iraq. The uplift of Arabian Plate was more effective in the Early Pleistocene (Yacoub *et al*., 2012; and Fouad, 2012). In the Pleistocene, the tectonic importance was less in comparison with the influence of climate changes. Climatic changes result in diversity of fluvial processes mainly in the time, variety of neotectonic movements result in their diversity in the space more than in time.

In the current study, the results of calculated indices have been compared with the geological map of the studied area. Relative tectonic activities were achieved by calculating geomorphic indices and averaging them. The total area of Mandili Quadrangle watershed basin is 8064.169 Km^2, and has 10 subbasins; subbasin 7 is the largest with 4283.068 Km^2 area and subbasin 9 is the smallest with 58.326 Km^2 area. To identify more active and less active subbasins, six geomorphic indices; ***Af, Sl, Hi, Vf, Bs*** and ***Smf*** indices are calculated.

In Mandili Quadrangle watershed basin ***Af*** values varies from 20.152 in subbasin 7 to 56.74 in subbasin 4 (Table 1). Some subbasins are asymmetrical and demonstrate longer tributaries on the left side of their main trunk stream than those to the right, which means a westward (right ward) tilting, such as subbasins; 1, 2, 5, 7, 9 and 10. The other subbasins such as; 3, 4, 6 and 8, are so close to the symmetry case, that mean no or little tilting effects.

The highest values (> 50%) of ***Af*** index demonstrate low asymmetry occurring in sub-basins 3 and 4. These two subbasins were tilted left of the main stream trunk. The high values (class 1) are in the subbasins; 2, 5, 7 and 9, that means highly tilted subbasins, while the low values (class 3) are in the subbasins; 3, 4, 6 and 8, that means low tilted subbasins, but subbasins; 1 and 10 are with moderate value (class 2), according to El Hamdouni *et al*. (2008), which means moderately tilted subbasins (Fig. 3). All the subbasins, show right ward tilting with relatively long left side tributaries, except subbasins; 3 and 4, which show left ward tilting with relatively long right side tributaries.

All ***Sl*** values are less than 300 and thus classified within class 3, because most of the streams cross through very low resistant (soft) sediments of the young and old alluvial fans.

Hypsometric integral (***Hi***) values are low in the adjacent subbasins; 5, 6, 7 and 10, which may be related to older landscapes that have been more eroded and less affected by recent active tectonics. The high values are within subbasins 2, 4 and 8 and could be resulted from recent incision into a young geometric surface formed by deposition. Subbasins; 1, 3 and 9 are within class 2 of moderate ***Hi*** values.

The values of the calculated ***Vf*** index illustrate that only subbasins; 3 and 4 show low rightward tilt (within class 3), while the other subbasins are of leftward tilt. Among these leftward tilted subbasins, the subbasin; 2, 5, 7 and 9 are highly tilted (within class 1), subbasins; 1 and 10 are moderately tilted (within class 2), whereas, subbasins; 6 and 8 are low tilted (within class 3).

Subbasin 7 has ***Vf*** value less than 1.0 and deep V-shaped valley related to linear, active down cutting stream distinctive of area subjected to active uplift, while other subbasins have ***Vf*** values greater than 1.0 and flat floored U-shaped valley floors, show an attainment of the base level of erosion mainly in response to relative tectonic quiescence.

Valleys upstream from the mountain front tend to be narrow, and ***Vf*** is usually calculated at a given distance upstream from the mountain front.

Smf values of the studied subbasins are more than 3, within class 3, that are normally associated with inactive fronts in which the initial range front fault may be more than 1 Km away from the present erosional front. This case is easily observed in the irregular or sinuous front due to erosional processes along Himreen ridge.

Bs values of the studied subbasins indicate only two subbasins; 6 and 10 to be high (> 4, within class 1), which indicate elongated shape that refer to relatively active tectonics. Whereas, subbasins; 2, 3, 5, 7 and 9 of low ***Bs*** values (< 3, within class 3), which indicate close to the circular shape subbasins that refer to inactive tectonics, while subbasins; 1, 4 and 8 are within class 2 with ***Bs*** values between (3 – 4), which indicate the pear shape subbasins.

The results of the measured indices and average ***Iat*** indicate that, the ten subbasins have Low and Moderate classes of relatively active tectonics, which means that about 64% of the studied area are of Moderate relative activity and about 36% of the area are of Low active tectonics.

The currently obtained ***Iat*** results coincide with results gained for a nearby areas in west Iran, (Arian and Aram, 2014; Faghih *et al*., 2015; Gholamhosein Fard *et al*., 2015; Omidali *et al*., 2015; Ahmed *et al*., 2016; and Lari, *et al*., 2016), which were classified within classes 3 and 4 of moderate and low active (inactive) tectonics, for each. Also, it strongly supports the inference that "the progressive decrease in the magnitude of deformation, of the Zagros Fold – Thrust Belt, from northeast to southwest towards the Foredeep" (Fouad, 2012).

CONCLUSIONS

It seems that the calculated geomorphic indices by using GIS are suitable for assessment of the tectonic activity of the study area. Therefore, the analyses of the raster DEM-30 m, of Mandili Quadrangle watershed, displays ten subbasins with streams ranging between 4th and 7th order. Six measured morphotectonic indices for these ten sub-basins are added and a unit index obtained as the relative tectonic activity (*Iat*) with two classes of tectonic activities. Six subbasins of the studied watershed become related to class 4 (***Iat***) with an area of 2921.476 Km² (36.2%), which indicate low active tectonics (inactive), and four subbasins of class 3 (***Iat***) with an area of 5142.693 Km² (63.8%) that indicate moderate active tectonics.

The prevailing low and moderate active tectonics may be due to the low resistant (soft) sediments, climatic changes and tectonic quiescence, dominating most of the Mesopotamian Foredeep Zone, and the erosional processes have overcome the tectonic processes and the initial development of alluvial fans is clearly distinguished.

The results of this paper coincide with many previous researches in the adjacent Zagros Fold Thrust Belt, in west Iran region and support the concept that the magnitude of deformation in the Zagros Fold – Thrust Belt progressively decreases from northeast towards southwest towards the Foredeep.

REFERENCES

Ahmed A.L., Maryam A. and Soraya A., 2016. Analyses Neotectonic Activity in Khafr Basin. Open Journal of Geology, Vol.6, p. 484 – 497.

Ajirlu M.S., Moazzen M., and Hajialioghli R., 2016. Tectonic Evolution of Zagros Orogen in the realm between of the Neotethys between the central Iran and Arabian Plates: An Ophiolite perspective. Central European Geology, Vol.59/ 1 – 4, 1 – 7.

Faghih A., Soudejani A.E., Nourbakhsh A. and Rokni S., 2015. Tectonic Geomorphology of High Zagros Ranges, SW Iran: an initiative towards Siesmic hazard assessment. Envir. Earth Sci., Vol.74, p. 3007 – 3017.

Andermann, C. and Gloaguen, R., 2009. Estimation of Erosion in Tectonically Active Orogeny. Example from the Bhotekoshi catchment, Hemalaya (Nepal). International Journal of Remote Sensing Vol.30, p. 3075 – 3096.

Aqrawi, A.A.M., Goff, J.C., Horbury, A. and Sadooni, F.N., 2010. The Petroleum Geology of Iraq, Scientific Press, Great Britain, 424pp.

Arian, M. and Aram, Z., 2014. Relative Tectonic Activity Classification in the Kermanshah Area, Western Iran. Solid Earth, Vol.5, p. 1277 – 1291.

Barwary, A.M., 1991. The Geology of Mandili Quadrangle, Sheet NI-38-1, scale 1: 250 000, GEOSURV, int. rep. no. 2227, Baghdad, Iraq.

Bull, W.B., 2007. Tectonic geomorphology of mountains: a new approach to paleo-seismology. Blackwell, Malden. Binghamton, NY: State University of New York at Binghamton.

Bull, W.B., and McFadden L., 1977. Tectonic geomorphology north and south of the Garlock Fault, California, Geomorphology in Arid regions, DO. Doehring, ed., Publications in Geomorphology, State University of New York at Bingamton, p. 115 – 138.

Cox R.T., 1994. Analysis of drainage basin symmetry as a rapid technique to identify area of possible Quaternary tilt block tectonics: an example from the Mississipi Embayment. Geo. Soc. Am. Bull. Vol.106, p. 571 – 581.

EL Hamdouni, R., Irigaray, C., Fernandez, T., Chacon, J., Keller, E. A. 2008. Assessment of relative active tectonics, southwest border of Sierra Nevad (southern Spain). Geomorphology, Vol.96, p. 150 – 173.

Fouad S.F., 2012. Western Zagros Fold-Thrust Belt, Part I: The Low Folded Zone. Iraqi Bull. Geol. Min., Special Issue No.5, p 39 – 62.

Fouad, S.F.A., 2014. Tectonic Map of Iraq, scale, 1: 1000 000, 3rd edit, GEOSURV, Baghdad, Iraq.

Gholamhosein Fard, N., Sorbi, A. and Arian, M., 2015. Active Tectonics of Kangavar Area, West Iran. Open Journal of Geology, Vol.5, p. 422 – 441.

Hack, J.T., 1957. Submerged river system of Chesapeake Bay. Geol. Soc. Am. Bull. Vol.68, No.7, p. 817 – 830.

Hack, J.T., 1973. Stream Profile Analysis and Stream Gradient Index, U.S. Geological Survey, Vol.1, p. 421 – 429.

Hack, J.T., 1982. Physiographic divisions and differential uplift in the Piedmont and Blue Ridge.

Hare, P.P. W., and Gardner, T.W., 1985, Geomorphic indicators of vertical neotectonism along converging plate margins, Nicoya Peninsula Costa Rica. In M. Morisawa and J.T. Hack (Eds.). Tectonic Geomorphology proceedings of the 15th.

Hasan, A.A., 1985. Regional photogeological mapping of Mandili, Badra, Zurbatiya, Sheikh Fars and Al-Tib Area. GEOSURV, int. rep. no. 1378.

Hasan, A.A., 1985. Photogeological and Geomorphological of Mandili, Badra, Zurbatiya and Shaikh Faris. GEOSURV. int. rep. no. 1378. Baghdad, Iraq.

I.M.O., 2000. Climatic Atlas of Iraq, Ministry of Transportation and communications Iraq.

Kadhum T.H., 2012. Land Use Land Cover (LULC) map for Mandili Quadrangle, Scale, 1: 250 000, Sheet No.NI-38-11. Iraq Geological Survey GEOSURV, int. rep.no. 3363

Keller, E.A., 1986. Investigation of active tectonics: use of surficial earth processes. In Panel on Active Tectonics. National Academy press: Washington, D.C.

Keller, E.A. and Pinter, N., 1996. Active tectonics: Earthquakes, Uplift and Landscapes. Prentice Hall, New Jersey.

Keller, E.A. and Pinter, N., 2002. Active tectonics: Earthquakes uplift and Landscape (second edition): Englewood Cliffs, New Jersey, Prentice Hall, 362pp.

Mahmood A.A., Ali, M.A., Mohammed, A.J., Al-Mukhtar, L.E., Al-Kubaisy, K.N., Hussien, M.S., Al-Obaidy, R.A., Muhammad, E.M. and Tawfeeq, N.T. (in press). Detailed Geological Survey of Zurbatiya Region, scale 1: 25 000 east of Iraq, First stage. GEOSURV, Baghdad Iraq.

Omidali M., Arian M and Sobri A., 2015. Neotectonics of Borougerd Area, SW Iran by Index of Active Tectonics. Open Journal of Geology, 2015, Vol.5, p. 309 – 324.

Perez-Pena, J.V., Azanon, J.M. and Azor, A., 2009, Calypso: an ArcGIS extension to calculate hypsometric curves and their statistical moments. Applications to drainage basin analysis in SE Spain. Computers and Geosciences. Vol.35, p. 1214 – 1223.

Ramirez-Herrera, M.T., 1998. Geomorphic assessment of active tectonics in the Acambay graben, Mexican volcanic belt. Earth Surface Processes and Landforms, Vol.23, p. 317 – 332.

Sarp, G., Gecen, V., Toprak and Duzgun, S., 2010. Morphotectonic Properties ofYenicaga Basin Area in Turkey. METU, Geodetic and Geographic Information Technologies, Inonu Bulvari 06531 Ankara, Turkey, 5pp.

Sissakian, V.K., 2014. Geology of Mandili Quadrangle, sheet No. NI-38-11, a series of geological maps of Iraq. GEOSURV, int. rep. no. 3517.

Strahler, A.N., 1952. "Hypsometric (area-altitude) analysis of erosional topology", Geological Society of America Bulletin Vol.63, No.11, p.1117 – 1142.

Strahler, A.N., 1957. "Quantitative Analysis of Watershed Geomorphology." Transactions of the American Geophysical Union Vol.8, No.6, p. 913 – 920.

Yacoub, S.Y., 1983. The Geology of Mandili Area. GEOSURV, int. rep. no. 1383.

Yacoub, S.Y., Othman A.A., and Kadhim T.H., 2012. Geomorphology of the Low Folded Zone. Iraqi Bull. Geol. Min., Special Issue, No.5, p. 7 – 37.

Youkhana, R.Y., 1978. Report on the Regional geological mapping of Khanaqin – Maidan area. GEOSURV, int. rep. no. 903.

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