Assessment of the Tectonic Activity in Northwestern Part of the Zagros Mountains, Northeastern Iraq by Using Geomorphic Indices

Ziyad Elias · Varoujan K. Sissakian · Nadhir Al-Ansari

Abstract The Tectonic Activity of regions with active tectonics can be assessed by using of the geomorphic indices. Six Geomorphic indices including stream-gradient index (**SL**), drainage basin asymmetry (**Af**), drainage basin shape (**Bs**), hypsometric integral (**Hi**), valley floor width-valley height ratio (**Vf**), and mountain-front sinuosity (**Smf**) were calculated using GIS technique in Kifri Chai Basin; northeast Iraq, which belongs to the Western Zagros Mountain. The basin was divided into eighteen sub-basins depending on the 4th, 5th and 6th stream orders of the drainage within Kirfi Basin. It was found that the **SL, Af, Bs, Hi, Vf,** and **Smf (J)** values are uniform and exhibit almost the same classes. However, few exceptions occur, especially in **Bs** values, but the exceptional values do not influence significantly on the acquired results, in each of the eighteen sub-basin.

From these indices the relative active tectonics index value (**Iat**) was determined. The results of average **Iat** values (2.35) showed that the tectonic activity in the whole basin is Moderate. Moreover, an attempt was carried out to compare the regional Neotectonic activity with the relative tectonic activity in the basin. The results showed that there is a positive relation between the two comparatives; especially the subsidence amount and scored relative tectonic activity.

Keywords Geomorphic indices · Tectonic activity · Neotectonic · Western Zagros · Iraq

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1 Introduction

The phenomenon of tectonic movements is the best recognized in the history of basin development. Therefore, landscape analyses of such areas and studies of drainage networks, in particular, provide insights into current tectonic processes and their activities. Attempts to quantify tectonic deformation from landscape analyses have been performed for decades (e.g., Bull and McFadden 1977; Rockwell et al. 1985; Merritts and Vincent 1989; Burbank 1992; Burbank and Anderson 2001; Keller and Pinter 2002; Crosby and Sheehan 2006; Wobus et al. 2010, 2012; Kirby and Whipple 2012). The rapid development of GIS techniques and the constant advancement in

digital elevation model (DEM) quality and access provide significant and efficient tools to compute, calculate and analyze geomorphic indices across areas of various environments and scales (e.g., Keller et al. 1982; Ramírez-Herrera 1998; Kirby et al. 2003; Gürbüz and Gürer 2008; Arrowsmith and Zielke 2009; Gasparini and Whipple 2014). However, studies that use geomorphic indices to explore the relative activity of tectonic processes in the fore-arc regions of active subduction zones are limited and/or use only one or two indices (e.g., Wells et al. 1988; Fisher et al. 1998; Morell et al. 2008; Rehak et al. 2008).

Active deformation in the Zagros Mountains is caused by the northward motion of the Arabian Plate with respect to Eurasian Plate, which occurs at a rate of 25 mm year^{-1} at longitude 56°E (Ramsey et al. 2008). The style of deformation appears to vary along the strike of the Zagros Mountain Range. In the NW (Dezful), N–S shortening between Arabia and Eurasia plates is accommodated on a spatially separated system of NW trending right-lateral strike–slip and thrust faults (Ramsey et al. 2008). It is worth to mention that Dezful Embayment in Iraq is called Kirkuk Embayment (Fouad 2012).

Recent works have been carried out on the tectonic activity; among them are Verrios et al. (2004), they performed their study in Greece. El-Hamdouni et al. (2008) performed their study in South of Spain. In Iran many studies were performed, Ghassemi (2005) has commented on the fold growth in NE Alborz, Dehbozorgi et al. (2010) in central Zagros Range, Mumipour and Najad (2011) in south of Iran, Toudeshki and Arian (2011) in northwest Iran, Habibi and Gharibreza (2015) in central part of Iran, and Mosavi and Arian (2015) in northeast of Iran. All those studies have used the geomorphological indices to indicate the tectonic activity in their studied areas.

The above mentioned review for a part of the existing literature indicates that the knowledge about the effects of tectonic movements upon river valley forms; fluvial processes are not sufficiently investigated in the Iraqi territory where these issues are very rarely studied and require more detailed studies.

Kfiri Chai Basin is located in the north-eastern part of Iraq (Fig. 1). The coverage area is 2821.15 km^2. The Kifri Chai Basin was divided into eighteen sub-basins and called them in this study as Sub-basins No. 1 to No. 18.

The main aim of the current study is to indicate the tectonic activity of Kifri Chai Basin which is part of the Western Zagros Range. Moreover, the relative tectonic activity was compared with the regional Neotectonic movements in Kifri Chai Basin to indicate the relation between both aspects.

1.1 Geological and Neotectonic Setting

The studied area is located within the Low Folded Zone of the Outer Platform, which belongs to the Arabian Plate (Fouad 2012). Four anticlines occur in the study area; these are from the north to south: Kalar, Pulkhana, Qumar and Gillabat (Fig. 2).

All the anticlines exhibit thrusting, where their northeastern limbs are thrusted over their southwestern limbs causing their disappearance and the anticlinal axis (Sissakian 1978; Youkhanna and Hradecky 1978). The youngest exposed formation is the Bai Hassan Formation. This means that the thrusting had occurred after the Middle Pleistocene; accordingly, it is considered as a neotectonic movement (Obruchev 1948).

The exposed formations in the Kifri Chai Basin are:

1. **Fatha Formation** (Middle Miocene): Consists mainly of reddish brown claystone, marl, limestone and gypsum and cyclic nature.
2. **Injana Formation** (Upper Miocene): Consists mainly of reddish brown sandsotone, siltstone and claystone in cyclic nature.
3. **Mukdadiya Formation** (Upper Miocene–Pliocene): Consists of greyish sandsotone, siltstone and claystone in cyclic nature. With some pebbly sandstone.
4. **Bai Hassan Formation** (Pliocene–Pleistocene): Consists mainly of conglomerate, reddish brown claystone in cyclic nature, with some sandstone beds.
5. **Quaternary sediments**: Mainly valley fill, flood plain and slope sediments, besides river terraces

The neotectonic activity in Iraq is considered since the Upper Miocene, when the marine environment was terminated and continental depositional environment prevailed. This assumption is based on Obruchev (1948) and Atomenergoexport (1985). Sissakian and Deikran (1998) compiled the Neotectonic Map of Iraq, which is based on the contact between the Fatha Formation (Middle Miocene) and the Injana
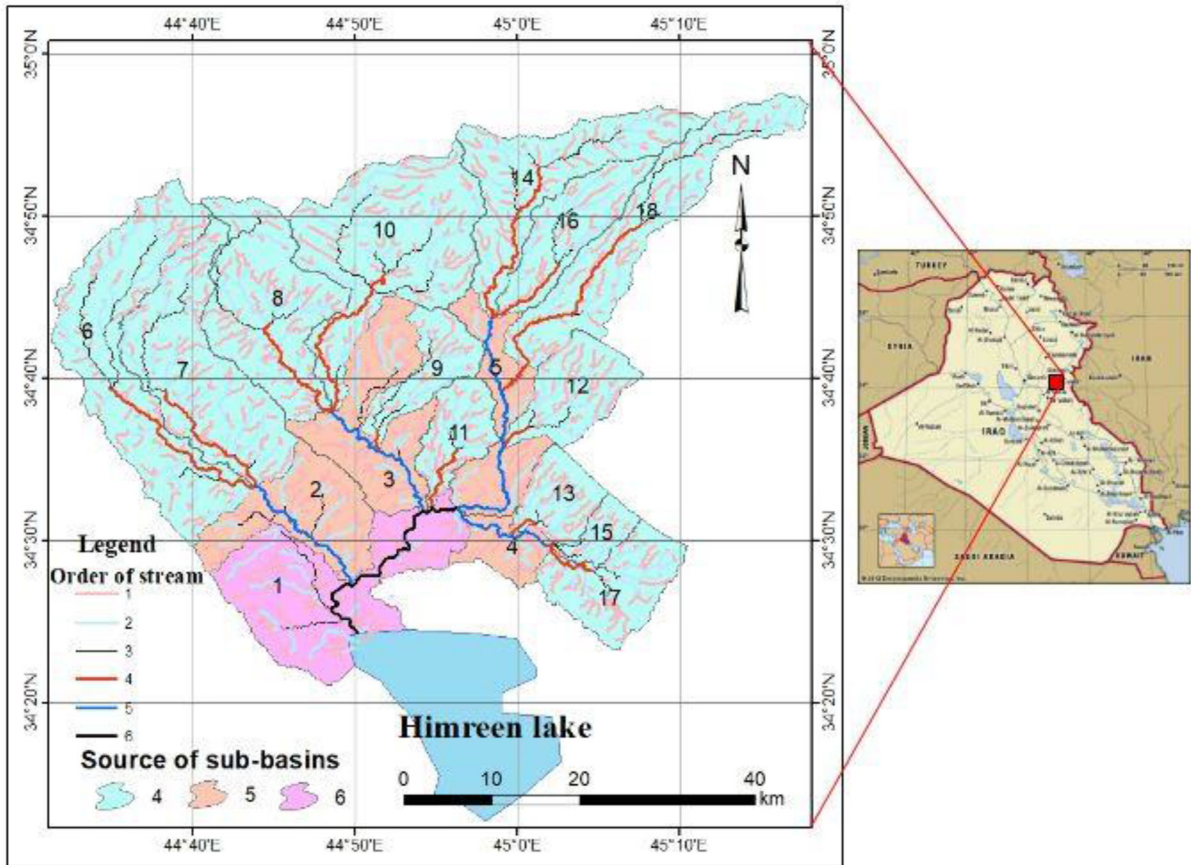
Fig. 1 Location map of the studied area and the 18 sub-basins

Formation (Upper Miocene) as compared to the present topography.

1.2 Data Used and Methodology

This study was carried out using Radar Topography Mission (SRTM) data with extensive use of previously published geological, and Neotectonic maps. The borders of the sub- basins were delineated using SRTM image that has a ground resolution of 3-arc-second (90 m) and a vertical resolution of approximately 10 m.

Kifri Chai Basin was divided into eighteen sub-basins according to the ordering of the streams, using Straller's stream ordering method. The stream order was generated up to 6th orders using the stream ordering module of ArcGIS. The eighteen sub-basins are located depending on the 4th, 5th, and 6th stream orders. The coverage area of the basin was extracted from the DEM map using the basin extraction tool of ArcGIS which gives accurate size and shape of each sub basin.

2 Geomorphic Indices

Six geomorphic indices were used to estimate the relative tectonic activity in Kifri Chai Basin. For each index, a map was constructed based on DEM image which shows the classes of each index at each sub-basin. The measured six geomorphic indices at each sub-basin are mentioned hereinafter. The acquired values (Table 1) and classes are according to El-Hamdouni et al. (2008) and enclosed references.

2.1 Stream-Gradient Index (Sl)

This index shows the relation between the length of a valley and its gradient, it is defined as:

$$SL = (\Delta H / \Delta L) * L$$

where **SL** denotes the Stream length gradient index, **ΔH/ΔL** denotes the channel slope or gradient of the reach (ΔH is the change in elevation of the reach and
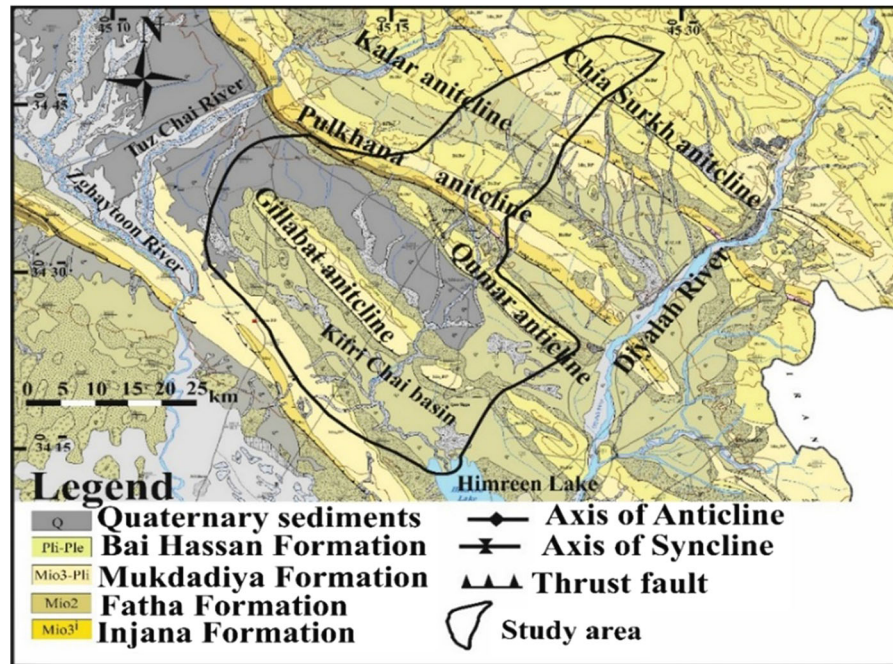
Fig. 2 Geological map of the studied area and near surroundings (After Sissakian and Fouad 2014; Barwary and Slewa 2014a, b)

Table 1 Values of geomorphic indices of the eighteen sub basins

Sub-basin no	Stream order	Sub basin area (km^2)	Sl	Af	Bs	Hi	Vf	Smf
1	6	521.34	90	39.28	2.78	0.14	2.8	2.3
2	5	129.96	160	41.89	2.18	0.16	3.2	1.6
3	5	152.76	220	47.86	5.6	0.19	9.7	1.2
4	5	46.75	49	27.98	2.17	0.10	9.1	*
5	5	105.59	257	59.06	15.96	0.29	7.7	1.2
6	4	274.49	180	48.5	5.5	0.13	2.3	2.4
7	4	220.82	220	36.48	4.96	0.13	2.6	2.2
8	4	204.81	280	46.06	2.83	0.15	2	1.2
9	4	69.15	240	36.22	3.9	0.16	7.2	1.3
10	4	273.75	700	53.75	2.78	0.26	0.9	2.5
11	4	64.51	200	61.74	3.27	0.16	13.9	*
12	4	90.10	280	38.93	2.16	0.22	5.1	1.3
13	4	58.82	200	53.23	2.04	0.12	11.7	1.3
14	4	176.87	800	73.39	5.68	0.28	4.0	2.8
15	4	30.08	160	50.99	3.33	0.11	4.0	1.4
16	4	99.70	400	62.89	5.51	0.25	10.9	2.7
17	4	106.47	140	31.01	2.2	0.08	12.2	1.1
18	4	195.18	1000	50.18	9.18	0.32	8.6	1.9
Average			309.8	47.75	4.56	0.18	6.55	1.8

*No mountain front exists in the sub-basin

ΔL is the length of the reach), and **L** denotes the total channel length from the point of interest (Hack 1973). The values of the **Sl** in the eighteen sub-basins are assigned in Table 1. The (**Sl**) Index is classified into three tectonic activity classes: (**Class 1**) High ($Sl > 500$), (**Class 2**) Moderate ($300 \geq Sl < 500$), and (**Class 3**) Low ($Sl < 300$). The acquired average Sl value is 309.8 which indicates Class 2, meaning Moderate tectonic activity, the classes of the eighteen sub-basins are shown in Fig. 3.

2.2 Asymmetric Factor (Af)

The asymmetric factor (**Af**) was used to evaluate the tectonics activity at a drainage basin scale. Its area of application is relatively large (Hare and Gardner 1985; Keller and Pinter 2002). The **Af** index is formulated as follows:

$$Af = 100 * (Ar/At).$$

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

The values of the Af in the eighteen sub-basins are assigned in Table 1. The Asymmetric Factor (Af) is classified into three classes: (**Class 1**) (Af < 35 or Af > 65), (**Class 2**) (57 < Af < 65 or 35 < Af < 43), and (**Class 3**) (43 < Af < 57). The average Af value is 47.7 which indicates Class 3, and the classes of the eighteen sub-basins are shown in Fig. 3.

2.3 Basin Shape Index (Bs)

This index indicated the shape of the basin and its relation with the relative tectonics. This index is identified as:

$$Bs = Bl/Bw$$

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

The basin shape index (Bs) includes three classes: (**Class 1**) Elongate basin with $Bs > 4$; (**Class 2**) Semi-elongate basin with $3 \leq Bs < 4$; and (**Class 3**) Circular basin with $Bs < 3$. The values of the Bs in the eighteen sub-basins are assigned in Table 1. The average Bs value is 4.56 which indicates Class 1. The classes of the eighteen sub-basins are shown in Fig. 4.
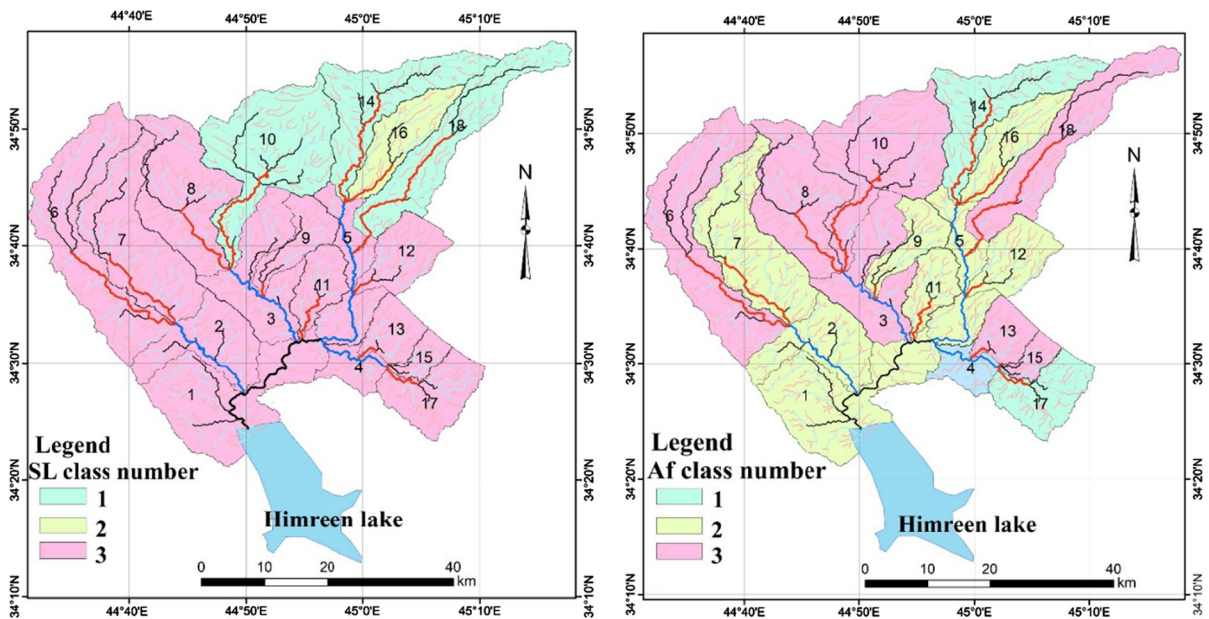

Fig. 3 Map of the eighteen sub-basins classes. (**Left**) Stream Gradient Index (*Sl*), (**Right**) Asymmetric Factor (Af)
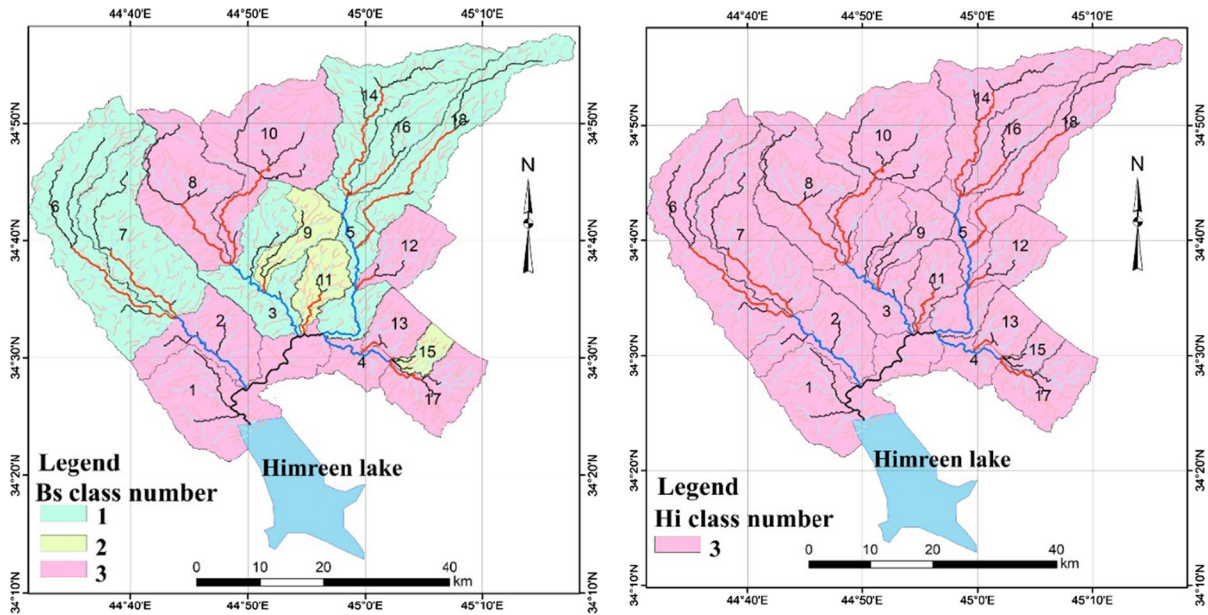
Fig. 4 Map of the eighteen sub-basins classes. (**Left**) Basin Shape Index (Bs), (**Right**) Hypsometric Integral (Hi)

2.4 Hypsometric Integral (Hi)

The hypsometric integral (**Hi**) describes the relative distribution of elevation in a given area of a landscape, particularly a drainage basin (Strahler 1952). The index is defined as the relative area below the hypsometric curve and thus expresses the volume of a basin that has not been eroded. A simple equation to approximately calculate the index is (Pike and Wilson 1971; Mayer 1990; Keller and Pinter 2002):

$$Hi = (\text{average elev.} - \text{min. elev.})/(\text{max. elev.} - \text{min. elev.})$$

The Hypsometric Integral index (Hi) is classified into three classes: (**Class 1**) (**Hi** $\geq$ 0.5), (**Class 2**) (0.4 $\leq$ **Hi** < 0.5) and (**Class 3**) (**Hi** < 0.4). (Table 1). The values of the Hi in the eighteen sub-basins are assigned in Table 1. The average **Hi** value is 0.18, which indicates Class 3. The classes of the eighteen sub-basins are shown in Fig. 4.

2.5 Ratio of Valley Floor Width to Valley Height (Vf)

This index gives the ration between the width of the valley floor and the height of the valley in certain area within a valley, it is a good indication about the

erosion and tectonic activity. This parameter is calculated as:

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

where **Vf** denotes the valley floor width to valley height ratio, V_{fw} denotes the width of the valley floor, E_{ld} and E_{rd} stand for elevations of the left and right valley divides, respectively E_{sc} denotes the elevation of the valley floor (Keller and Pinter 2002; Cuong and Zuchiewicz 2001).

The Vf index is divided into three classes: (**Class 1**) (*Vf* $\leq$ 0.5), (**Class 2**) (0.5 $\leq$ *Vf* < 1.0) and (**Class 3**) (*Vf* $\geq$ 1). The valleys are often narrow upstream from the mountain front (Ramírez-Herrera 1998). The indicated values of *Vf* are assigned in Table 1. The acquired average Vf value is 6.55 which indicates Class 3. The classes of the eighteen sub-basins are shown in Fig. 5.

2.6 Mountain-Front Sinuosity Index (Smf) (J)

The index reflects the balance between erosion forces that tend to cut embayment into a mountain front and tectonic forces that tend to produce a straight mountain front (Verrios et al. 2004).

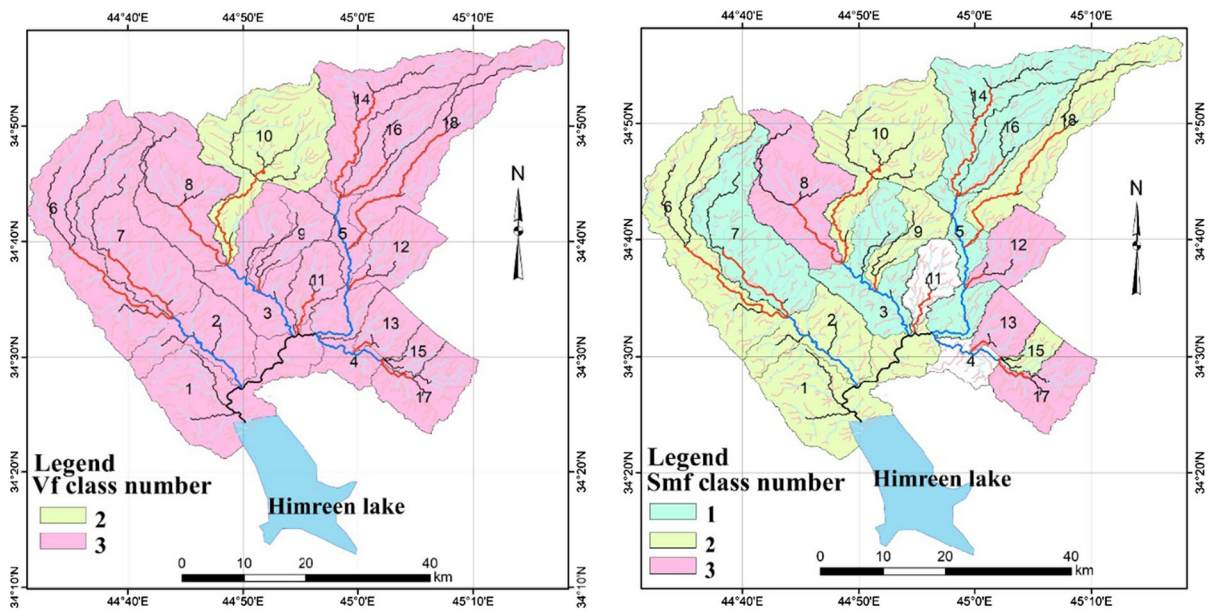Mountain front sinuosity index is defined as:

Fig. 5 Map of the eighteen sub-basins classes. (**Left**) Ratio of Valley Floor Width to Valley Height (Vf), (**Right**) Mountain-front sinuosity index (Smf)

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

where S_{mf} denotes the mountain front sinuosity; L_{mf} denotes the length of the mountain front along the foot of the mountain at the pronounced break in slope, and L_s denotes the straight-line length of the mountain front.

The values of the **J** in the eighteen sub-basins are assigned in Table 1 and the classes are presented in Fig. 5. The measured mountain-fronts are shown in Fig. 6. The Mountain Front Sinuosity Index (**J**) is divided into three classes: (**Class 1**) High, **J** = 1.0 to 1.5, (**Class 2**) Moderate, **J** = 1.5 to 2.5, and (**Class 3**) Low, **J** > 2.5 (El-Hamdouni et al. 2008). The acquired average Smf value is 1.8 which indicates Class 2.

3 Evaluation of Relative Tectonic Activity (Iat)

We have used the average of the six measured geomorphic indices to indicate the relative tectonic activity (Iat), following El-Hamdouni et al. (2008). This index represents a summary and average of the given geomorphic indices, it is calculated as follows (Habibi and Gharibreza 2015):

$$Iat = S/N,$$

where S represents the sum of previous indices, N represents the number of selected indices.

The values of the Iat index are divided into four classes (El-Hamdouni et al. 2008) to define the degree of active tectonics: Class 1—Very high ($1.0 \leq Iat < 1.5$), Class 2—High ($1.5 \leq Iat < 2.0$), Class 3—Moderate ($2.0 \leq Iat < 2.5$), and Class 4—Low ($Iat > 2.5$). The Iat values in the eighteen sub-basins range from 2.00 to 2.66 and the average Iat value is 2.35 (Table 2), which indicates Class 3; meaning Moderate tectonic activity. The Iat classes of the eighteen sub-basins are presented in Fig. 6.

4 Relation Between Regional Neotectonic Activity and Local Tectonic Activity

The Kifri Chai Basin represents the deepest subsided areas within the whole Zagros Foreland Basin inside the Iraqi territory. The depth of the Middle–Upper Miocene contact reaches up to 3000 m below the sea level (Table 3 and Fig. 7). However, the maximum up-warped reaches 250 m (a.s.l.) and the Zero Line (Fig. 7) which represents the Middle–Upper Miocene sea level runs in the middle part of the basin.
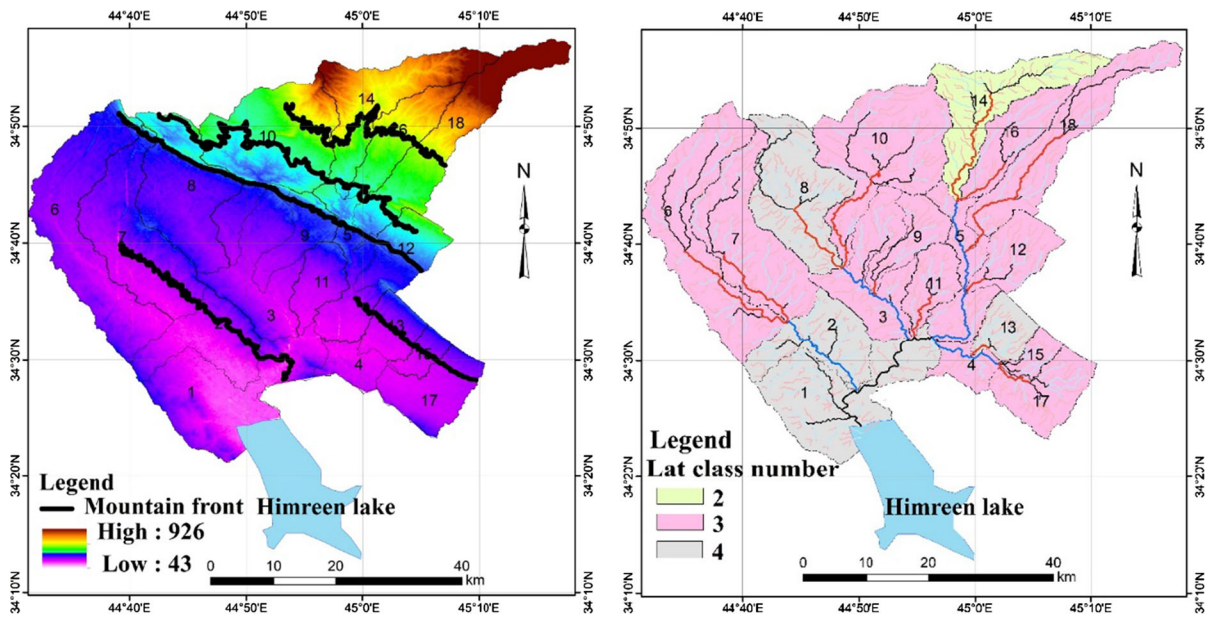
Fig. 6 (**Left**) The measured Mountain Fronts (J) within the eighteen sub-basins, (**Right**) Map of Relative Tectonic Activity (Iat) Classes of the eighteen sub-basins

Table 2 Classes of the geomorphic indices with *Iat* values and classes, and tectonic activity of the eighteen sub-basins

Sub-basin no	Stream order	Sl	Af	Bs	Hi	Vf	Smf	*Lat*		Tectonic activity
		Class						Value	Class	
1	6	3	2	3	3	3	2	2.66	4	Low
2	5	3	2	3	3	3	2	2.66	4	Low
3	5	3	3	1	3	3	1	2.30	3	Moderate
4	5	3	1	3	3	3	*	2.15	3	Moderate
5	5	3	2	1	3	3	1	2.16	3	Moderate
6	4	3	3	1	3	3	2	2.50	3	Moderate
7	4	3	2	1	3	3	1	2.16	3	Moderate
8	4	3	3	3	3	3	1	2.66	4	Low
9	4	3	2	2	3	3	1	2.30	3	Moderate
10	4	1	3	3	3	2	2	2.30	3	Moderate
11	4	3	2	2	2	3	*	2.16	3	Moderate
12	4	3	2	3	3	3	1	2.50	3	Moderate
13	4	3	3	3	3	3	1	2.60	4	Low
14	4	1	1	1	3	3	3	2.00	2	High
15	4	3	3	2	3	3	1	2.50	3	Moderate
16	4	2	2	1	3	3	3	2.30	3	Moderate
17	4	3	1	3	3	3	1	2.30	3	Moderate
18	4	1	3	1	3	3	2	2.16	3	Moderate
Average		2.66	2.20	2.05	2.94	2.94	1.56	2.35	3	Moderate

*Means there is no Mountain Front in the sub-basin

Table 3 Neotectonic data and *Iat* values of the 18 sub-basins within Kifri Chai Basin

Sub-basin No.	Neotectonic activity (12 Ma)				Neotectonic activity during								*Iat*	Tectonic Activity
	Subsidence		Upward		Pleistocene (2.8 Ma)				Holocene (11.7 ka)				Value	
	Rate (cm/100 years)				Subsidence Amount (m)		Upward		Subsidence Amount (m)		Upward		Class	
	Min.	Max.	Min.	Max.	Min	Max	Min	Max	Min	Max	Min	Max		
1	1000	1500	*	*	7.18	11.64	*		0.98	1.47	*		**2.66**	**L**
	0.84	**1.26**											**4**	
2	1500		*	*	11.64		*		1.47		*		**2.66**	**L**
	1.26												**4**	
3	1000	1500	*	*	7.18	11.64	*		0.98	1.47	*		**2.30**	**M**
	0.84	**1.26**											**3**	
4	2000	2500	*	*	15.52	19.40	*		1.96	2.45	*		**2.16**	**M**
	1.66	**2.10**											**3**	
5	2500		*	*	19.40		*		2.45		*		**2.16**	**M**
	2.10												**3**	
6	750	1500	*	*	5.82	11.64	*		0.73	1.47	*		**2.50**	**M**
	0.63	**1.26**											**3**	
7	1000	1500	*	*	7.18	11.64	*		0.98	1.47	*		**2.16**	**M**
	0.84	**1.26**											**3**	
8	1000	2500	*	*	7.18	19.40	*		0.98	2.45	*		**2.66**	**L**
	0.84	**2.10**											**4**	
9	2000	2500	*	*	15.52	19.40	*		1.96	2.45	*		**2.30**	**M**
	1.66	**2.10**											**3**	
10	0	2000	0	250	0	15.52	0	1.94	0	1.96	0	0.24	**2.30**	**M**
	0	**1.66**	**0**	**0.21**									**3**	
11	2000	3000	*	*	15.52	23.28	*		1.96	2.93	*		**2.16**	**M**
	1.66	**2.50**											**3**	
12	0	500	0	250	0	3.88	0	1.94	0	0.49	0	0.24	**2.50**	**M**
	0	**0.42**	**0**	**0.21**									**3**	
13	2000	2500	*	*	15.52	19.40	*		1.96	2.45	*		**2.60**	**L**
	1.66	**2.10**											**4**	
14	0	2500	0	250	0	19.40	0	1.94	0	2.45	0	0.24	**2.00**	**H**
	0	**2.10**	**0**	**0.21**									**2**	
15	3000		*	*	23.28		*		2.93		*		**2.50**	**M**
	2.50												**3**	
16	0	2500	0	250	0	19.40	0	1.94	0	2.45	0	0.24	**2.30**	**M**
	0	**2.10**	**0**	**0.21**									**3**	
17	2500	3000	*	*	19.40	23.28	*		2.45	2.93	*		**2.30**	**M**
	2.10	**2.50**											**3**	
18	0	2500	0	250	0	19.40	0	1.94	0	2.45	0	0.24	**2.16**	**M**
	0	**2.10**	**0**	**0.21**									**3**	

Table 3 continued

Sub-basin No.	Neotectonic activity (12 Ma)				Neotectonic activity during								Iat	Tectonic Activity
					Pleistocene (2.8 Ma)				Holocene (11.7 ka)					
	Subsidence		Upward		Subsidence		Upward		Subsidence		Upward		Value	
	Rate (cm/100 years)				Amount (m)				Amount (m)				Class	
	Min.	Max.	Min.	Max.	Min	Max	Min	Max	Min	Max	Min	Max		
Average	1125	2166	0	69.44	9.463	15.522	0	0.538	1.21	2.58	0	0.067	**2.35**	M
	0.937	**1.805**	**0**	**0.578**									**3**	

Bold indicates the rate or subsidence or upward movements (cm/100 years)

The recorded upward and downward movements are in meter

*Means no upward movement

H high, M moderate, L low
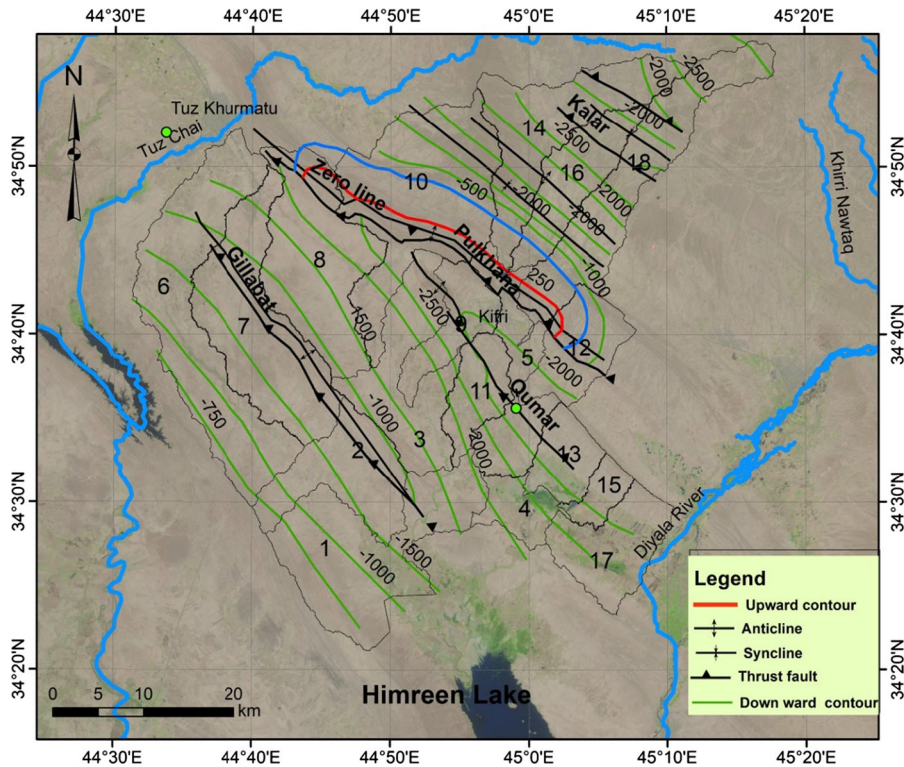
Fig. 7 Neotectonic map of the studied four sub-basins. (Modified from Sissakian and Deikran 1998). The background is Sentinel image

The amounts and rates of the subsidence and/or upward movements, during the Neotectonic Period, and the *Iat* values and tectonic activity class in each of the eighteen sub-basins are assigned in Table 3. Moreover, the subsidence and upwards amounts were calculated during the Pleistocene (2.8 Ma) and the Holocene (11.7 Ka) (ICS 2012) in the eighteen sub-basins (Table 3). The amount of the subsidence during the Neotectonic period, Pleistocene and Holocene range from (0–3000), (0–23. 28) to (0–2.93) m, respectively. Whereas the amount of the upward movement during the three intervals range (0–250), (0–1.94) and (0–0.24) m, respectively. The subsidence

and upward rates during the Neotectonic period range (0–2.5) and (0–0.21) cm/100 year, respectively.

Those sub-basins which exhibit wide range of subsidence, the *Iat* values indicate High tectonic activity (Sub-basin No. 14) or Medium tectonic activity, but with *Iat* value of 2.16 which is very close to Class 2 (for example Sub-basin No. 18).

The subsidence amount depends on the thickness of the exposed formations younger than the Fatha Formation which forms the beginning of the Neotectonic phase in Iraq. The thicknesses of the Injana, Mukdadiya and Bai Hassan formations which overlie the Fatha Formation are considered in the construction of the Neotectonic map of Iraq (Sissakian and Deikran 1998). The thicknesses are highly variable in the area; therefore, any miss-estimation of the thicknesses will give subsidence wrong amount of subsidence. This may be the case with Sub-basin No. 4.

5 Results

The acquired data of the six studied geomorphic indices showed that the average *Iat* value in Kifri Chai Basin is 2.35, which means Class 3; meaning that the Relative Tectonic Activity in the basin is Moderate (Table 2). Moreover, the regional Neotectonic activity data showed that there is positive relation with the relative tectonic activity in Kifri Chai Basin.

6 Discussion

The tectonic activity and the values of each of the six geomorphic indices are discussed showing the main differences and the reasons for similarities and/or anomalous results within the eighteen sub-basins. The average value of tectonic activity indicator (*Iat*) in the eighteen sub-basins is **2.35** (Tables 2, 4), which indicates Class 3 and means that the tectonic activity is Moderate. Accordingly, the tectonic activity of Kifri Chai Basin is Moderate.

The prevalence of the Medium tectonic activity in Kifri Chai Basin (Tables 2, 3, 4, and Fig. 6, Right) is attributed to the following reasons: (1) The exposed rocks within the eighteen sub-basins are mainly clastics, with exception of the Fatha Formation, which includes gypsum and limestone beds with thick claystone beds and thin sandstone beds. Although the Fatha Formation is exposed only in Sub-basins No. 5, 8, 9 and 10 and a very small part in Sub-basin No. 11 (Fig. 2), but the coverage area is very small, along the thrust of Pulkhana anticline only (Fig. 2); therefore, the presence of both rock types does not affect significantly the geomorphological indices as compared to the clastic rocks which cover the majority of the basin, (2) Tectonically, the eighteen sub-basins are located within the Low Folded Zone (Fouad 2012); therefore, have influenced by the same tectonic stresses during the past geological time, (3) The average of the Mountain Front index values is 1.8 (Tables 1, 2), which means Moderate class, but, within Sub-basins No. 3, 5, 8, 9, 12, 13, 15 and 17 is High Class (Table 1). This means in those sub-basins the tectonic activity was higher. Otherwise the Mountain Front index value wouldn't be High, (4) The eighteen sub-basins are covered mainly by clastic rocks (Sissakian and Fouad 2014, Barwary and Slewa 2014a, b), and are under the same climatic conditions, as the annual rain fall and temperature are concerned; therefore, the shape, size and orders of the valleys are almost the same. Accordingly, the *SL*, *Af*, *Bs*, **Hi** and **Vf** values (Table 1) are uniform and exhibit almost the same classes. However, few exceptions

Table 4 Statistical data about the classes of the geomorphic indices and *Iat*

Class	Geomorphic indices (Scored numbers in sub-basins)						Tectonic activity	
	Sl	Af	Bs	Hi	Vf	Smf	Class	Grade
1	3	3	7	*	*	9	1	High
2	1	8	3	1	1	5	13	Moderate
3	14	7	8	17	17	2	4	Low
Total	18	18	18	18	18	16**	18	

*No class exists

**No Mountain front exist in 2 sub-basins

occur, especially in **Hi** and **Vf** values (Table 2). All the sub-basins have the same class in both indices; Class 3, except Sub-basin No. 11 and 10, respectively which have Class 2 (Table 2). These exceptional values do not influence significantly on the average results of the acquired values.

The **Af, Bs** and **Smf** indices are distributed over the three main classes of El-Hamdouni et al. (2008) (Table 2). This is attributed to: (1) Locally, hard and massive beds of conglomerate and/or sandstone may influence on the shape of the valleys and their width and depths; accordingly, different results are acquired at different parts in the same sub-basins, (2) The dip amount of the exposed rocks may also influence on the symmetry of the valleys, especially when a valley runs parallel to the main strike of the exposed rocks, the exposed rocks on both sides may have different dip amounts; accordingly, the valley will show different symmetry, and (3) Locally, soft and thick claystone beds, especially in the Bai Hassan Formation will exhibit flat or gently sloping areas within a certain sub-basin; accordingly, the acquired values will differ from the acquired values of other indices. The values of **Sl** index are also distributed over the classes with the majority being of Class 3 (Table 2), which means Low tectonic activity. This can be attributed to the prevailing of the clastic rocks in the sub-basins; therefore, the grade and rate of the weathering and erosion will be almost the same. Accordingly, the ratio of the valley length to its width will be almost the same; with few exceptions due to the presence of different rock types; rather than the clastics.

7 Conclusions

The Kifri Chai Basin is divided into eighteen sub-basins depending on the 4th, 5th and 6th stream orders to indicate the tectonic activity in the main basin. The tectonic activity is acquired by indicating the six geomorphologic indices that lead to the value of the tectonic activity (**Iat**). To indicate the values of the six indices, the required data were measured at each sub-basin using ArcGIS technique, the numerical data is acquired from the DEM.

The tectonic activity of each sub-basin is indicated; accordingly, the average tectonic activity of the Kifri Chai Basin is indicated. A Moderate tectonic activity is assigned to the Kifri Chai Basin; because the

average **Iat** value is found to be 2.35, which assigns to Class 3 and means Moderate tectonic activity.

The regional Neotectonic activity is compared with the relative tectonic activities in the eighteen sub-basins. Generally, there is a fair relation between the two comparatives; especially the subsidence amounts and the scored relative tectonic activity value (**Iat**), especially, when the range of the subsidence in a certain sub-basin is high.

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