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Comparison Between Tectonic Activity and Erosion Rate of Al-Adhaim River Basin, Iraq Using DEM and GIS

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ABSTRACT

Geomorphic indices are a basic tool to indicate Neotectonic activities in certain areas like Al-Adhaim River Basin in Iraq. Different geomorphic indices including stream length gradient index, drainage basin asymmetry, hypsometric integral, valley floor width-to-height ratio, and mountain front sinuosity have been calculated. The ArcGIS, DEM, Geological maps at a scale of 1:250000 and different erosional data to perform the current research have been used. The study area has been divided into 14 sub-basins in the ArcGIS Software. Accordingly, the tectonic activity ranges from moderate in sub-basins (4, 5, 11, 13, and 14) and high sub-basins (2, 3, 6, 7, 9, and 10) to very high in the sub-basins (1 and 8). Erosion rates range from moderate in the sub-basin (2) to severe in sub-basins (1, 7, and 14) and very severe in the sub-basins (8, 11, and 12). The comparison between the relative tectonic activity and erosion rate shows different types of relationships in different sub-basins. In three sub-basins (7, 9, and 10), the two variables coincide, and in sub basins (1, 2, 4, 5, 8, and 13) there is a mutual relation between the two variables, and only in sub basin 11, there is an opposite relation between the two variables.

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المقارنة بين النشاط التكتوني ونسبة التعرية في حوض نهر العظيم، العراق *باستخدام* انموذج الارتفاع الرقمي وتقنية نظم المعلومات الجغرافية

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الملخص

تعتبر الدالات الجيومورفولجية ادوات اساسية في برنامج نظم المعلومات الجغرافية (Arc GIS) لمعرفة النشاط البنيوي الحديث في مناطق معينة مثل حوض نهر العظيم في العراق. تم احتساب دالات جيومورفولوجية مختلفة مثل دالة انحدار طول النهر، تناظر حوض النهر، المنحنى الهيبسومتري، نسبة عرض قعر الوادي الى طوله، وتعرج أقدام الجبال. تم استخدام برنامج نظم المعلومات الجغرافية (ArcGIS) وانموذج الارتفاع الرقمي (DEM) وخرائط جيولوجية مقياس 1:250000 فضلاً عن معطيات مختلفة عن التعرية. قسّم حوض نهر العظيم الى 14 حوضاً ثانوياً، ووجد ان النشاط التكتوني تراوح من معتدل في (الاحواض الثانوية 4 و5 و11 و13و 14)، الى عالٍ في (الاحواض الثانوية 2 و3 و6 و7 و9 و19) والى عالٍ جدا في (الحوضين الثانويين 1 و8). وان نسبة التعرية تراوحت ما بين معتدلة في (الحوض الثانوي 2) وشديدة في (الاحواض الثانوية 1 و7 و14) وشديدة جدا جدا في (الاحواض الثانوية 8 و11 و12). أظهرت المقارنة بين النشاط التكتوني النسبي ونسبة التعرية انواعاً مختلفة من العلاقات وذلك في احواض ثانوية مختلفة. تطابق المتغيران الاثنان في أعلاه في الاحواض الثانوية (7 و9 و10)، بينما كانت هناك علاقة مكانية بين المتغيرين الاثنين في الاحواض الثانوية (1 و2و 4 و5 و8 و13)، وقد أظهرت المقارنة بين هذين المتغيرين علاقة عكسية في الحوض الثانوي رقم 11.

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Introduction

Quantifying the tectonic deformation from analyses of landscapes was attempted for a long time by different researchers (e.g., Bull and McFadden, 1977; Burbank and Anderson, 2001; Keller and Pinter, 2002). The impact of the tectonic activity on the geomorphological processes and landscape development can be achieved through qualitative and quantitative analyses. GIS techniques are rapidly developing, as well as the advancements in the quality of the Radar Topography Mission. These techniques facilitate as tools in computing, calculating, and analysing geomorphic indices through different environments and scales (e.g., Gasparini and Whipple, 2014; Keller et al., 1982). Quantitative assessments of drainage networks identify tectonic and/or erosional transformations responsible for the evolution of landscapes (Segura et al., 2007). In tectonically active regions, drainage networks exhibit the relationship between surface processes and structural deformations (Burbank and Anderson, 2001), and thus their morphometric parameters assist in identifying active tectonic zones (Chen et al., 2003; Elias, 2015; Elias et al., 2021).

The tectonic activity is well studied in research works in different parts of the world. In Greece, it was studied by Verrios et al. (2004), and in Iran, Ghassemi (2005) studied the fold growth at Alborz Mountain. Tens of researchers conducted the same style of studies in different parts of Iran, among them are Mosavi and Arian (2015) and Dehbozorgi et al. (2010). All the mentioned researchers used geomorphological parameters in their research. Sajadi et al. (2019) mentioned the relationship between sediment transport and tectonic activity. The results of numerous studies evaluating active tectonics using morphometric parameters demonstrate the ability of this technique to assess and classify active tectonic zones.

The catchment area of Al-Adhaim River is located in the central part of Iraq (Fig. 1), covering an area of about 12323 km^2.

The goal of this study is to compare the active tectonics and erosion rate in the 14 sub-basins of the Al-Adhaim River basin to elucidate the relationship between the two mentioned comparatives. Moreover, it indicates the role of the rocks and the Quaternary deposits at the 14 sub-basins on the tectonic activity and erosion.

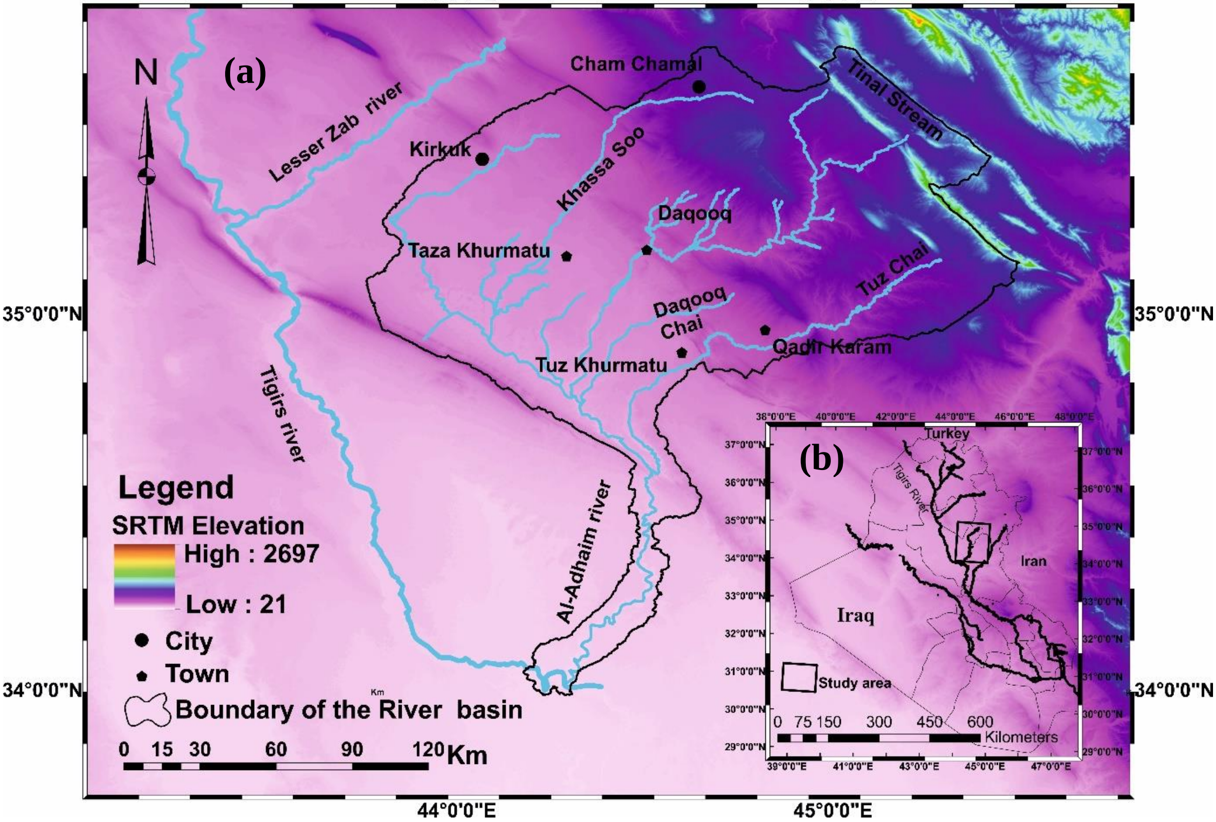


Fig. 1. (a) Catchment area of Al-Adhaim River and (b) location in Iraq.

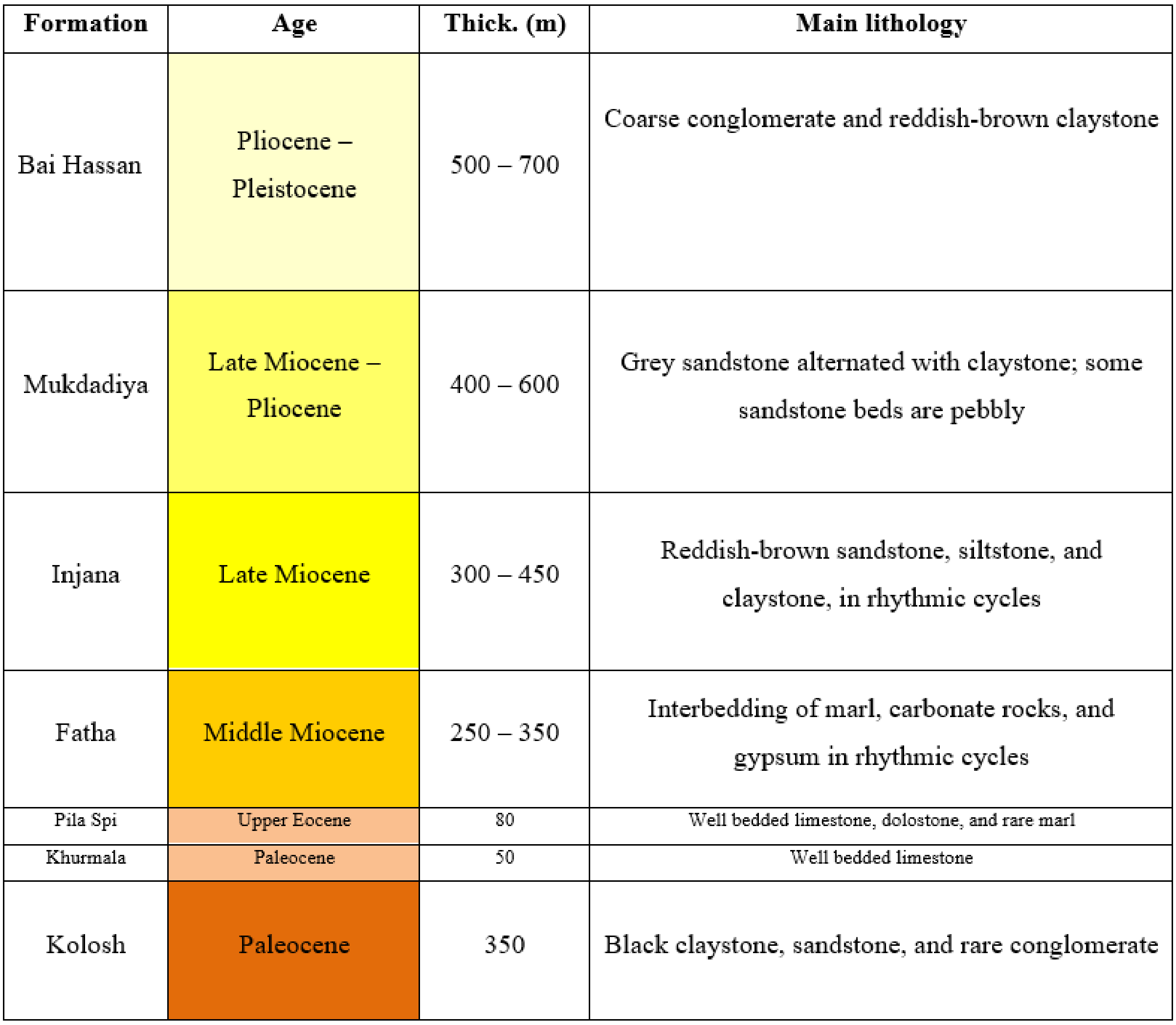
Geological Setting of the Study Area

The exposed formations and Quaternary sediments in the studied area are presented in Figure 2, according to Sissakian and Fouad (2015). The geological map of Al-Adhaim River Basin is shown in Figure 3. The Quaternary deposits in the studied area are well developed; they are described briefly hereinafter.

Terraces (Pleistocene): The three main tributaries of the Adhaim River have terraces. The main constituents are gravels of different types of sedimentary, igneous, and metamorphic rocks, well cemented. The thickness ranges from 5 to 12m.

Polygenetic Sediments (Pleistocene – Holocene): They consist of pebbles and different types of rock fragments, usually covered by gypcrete, with a thickness of a few meters and may locally attain 10 m.

Alluvial Fan Sediments (Pleistocene – Holocene): The sediments of old fans can be seen in many parts of the studied area in the form of small mesas covering pre-Quaternary rocks. The main constituents are pebbles of different rock types, cemented by calcareous and sandy materials. The thickness ranges between a few meters to 10 m and locally more.



Formation	Age	Thick. (m)	Main lithology
Bai Hassan	Pliocene – Pleistocene	500 – 700	Coarse conglomerate and reddish-brown claystone
Mukdadiya	Late Miocene – Pliocene	400 – 600	Grey sandstone alternated with claystone; some sandstone beds are pebbly
Injana	Late Miocene	300 – 450	Reddish-brown sandstone, siltstone, and claystone, in rhythmic cycles
Fatha	Middle Miocene	250 – 350	Interbedding of marl, carbonate rocks, and gypsum in rhythmic cycles
Pila Spi	Upper Eocene	80	Well bedded limestone, dolostone, and rare marl
Khurmala	Paleocene	50	Well bedded limestone
Kolosh	Paleocene	350	Black claystone, sandstone, and rare conglomerate

Fig.2. Brief description of the exposed formations in the study area (Sissakian and Fouad, 2015) (Approximate scale 1 cm = 200 m)

***Valley Fill Sediments (Holocene)*:** They fill in the courses of the tributaries of Al-Adhaim River and the main valleys. They consist of pebbles of different sizes (15 – 25 cm), mainly carbonates, silicates, and rare igneous and metamorphic rocks, with a thickness of a few meters, not more than 5 m.

***Flood Plain Sediments (Holocene)*:** These sediments are developed along the main tributaries of Al-Adhaim River. They consist of sand, silt, and clay, with a thickness of not more than 3 m.

The study area is located tectonically mainly in the Lower Folded Zone, whereas small parts in the north and south are located in the High Folded Zone and Mesopotamia Zone respectively (Fouad, 2015) It is clear that the main trend of the folds is NW – SE and many of the folds exhibit long thrust faults along their northeastern limbs (Fig. 4). Locally, the whole southwestern limbs are hindered by the thrust faults. In the majority of the folds, the sediments of the Bai Hassan Formation (Pliocene – Pleistocene) are faulted, indicating neotectonic activity.

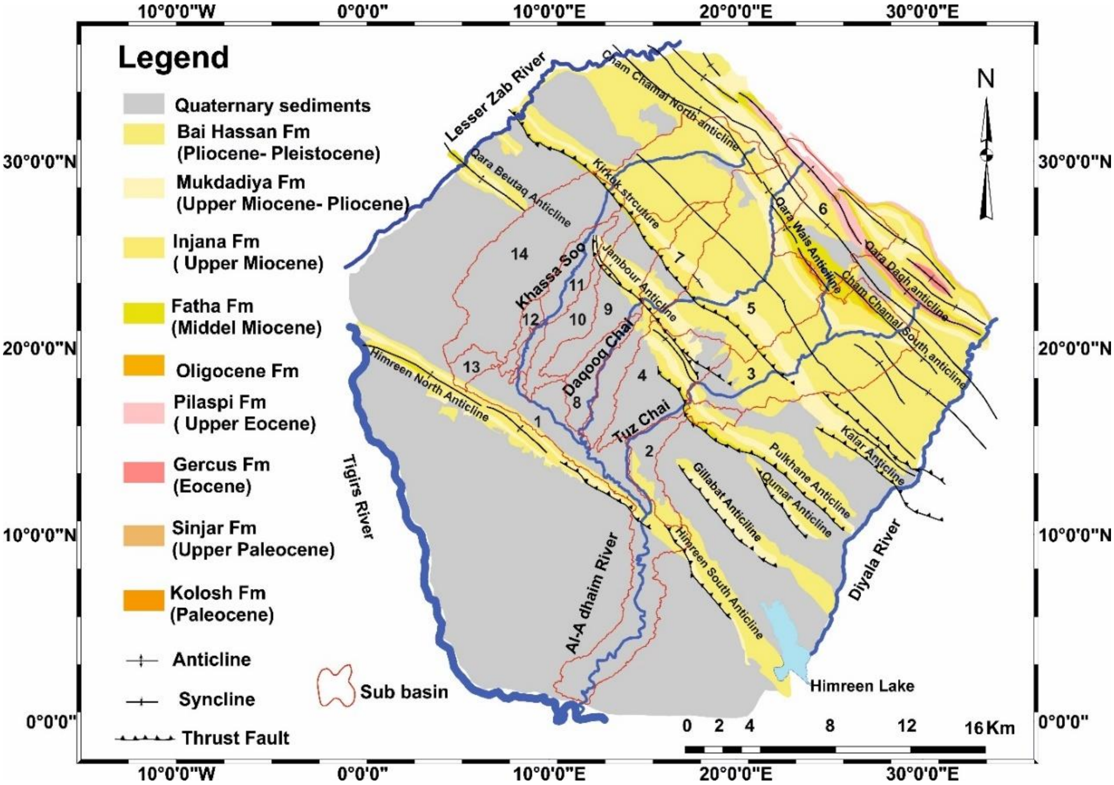


Fig. 3. Geological map of Al-Adhaim River Basin (Modified from Sissakian and Fouad, 2015).

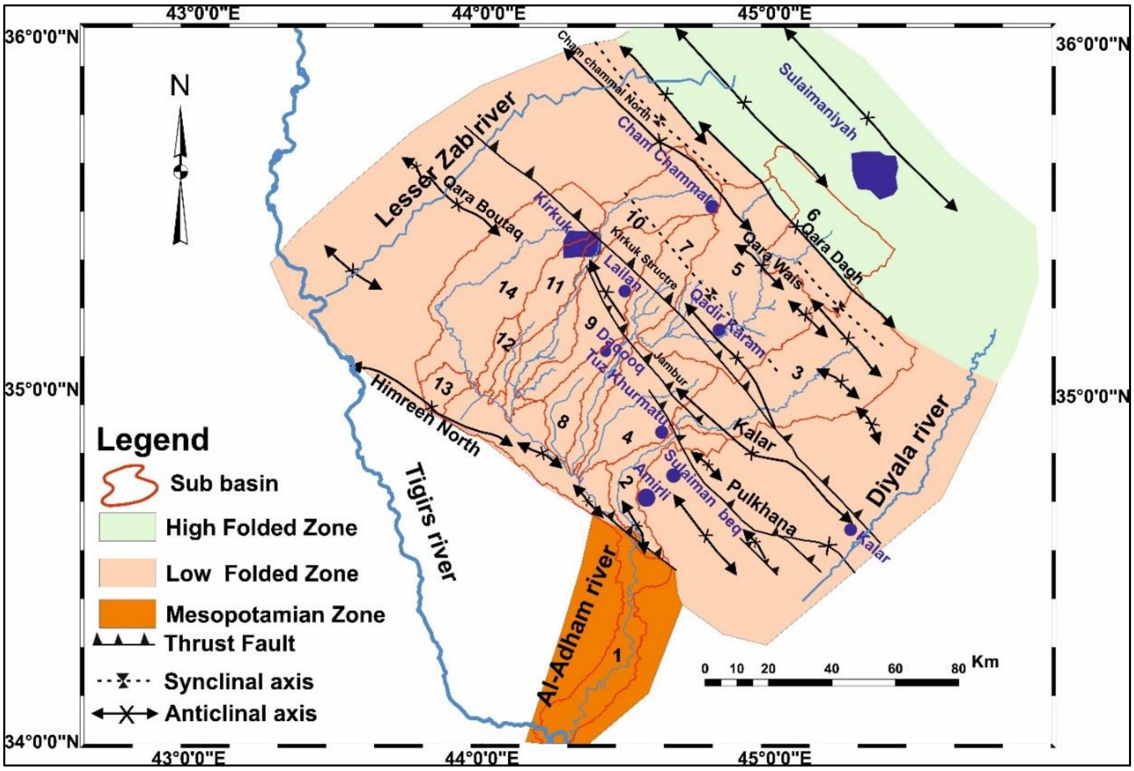


Fig. 4. Tectonic and Structural map of the study area (Modified from Fouad, 2015).

Materials and Methods

SRTM data with satellite images of Sentinel type are used to perform the current study, besides the usage of published geological maps. The Radar Topography Mission (SRTM) image is used in measuring different data, which are used in indicating the six geomorphic indices.

A ground resolution of 3-arc-second (90 m) and a vertical resolution of approximately 10 m have been used. Compilation of the geological, geomorphological, and tectonic structural geological maps is done using ArcGIS (ArcMap). Sissakian et al. (2023) have already used ArcGIS for dividing the main basin of the river into 14 sub-basins (Fig. 5).

Furthermore, those basins located in more than one tectonic zone are subdivided according to the limits of the tectonic zones into subzones. The coverage area and drainage density at each 14 sub-basins are indicated using ArcGIS. The drainage density and other erosion parameters at each sub-basin are correlated with the indicated relative tectonic activity (*Iat*) to elucidate the relation between the tectonic activity and erosion within the whole Al-Adhaim River basin.

Al-Adhaim River is selected to be a sample area for the current study to fulfill its goals. The selection of Al-Adhaim River is attributed to: 1) It is the unique river in Iraq that has its total basin located within the Iraqi territory, 2) The basin includes different rock types, 3) The basin exhibits the most severely active erosion basins in Iraq, and 4) According to Fouad (2015), the basin is located in three different tectonic zones within the Outer Platform.

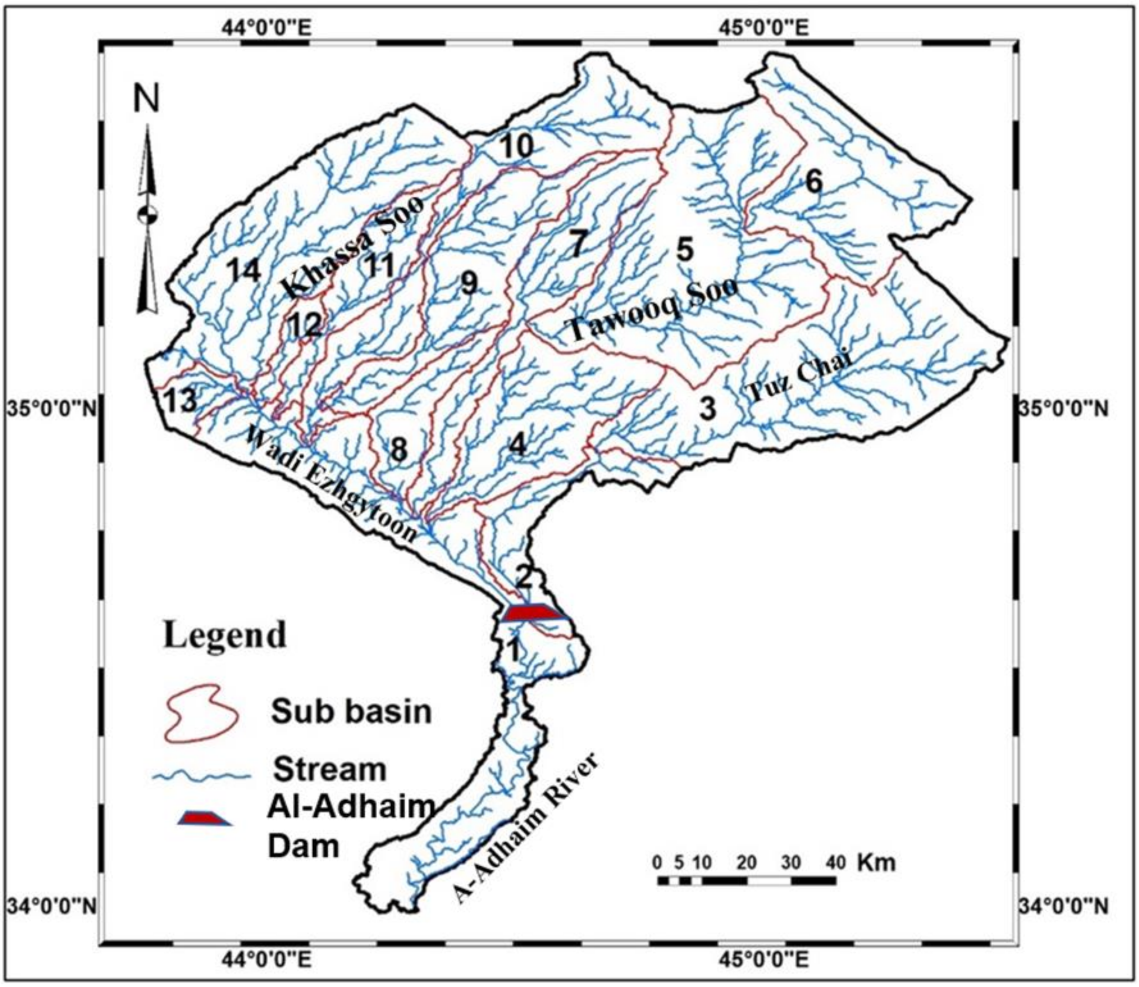


Fig. 5. Sub-basins in the study area with their serial numbers.

Figure (5) shows three tributaries (Khassa Soo, Tawooq Soo, and Tuz Chai) flowing from the north and merging into Wadi Ezghytoon, which then forms Al-Adhaim River as one of the main tributaries of the Tigris River.

Results

Calculation of Geomorphic indices of Active tectonics

Six geomorphological indices have been calculated for the 14 sub-basins. The calculation method and data achievement are described hereinafter based on El-Hamdouni et al. (2008).

The acquired data are tabulated in Table 1, whereas the classes of the indices are tabulated in Table 2.

1. Stream-Gradient Index (*SL*)

The SL index represents the relation between the length and gradient of a valley, and can be calculated by equation (1) of Hack (1973):

$$\boldsymbol{SL = (\Delta H/\ \Delta L) \times L} \quad \ldots\ldots\ldots\ldots (1)$$

where: SL is the stream-gradient index, $\Delta H / \Delta L$ is the channel slope or gradient of the reach (ΔH is the difference in elevation of the reach, whereas ΔL is the length difference), and L represents the total channel length from the point of interest.

Table 1 shows the acquired SL values in the studied sub-basins. This index includes three classes depending on the tectonic activity (Fig. 6 and Table 2). The acquired SL average value of the studied sub-basins is 421.54, which means Class 2 and indicates a moderate tectonic activity (Table 2) due to streams that cross significant geological structures in the study area.

Table 1: Acquired values of the 6 geomorphological indices.

Sub-basin No	Subbasin area (km^2)	Stream length (km)	SL	Af	Bs	Hi	Vf	Smf
1	1551.826	498.861	737.59	51.08	10.01	0.5	0.8	*
2	419.619	127.462	205.59	77.44	7.90	0.5	0.2	3.5
3	1716.365	526.050	500.12	61.84	2.73	0.5	0.6	2.4
4	831.656	299.551	249.78	76.93	3.20	0.4	1.8	2.8
5	1834.127	578.670	501.09	62.88	2.16	0.5	0.5	5.3
6	1024.421	269.970	499.92	73.24	0.85	0.5	0.1	2.7
7	723.192	274.290	800.06	60.12	13.73	0.5	1.0	2.6
8	324.819	100.842	899.45	81.79	6.04	0.5	3.0	1.1
9	796.738	296.755	600.09	84.06	8.23	0.5	3.5	2.7
10	953.566	311.889	498.99	67.49	9.56	0.5	2.0	2.4
11	411.505	152.368	153.86	52.97	9.59	0.5	3.5	3.8
12	119.954	43.010	44.89	57.77	5.68	0.5	5.5	*
13	146.894	56.835	60.08	62.77	1.92	0.5	3.1	*
14	1468.707	493.229	150.09	49.56	3.60	0.5	3.9	2.7
		Average	421.54	65.71	6.09	0.49	2.1	2.9

* The sub-basin doesn’t include mountain front.

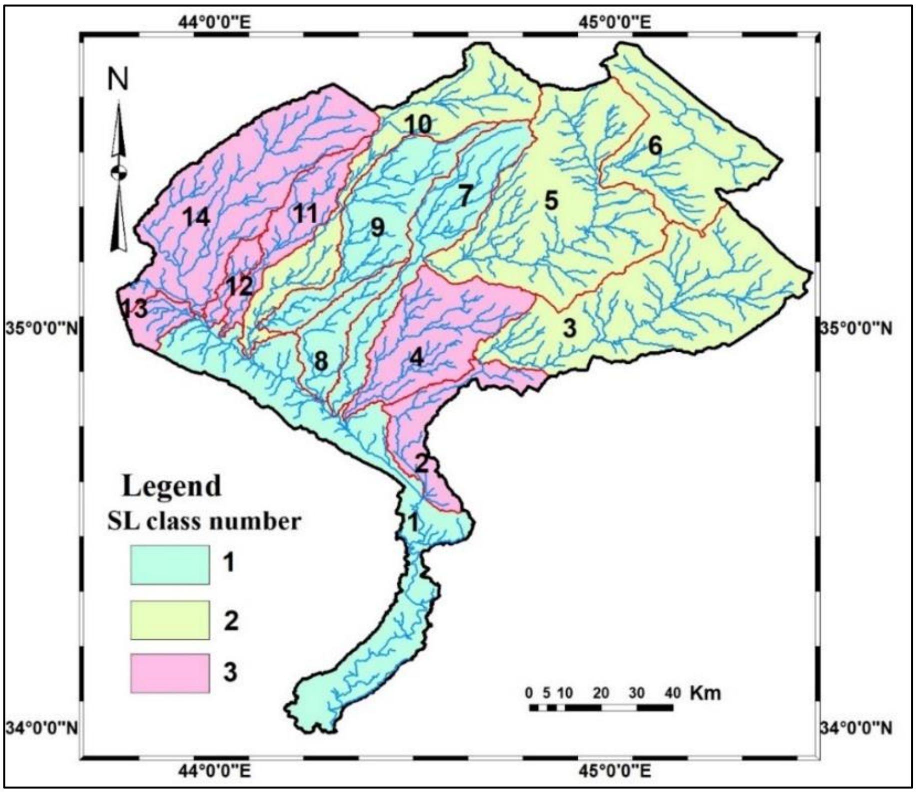


Fig. 6. Stream-gradient Index (SL) Classes in Al-Adhaim River basin.

Table 2: Ranges of the classes of the studied indices (El-Hamdouni et al., 2008).

Index	Range		
	Class 1	Class 2	Class 3
Sl	High ($SL > 500$)	Moderate ($300 \leq SL < 500$)	Low ($SL < 300$)
Af	Af < 35 or $Af > 65$	$57 < Af < 65$ or $35 < Af < 43$	$43 < Af < 57$
Bs	Elongated ($Bs > 4$)	Semi-elongated ($3 \leq Bs < 4$)	Circular basin with Bs < 3
Hi	$Hi \geq 0.5$	$0.4 \leq Hi < 0.5$	$Hi < 0.4$
Vf	$Vf \leq 0.5$	$0.5 \leq Vf < 1.0$	$Vf \geq 1.0$
Smf	High (J = 1.0 to 1.5)	Moderate (J = 1.5 to 2.5)	Low ($J > 2.5$)

2. Asymmetric Factor (*Af*)

This index is used to estimate the tectonic activity in a drainage basin (Keller and Pinter, 2002). The *Af* is calculated by equation (2):

$$Af = 100 * (Ar/At) \text{ …………… (2)}$$

where: *Ar* is the area on the right side of the trunk stream, and *At* is the total area of the drainage basin.

Table 1 shows the acquired results of the *Af* index in the studied area. The *Af* includes 3 classes (Fig. 7 and Table 2). The average value of the *Af* index is 65.71, indicating Class 1 (Table 2).

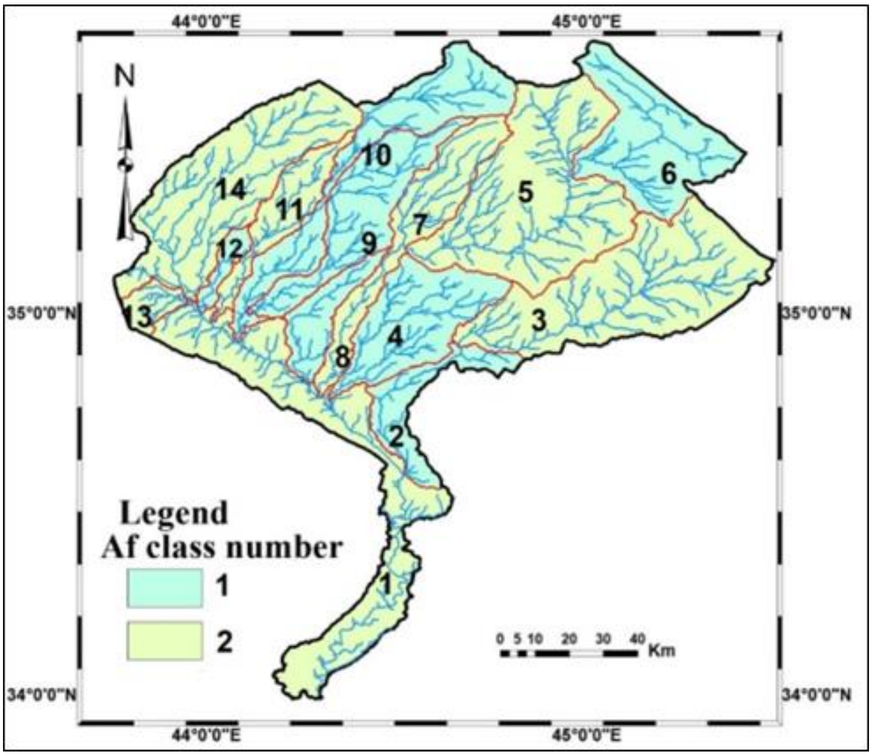


Fig. 7. Asymmetric Factor (*Af*) Classes in Al-Adhaim River basin.

3. Basin Shape Index (*Bs*)

The shape of a basin is indicated by its relative tectonic activity and is represented by this index (*Bs*). The value of this index can be determined by equation (3) (Ramírez-Herrera, 1998).

$$Bs = Bl / Bw \text{ ………….. (3)}$$

where: *Bl* is the length of a basin measured from the headwaters point to the mouth of the sub-basin , *Bw* is and the width of the sub-basin measured at its widest point.

The *Bs* index includes three classes (Ramírez-Herrera, 1998) (Fig. 8 and Table 2). The Basin shape has an average value of 6.09, which means Class 1. The acquired *Bs* values in the studied 14 sub-basins are presented in Table (1).

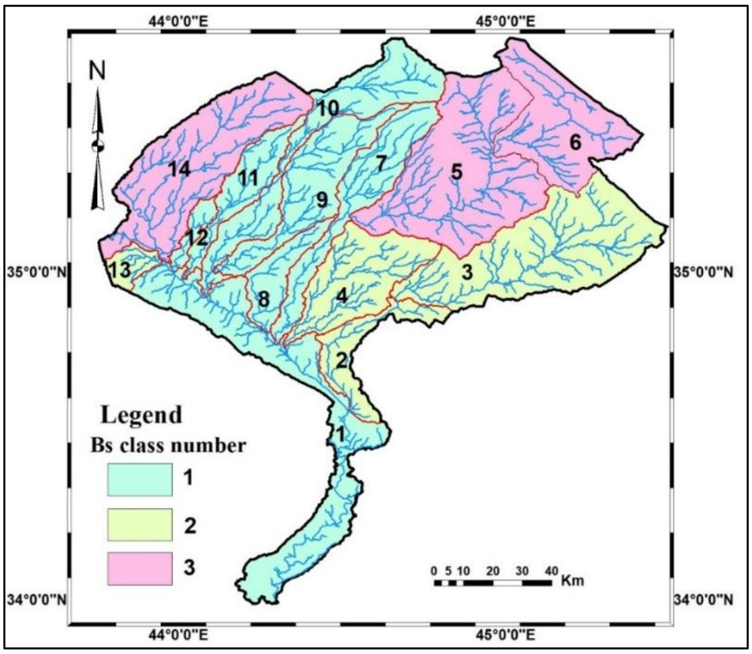


Fig. 8. Basin Shape (*Bs)* Classes in Al-Adhaim River basin.

4. Hypsometric Integral (*Hi*):

The relative distribution of an elevation in a certain landscape area, especially a drainage basin, is the Hypsometric Integral (*Hi*) (Strahler, 1952). It is also defined as the relative area below the hypsometric curve and thus expresses the volume of a basin that has not been eroded. This index can be calculated by equation (4) (Keller and Pinter, 2002):

$$\boldsymbol{Hi = (average\, elev. - min.\, elev.)\, /\, (max.\, elev. - min.\, elev.)} \;\ldots\ldots\ldots\ldots (4)$$

The (*Hi*) index includes three classes (Fig. 9): The acquired Hi values are presented in Table 1. The average *Hi* value is 0.49, which means Class 2.

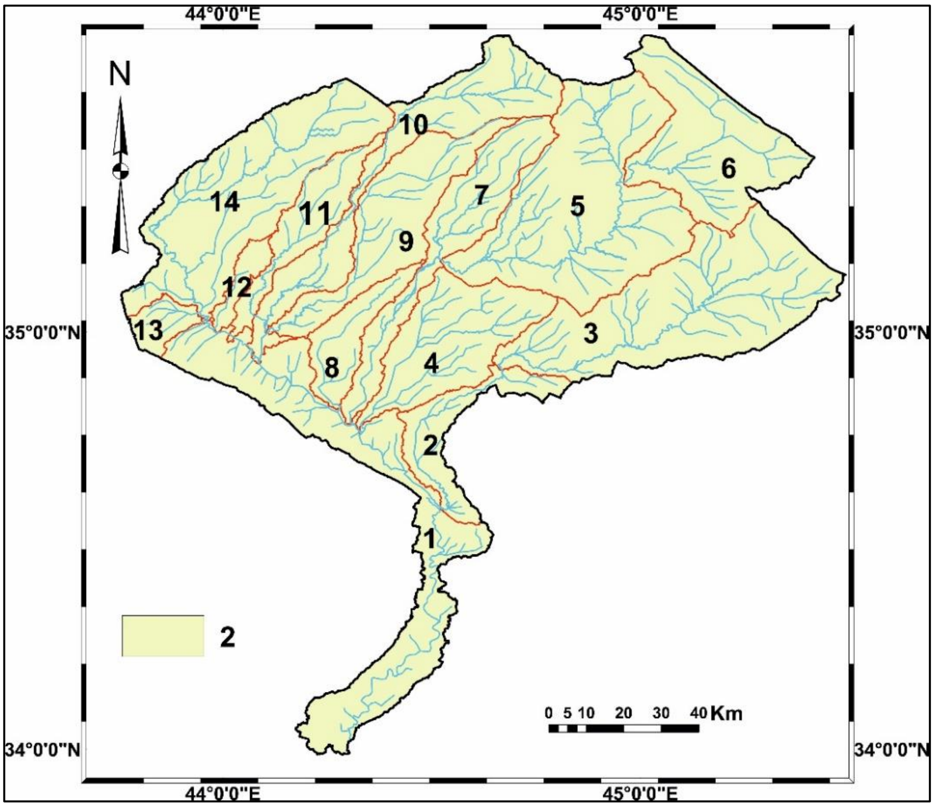


Fig. 9. Hypsometric Integral (*Hi*) in Al-Adhaim River basin.

5. Ratio of Valley Floor Width to Valley Height (*Vf*)

The ratio of the width of a valley's floor to the height in a known area along the valley is represented by this index (*Vf*). This index can be used as a good indication of erosion and tectonic activity. This index is calculated by equation (5) (Keller and Pinter, 2002).

$$\boldsymbol{Vf = 2Vfw / [(E\,ld - E\,sc) + (E\,rd - E\,sc)]} \;\ldots\ldots\ldots\; (5)$$

where: *Vf* is the valley floor width to valley height ratio, *Vfw* is the width of the valley floor, *E ld* and *E rd* are the elevations of the left and right valley divide, respectively, and *E sc* is the elevation of the valley floor.

The *Vf* index is divided into three classes (Fig. 10). Table 1 shows the obtained *Vf* values. The obtained average *Vf* value is 2.1, which means Class 3.

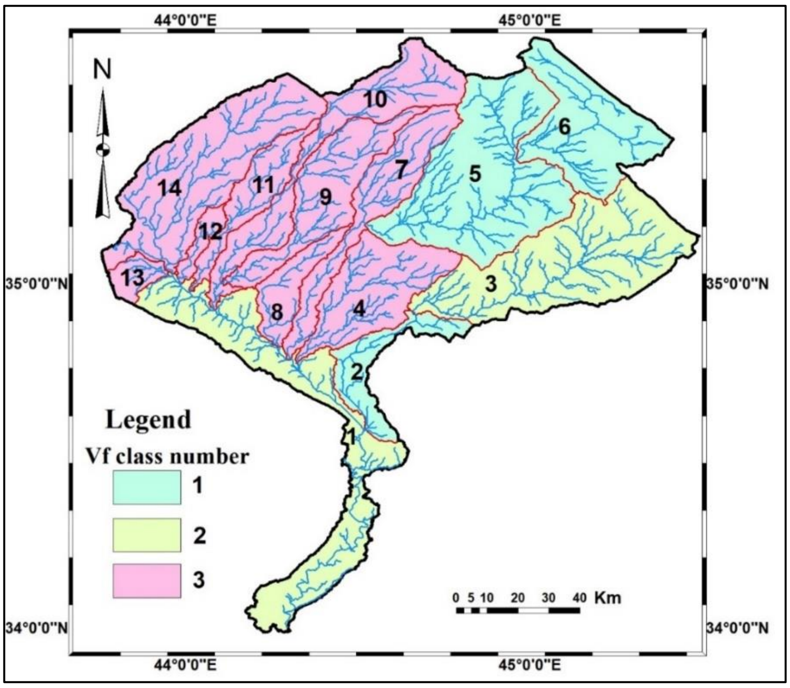


Fig.10. Ratio of Valley Floor Width to Valley Height (Vf) in Al-Adhaim River basin.

6. Mountain-front Sinuosity Index (Smf) or (*J*)

The balance between erosional forces, which tend to cut embayment into mountain fronts and the tectonic forces acting on the mountain and tend to develop a straight mountain front, is represented by this index (*Smf* or *J*) (Verioss et al., 2004). This index can be calculated by using equation (6).

$$\boldsymbol{S\,mf = L\,mf \;/ L\,s} \;\ldots\ldots\ldots\ldots\ldots\; (6)$$

where: *S mf* is the mountain front sinuosity, *L mf* is the length of the mountain front along the foot of the mountain at the pronounced break in slope, and *L s* is the straight-line length of the mountain front.

The acquired *J* values in the studied 14 sub-basins are presented in Table 1, whereas the measured mountain fronts are shown in Figure 11. This index (*Smf*) includes three classes (Table 2, Fig. 12). The acquired average *J* value is 2.9, which means Class 3.

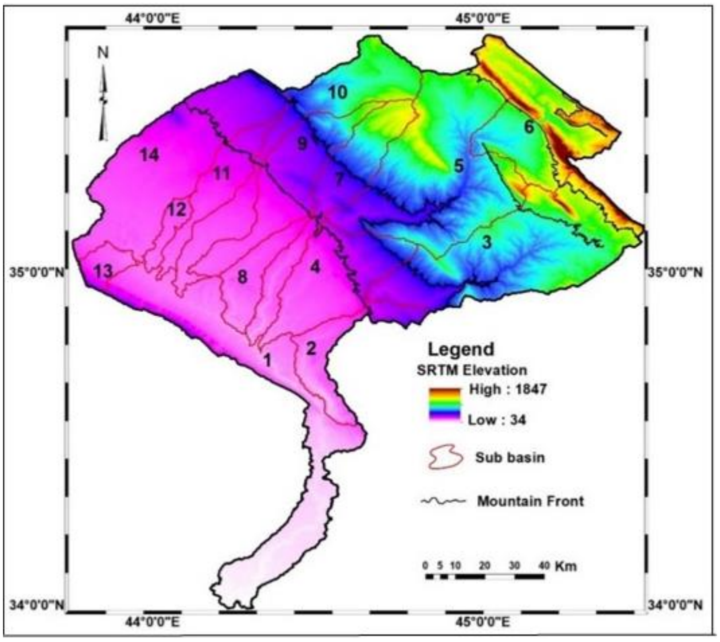


Fig. 11. Sinuous line representing the measured mountain fronts in the Al-Adhaim River basin.

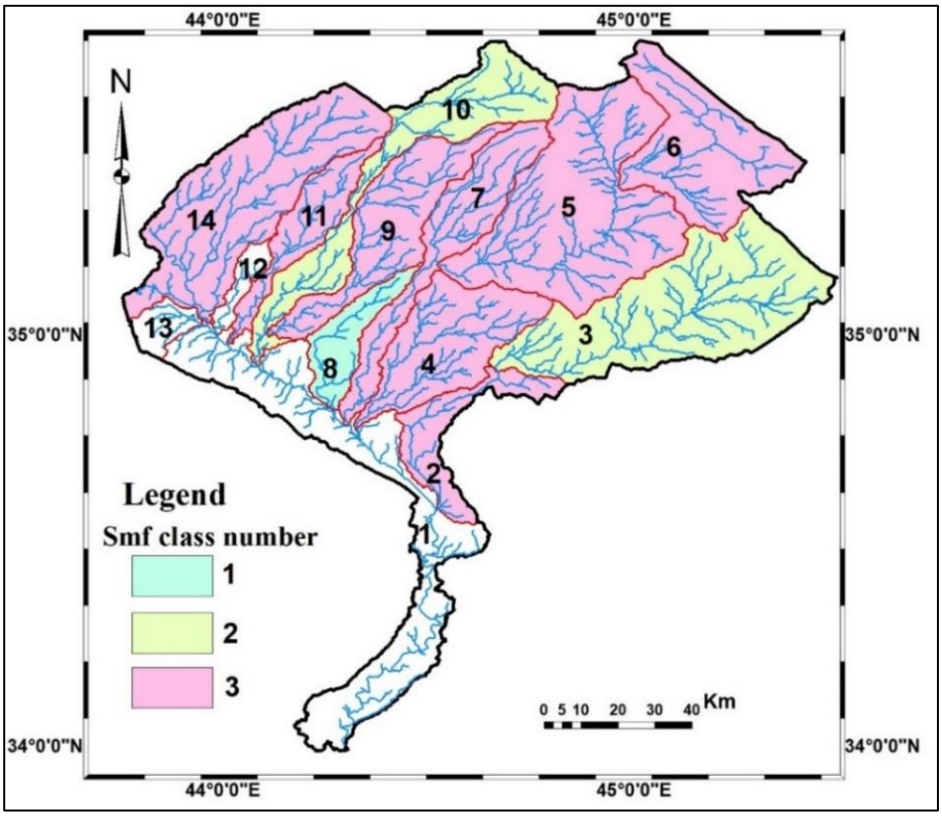


Fig. 12 Smf Classes in Al-Adhaim River basin.

Evaluation of the Relative Tectonic Activity Index (*Iat)*

To calculate the tectonic activity (*Iat*) in the Al-Adhaim River Basin, the opinion of El-Hamdouni et al. (2008) is adopted and used. The six measured geomorphological parameters are shown in Table 3. The (*Iat*) index represents the average of the six evaluated geomorphic indices, and this index is calculated by equation (7) (Habibi and Gharibreza, 2015):

$$\boldsymbol{Iat = S/\ N} \text{ …………….. (7)}$$

where: *S* is the sum of the indices, and *N* is the number of the used indices.

The (*Iat*) values include four classes (El-Hamdouni et al., 2008) with the following ranges: Class 1) Very high (1.0 ≤ *Iat* < 1.5), Class 2) High (1.5 ≤ *Iat* < 2.0), Class 3) Moderate (2.0 ≤ *Iat* < 2.5), and Class 4) Low (*Iat* > 2.5).

Figure 13 shows the (*Iat*) classes of the 14 sub-basins case study. Figure (13) and Table (3) show that there are 2 sub-basins (Nos. 1 and 8) of Very High tectonic activity, 7 sub-basins (Nos. 2, 3, 6, 7, 9, 10, and 12) with High tectonic activity, whereas the remaining 5 sub-basins (Nos. 4, 5 11, 13 and 14) are with Moderate tectonic activity. Therefore, the relative tectonic activity of the Al-Adhaim River basin is High with a value of 1.83 (Table 3).

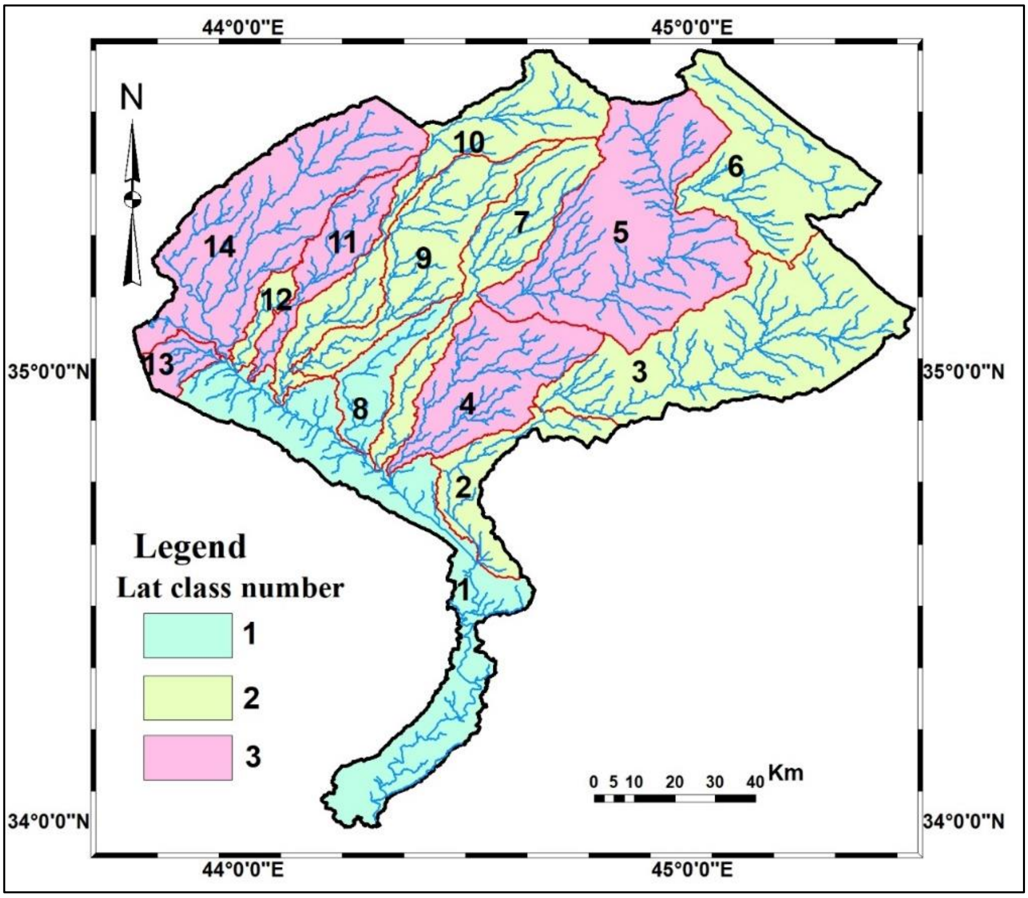


Fig. 13. Distribution of the index of tectonic activity (lat) in the Al-Adhaim River basin.

Table 3: Values and classes of the studied geomorphological parameters.

Sub–basin No	Sl	Af	Bs	Hi	Vf	Smf	*Iat*		Tectonic activity
	Class						Value	Class	
1	1	2	1	1	3	*	1.33	1	Very High
2	3	1	2	1	1	3	1.83	2	High
3	2	2	2	1	2	2	1.83	2	High
4	3	1	2	2	3	3	2.33	3	Moderate
5	2	2	3	1	1	3	2.00	3	Moderate
6	2	1	3	1	1	3	1.83	2	High
7	1	2	1	1	3	3	1.83	2	High
8	1	1	1	1	3	1	1.33	1	Very High
9	1	1	1	1	3	3	1.66	2	High
10	2	1	1	1	3	2	1.66	2	High
11	3	2	1	1	3	3	2.17	3	Moderate
12	3	1	1	1	3	*	1.50	2	High
13	3	2	3	1	3	*	2.00	3	Moderate
14	3	2	2	1	3	3	2.33	3	Moderate
Average	2.14	1.50	1.71	1.07	2.50	2.63	1.83	2	High

* No Smf observed.

Relationship between Tectonic Activity, Rock and Soil Type, and Erosion Rate

Several erosion rates are estimated based on the soil (Quaternary deposits), rock types, and topography of the studied area (Table 4) following Khare et al. (2016). Accordingly, the estimated erosion rates are Moderate (Sub-basins Nos. 2, 9, and 10), Severe (Sub-basins Nos. 1, 7, 11, 12, and 14), Very severe (Sub-basins Nos. 3, 4, 5, 6, and 13) to Very very severe (Sub-basin No. 8)

Table 4: Iat values and erosion rates (after Khare et al., 2016).

Sub-basin No.	Iat value	Erosion rate	Sub-basin No.	Iat value	Erosion rate
1	1.33	Severe	8	1.33	Very very Severe
2	1.83	Moderate	9	1.66	Moderate
3	1.83	Very severe	10	1.66	
4	2.33		11	1.17	Very very Severe
5	2.00		12	2.00	
6	1.83		13	1.50	Very severe
7	1.83	Severe	14	2.33	Severe

Discussion

The *Iat* values have been compared with the different types of exposed rocks and/ or Quaternary deposits, as well as rates of erosion in the studied area (Table 4) to find the relation between *Iat* values and the hardness of the rock types. Accordingly, the exposed rocks and/ or Quaternary deposits have been divided into four main groups: 1) Alluvium, claystone and sandstone, 2) Alluvium, claystone, sandstone, conglomerate, gypsum, and limestone, 3) Claystone, sandstone, conglomerate, gypsum, and limestone, and 4) Alluvium (Table 5). This division is based on the geological map and the exposed geological formations (Sissakian and Fouad, 2015).

Table 5: Iat values, Erosion rate, and main rock and/ or Quaternary deposit types in the studied area.

Sub-basin No.	**Tectonic Activity**		**Erosion Rate**	**Main Lithology**					
	Iat	Class							
1	1.33	Very High	Severe	▒	░	🟨			
2	1.83	High	Moderate	▒	░	🟨	🟧	🟥	🟦
3	1.83	High	Very severe		░	🟨	🟧	🟥	🟦
4	2.33	Moderate		▒	░	🟨	🟧	🟥	🟦
5	2.00	Moderate			░	🟨	🟧	🟥	🟦
6	1.83	High			░	🟨	🟧	🟥	🟦
7	1.83	High	Severe	▒	░	🟨	🟧	🟥	🟦
8	1.33	Very High	V. very severe	▒					
9	1.66	High	Severe	▒	░	🟨	🟧	🟥	🟦
10	1.66	High		▒	░	🟨	🟧	🟥	🟦
11	2.17	Moderate	Very very severe	▒					
12	1.50	High		▒					
13	2.00	Moderate	Very severe		░	🟨	🟧	🟥	🟦
14	2.33	Moderate	Severe	▒					

▒ Alluvium ░ Claystone 🟨 Sandstone 🟧 Conglomerate 🟥 Gypsum 🟦 Limestone

The results (Table 5) indicate that there is no effective relation between the *Iat* values, types of exposed rocks and/ or Quaternary deposits, and erosion rates. For example, sub-basins Nos. 8, 11, 12, and 14 include only alluvium soil and still show Very High, Moderate, High, and Moderate relative tectonic activity (Iat value = 1.33, 2.17, 1.5, and 2.33, respectively), and Sub-basin Nos. 8, 11 and 12 include very very severe erosion; while Sub-basin 14 has severe erosion rate. Whereas sub-basins Nos. 11, and 14, which again include only alluvium, show Moderate relative tectonic activity (Iat values = 2.17 and 2.33 respectively) but show Very very severe and severe erosion rates. This comparison indicates that the relation between erosion rates is less influenced by relative tectonic activity than soil and rock types, and more influenced by the topography, which is included in assigning erosion rates to the type of soils and rocks.

The relation between the two mentioned variables is shown in Figure 14. It is clear that only in sub-basins Nos. 7, 9, and 10 do the two variables coincide. However, in sub-basins Nos. 1, 2, 4, 5, 8, and 13, there is a kind of relation; either a decrease or an increase in the two variables.

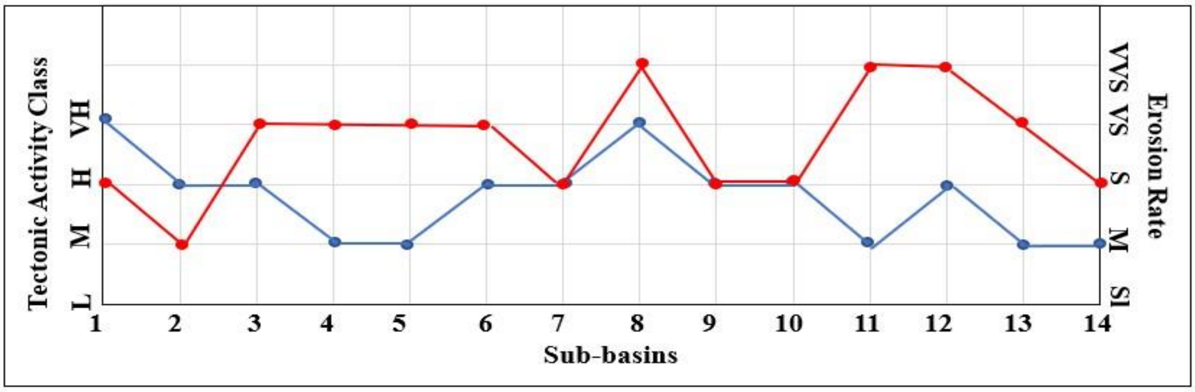


Fig. 14. The relation between tectonic activity (blue line) and erosion rates (red line) in the 14 sub-basins. Tectonic activity classes: L= Low, M= Medium, H= High, and VH= Very high. Erosion rates: Sl= Slight, M= Moderate, S= Severe, VS= Very severe, and VVS= Very very severe.

The only sub-basin that shows a negative relation between the two variables is No. 11 (Fig. 14). The discrepancy in non-matching the erosion rates with the *Iat* classes in the studied area can be due to: 1) The existing data about the Quaternary deposit within the studied area are of regional scale, 2) The characteristics of the used DEM through which the required data for indicating the geomorphological indices at the studied area, 3) Accuracy of *Iat* values, and 4) The lack of detailed topographic data.

Conclusions

The *Iat* values in the Al-Adhaim River basin range between 1.33 and 2.33, with an average value of 1.83, indicating a high level. When comparing the results of the *Iat* values at each sub-basin with the existing rocks and Quaternary deposits, and erosion rates, it is evident that there is a weak relation between the two variables. However, in three sub-basins (7, 9, and 10), the two variables completely coincide, and in sub-basins (1, 2, 3, 4, 5, 6, 8, 12, 13, and 14) there is a mutual relation between the two variables. On the other hand, in sub-basin 11, there is an opposite relation between the two variables. These discrepancies can be primarily attributed to the existing folds and faults in the sub-basins, the area‘s topography, the types of exposed rocks and soils, and partially to the locations of the sub-basins within the tectonic zone.

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Conflict of Interest

There is no conflict of interest for the authors regarding publishing this paper.

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