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Relative Tectonics Activity Assessment of Diyala River Area Using Lithological Strength Ratio and Morphometric Indices

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ABSTRACT

The study presents a new procedure for assessment relative tectonic activity based on morphometric indices and lithological strength useful in evaluating morphology and topography. The results produced from the analysis are cumulative and expressed as an index of lithological strength and relative tectonic activity (LRTI) , which is divided into five classes ranges from relatively very low to very high tectonic activity. The study area along the Zagros suture zone in eastern Iraq is an ideal location to test the concept of an index to predict relative tectonic activity on a basis of area rather than a single valley or mountain front. The study area has variable rates of tectonic activity resulting from the collision of Arabian and Eurasian plates that has produced linear northwestern–southeastern anticlinal forms, as well as extension with variable vertical rates of main collision zone (Zagros Suture Zone) to about -0.9 mm/y. In this study, the hypothesis test that known areas of relatively high rates of tectonic activity are associated with indicators values of lithological strength and relative tectonic activity (LRTI).

KEYWORDS: *Morphometric indices; Diyala River; Drainage basin; Tectonic activity*.

INTRODUCTION

The recent tectonic activity of Diyala River Basin (DRB) connected with continental uplift may be expressed along the Zagros Suture Zone (ZSZ) in eastern Iraq and western Iran by difference of lithological units, deeply incised rivers, folding, fault scarps, Quaternary deposits along the mountain fronts and basins bounded by faults (Alavi, 1994; Jassim & Goff, 2006). The regional seismic records in DRB are characterized by high frequency of relatively medium magnitude earthquakes (magnitude 4-5.5 Mw) with infrequent large earthquakes (> 6 Mw) and the seismic zones of DRB are divided into four zones: low, minor, moderate and high damage zones (Alsinawi & Al-Qasrani, 2003). Tectonic activity study, especially of those areas with relatively high tectonic activity in the Holocene and late Pleistocene eras are important for assessing the risk of earthquake (Keller & Pinter, 2002). Obtainment rates of tectonic activity are difficult in a regional scale even knowing where to go in a specific region to quantitative studies.

This study approach is to prepare a quantitative procedure to emphasis on regions for more detailed labor to delineate tectonic activity rates. The morphometric indices (MI) used to active tectonics are a known to be beneficial for tectonic activity studies(Azor, Keller, & Yeats, 2002; Bull & McFadden, 1977; Keller & Pinter, 2002). Previously, this approach have been tested as a valuable index in different tectonic activity areas such as, the integration between Smf and Vf indices that permit individual mountain fronts to be given different tectonic activity categories (Class 1 to Class 3) developed below decreasing uplift rates (Cooke, Findlay, Rockwell, & Smith, 1985). (Silva et al., 2003) used the Smf and Vf indices to evaluate the relative tectonic activity of different fronts of mountain in SE Spain. Also (Hamdouni, Irigaray, Fernández, Chacón, & Keller, 2008) developed a procedure a single index (Smf, Vf, Sl, Hi, Af and Bs indices) to be given to different tectonic activity categories (Class 1 to Class 4)that can be used to characterize relative tectonic activity. Many studies of (MI) have focused on specific geomorphic indices at specific locations, such as a mountain front or drainage basin. With the exception of the Drainage intensity index (Di), most of the (MI) are not spatially analyzed indices over a region.

The main objective of this study is to quantify many of (MI) for relative tectonic activity and combined them with lithological strength development to make new categories of relative tectonic activity. This purpose presents the analysis of (MI) with a discussion of the tectonic analysis activity depending on recent field observations and geomorphic, structural and topographic.

MATERIALS AND METHODS

Study area and Data

The Diyala River is a tributary of Tigris River, which is located in the east part central of Iraq and the west part central of Iran. It involves ten main tributaries and they are Al-Wind (Wi), QaraToo (QT), Abasan (Ab), Zamkan (Zm), Sirwan (Sr), Tanjero (Ta), Diewana (Di), Narin (Na), and Kurdarah(Ku). The main trend of the Al-wind, Abasan, Zamkan, Tanjero, Diewana and Narin tributaries is NE – SW. The main trend of the QaraToo, and Sirwan tributaries is E-S. The tributaries of DR run almost in straight lines, especially in the eastern side of their courses, which have almost parallel trends, before they merge to NE-SW flowing DR (Figure-1).

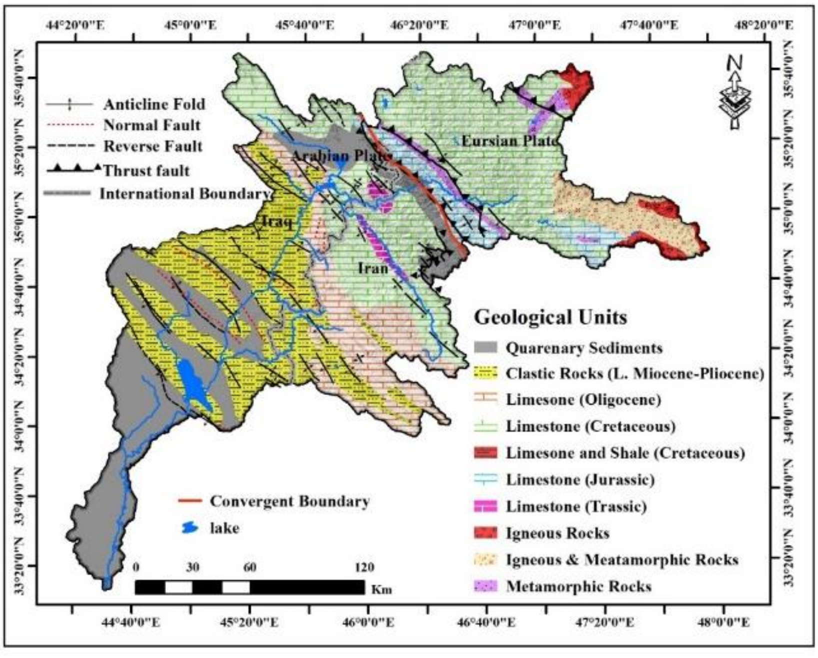

Figure 1: Geological map of DRB modified (Fouad, 2015; Fouad & Sissakian, 2015; Ghorbani, 2013a; Sissakian & Fouad, 2014).

The catchment area of the Diyala River is about 32850 Km2, and forms mainly badland landscape, which it is covered by fine and coarse clastics, which are weakly resistant to erosion, therefore the surface runoff is very high and the river rapidly reaches the peak. Geologically, the DRB is built up by formations ranging in age from the Triassic up to the Pleistocene, with different types of Quaternary sediments (Fouad & Sissakian, 2015; Ghorbani, 2013b; Kadhim & Al-Kubaisi, 2020). The exposed sequence is composed mainly of clastic and carbonate sedimentary rocks in addition to some igneous and metamorphic rocks as shown in figure 1.

The mainly data used in this study are Advanced Land Observing Satellite (ALOS) – "ALOS World 3D-30m" Digital Surface Model (DSM) (1arc-second) available through Earth Observation Research Center (EORC) and Japan Aerospace Exploration Agency (JAXA) data archive (http://www.eorc.jaxa.jp/ALOS/en/aw3d30/data/index.htm). Also, 42 scenes of QuickBird satellite and 6 topographic map at scale 1:250000 are used in this study.

Metholodgical

The drainage networks, streams, basin and sub-basins of the study area are generated from DSM. The drainage network streams and main basin and sub-basins boundaries of DR were outlined using automated procedures by the TecDEM program in MATLAB environment. Snap pour points are selected to define the basin and sub-basins boundaries. Topographic maps (Survey of Iraq; Survey of Iran) at scale 1:250,000 are used for validating the generated drainage networks, streams, basins and sub-basins from the DSM. The (MI) are divided into 4 classes: an aerial (A), relief (R), linear, and network drainage (N) indices (Table 1), and the (MI) used for significance of relative tectonic activity are shown in Table 2. The morphometric characteristics of main basin and sub-basins are obtained from Arc GIS 10.6. The (MI) are calculated using Microsoft Excel V.13 (Table 1 and 2). Different methods have been given to prioritize of basin study like quantitative, statistical algorithm, and fuzzy logic for AHP and weighting. The AHP is quite popular, but it is often criticized because of an inability deal with handling ambiguity associated with mapping and decision- making process (Deng, 1999; Saaty, 2003). The FAHP has more advantage than the AHP for handling fuzziness and vagueness. In this study, the comparison matrix of triangular fuzzy is applied to obtain vector of priority through FAHP for basin prioritization depending on tectonics (T).

To develop a procedure for calculating minimum eroded volume (Mr) from each drainage basin from the digital topographic data, an Arcmap 10.6 geoprocessing model was created for this purpose (Figure 2), following the method described by Cooley (2014).

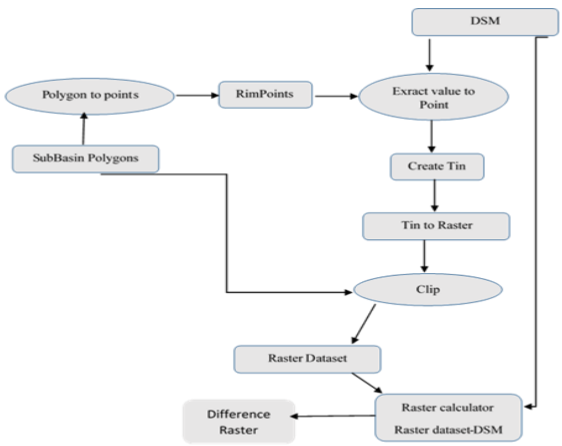

Figure 2: Minimum eroded volume (Mr) raster geoprocessing model displays the procedure of creating a Mr Raster from the local DSM raster.

The Mr are calculated by equation (1).

$$Mr = DSM - local\ DSM \qquad (1)$$

Where the DSM is the Digital Surface Model and local DSM is raster dataset in Fig. 2.

The (MI) values that are useful for tectonic activity study, include fifteen indices (Keller & Pinter, 2002b; Morrish, 2015; Panek, 2004), but in this study is used twenty-two of (MI) indices (table 1).

Table 1: Aerial, linear, relief and network morphometric parameters and their computation

	MI	Equation	Selected References
Aerial (A)			
1	Basin shape (Bs)	Bs=Bl/Bw	(Robert E Horton, 1932) (Ramírez-Herrera, 1998) (Schumm, 1956) (Ramírez-Herrera, 1998)
2	Form factor (Bf)	Bf=A/L^2	
3	Elongation ratio (Be)	Be=(2(A/PI)^0.5))/L	
4	Basin Compacteness (Bc)	Bc=0.2841(P/A^0.5)	
5	Basin perimeter (Rp)	Rp=(1/Bc)^0.5	(Schumm, 1956)
6	Basin Circularity (Rc)	Rc = 4*PI*A/P^2	(Miller, 1953)
7	basin Assymetry (Af)	AF=100(Ar/At)	(El Hamdouni, Irigaray, Fernández, Chacón, & Keller, 2008) (Cox, 1994)
8	Transverse topo. index(At)	T=100(Da/Dd)	
Relief (R)			
1	Local Releif ratio (Rl)	R= Hman-Hmin	Hugett and Cheesman, 2002 Formento&Pazzaglia,1998
2	Relative relief (Rr)	Rh= R/L m*km	
3	Ruggedness (Rg)	Rg=DH/L or Hmean/R	
4	Valley floor width (Vf)	Vf=2Vfw/[(Eld−Esc)+(Erd −Esc)]	(Bull & McFadden, 1977)
5	hypsometric integral (Hi)	Hi=(hmean−hmin)/(hmax −hmin)	(El Hamdouni et al., 2008)
6	Minmium eroded volume(Mr)	Mr=DSM- localDSM	(Cooley, 2013)
Linear (L)			
1	Mean Drainage length (Lm)	Lsm = Lu/Nu	(Strahler, 1964)
2	Mean Bifurcation (Rb)	Rbm = mean of bifurcation	(Strahler, 1964)
3	Sinousty (S)	S= C/V	(Keller and Pinter 2002)
4	Hack index (Sl)	Sl=(⊿ H/⊿ L)L	(Hamdouni et al., 2008)
Network Drainage (N)			
1	Drainage density (Dd)	D = Lu/A	(Robert E Horton, 1932)
2	Drainage frequency (Df)	Df = Nu/A	(Robert E Horton, 1932)
3	Drainage intensity (Di)	Di=Df/Dd	(Faniran, 1968)
4	Drainage texture ratio (Bt)	Rt = Nu/P	(R E Horton, 1945)

In addition, using lithological strength to develop (MI) by assuming lithological strength in each sub-basins are used in this study. In order to differentiate values at the index related to lithological strength, different classes of average lithological strength are determined by types of rock and sediments with field observation. The lithological strength classes are divided into five classes. The class A is a very low lithological strength (clay, silt, sand and marl), the class B is a low lithological strength (older alluvial fan deposits and weak of consolidated conglomerate), class C is a moderate lithological strength (clay stone, siltstone and sandstone), class D is a high lithological strength (calcareous sandstone, limestone, and conglomerate), and class E is a very high strength (dolomitic limestone, igneous and metamorphic rocks such as marble). Then, lithological strength (lit.) in each sub-basins is calculated by equation 2 (table 3).

$$Lit = \frac{Aa + Ba + Ca + Da + Ea}{5} \qquad (2)$$

Where, A, B, C, D and E are lithological strength (A =1, B=2, C=3, D=4 and E=5) is the area in each level lithological strength at sub-basins.

The lithological strength are divided into five class based on equation 1, table 3 Morphometric indices weights are calculated same as lithological strength, but based on the AHP. Characteristics of morphometric indices The sub-basins were prioritized based on weights of morphometric indices useful for tectonic activity assessment obtained through AHP (table 3).

Table 2: Morphometric indices for Significance of relative tectonic activity

MI				Selected references
	Class A	**Class B**	**Class C**	
Bs	Bs>4	3≤Bs≤4	Bs<3	Mdouni et al., 2008)
Bf	An areas with high uplift show high value of Bf			(Hamdouni et al., 2008) (Panek, 2004)
Be	Be>0.75	0.5≤Be≤0.75	Be<0.5	
Bt	An areas with high uplift show high value of Bt, Bc and Rp			(Panek, 2004)
Bc				
Rp				
Rc	An areas with high uplift show high value of Rc			
Af	An areas with high uplift show low value of Af and At			(Cox, 1994; El Hamdouni et al., 2008)
At				
Rl	An areas with high uplift show high value of Rl, Rr, and Rg			Formento-Trigilio & Pazzaglia, 1998)
Rr				
Rg				
Vf	Vf<0.3	0.3<Vf<1	Vf>1	(Bull & McFadden, 1977)
Hi	HI>0.5	0.4≤HI≤0.5	HI<0.4	(El Hamdouni et al., 2008)
Mr	An areas with high uplift show low value of Mr			by authors
Lm	An areas with high uplift show low values			by authors
Rb	An areas with high uplift show high value of Lb			(Nek, 2004)
S	S ≥1.6	1.6< S < 3	S≤3	(ams, 1980)
Sl	Sl ≥500	300≥Sl<500	Sl<300	008)
Dd	An areas with high uplift show high values of Dd and Df are showing the more intensive to lithology			(Panek, 2004)
Df				
Di	An areas with high uplift show high value of Di			by authors

Table 3: Lithological strength (Lit.) classes

Lit.	>4.5	3.5-4.5	2.5-3.5	1.5-2.5	<1.5
Class lit.	5	4	3	2	1
Description	V. Low	Low	Moderate	High	V. High
Weight (W)	<0.02	0.02-0.04	0.04-0.06	0.06-0.08	>0.8
Class W.	5	4	3	2	1
Description	V. Low	Low	Moderate	High	V. High

RESULTS

The DSM is used to identify the river, network drainage, basin and sub-basins of the DR (Figure 3). The results of the characteristics of (DRB), (MI) values and their tributaries subbasins are shown in (Tables 4, and 5).

The (MI) values are classified into three classes of lat depending on (Hamdouni et al., 2008): Class 1 is a strong tectonic activity, Class 2 moderate, strong tectonic activity and Class 3 low tectonic activity, and the result of final lat classes insert to Table 5.

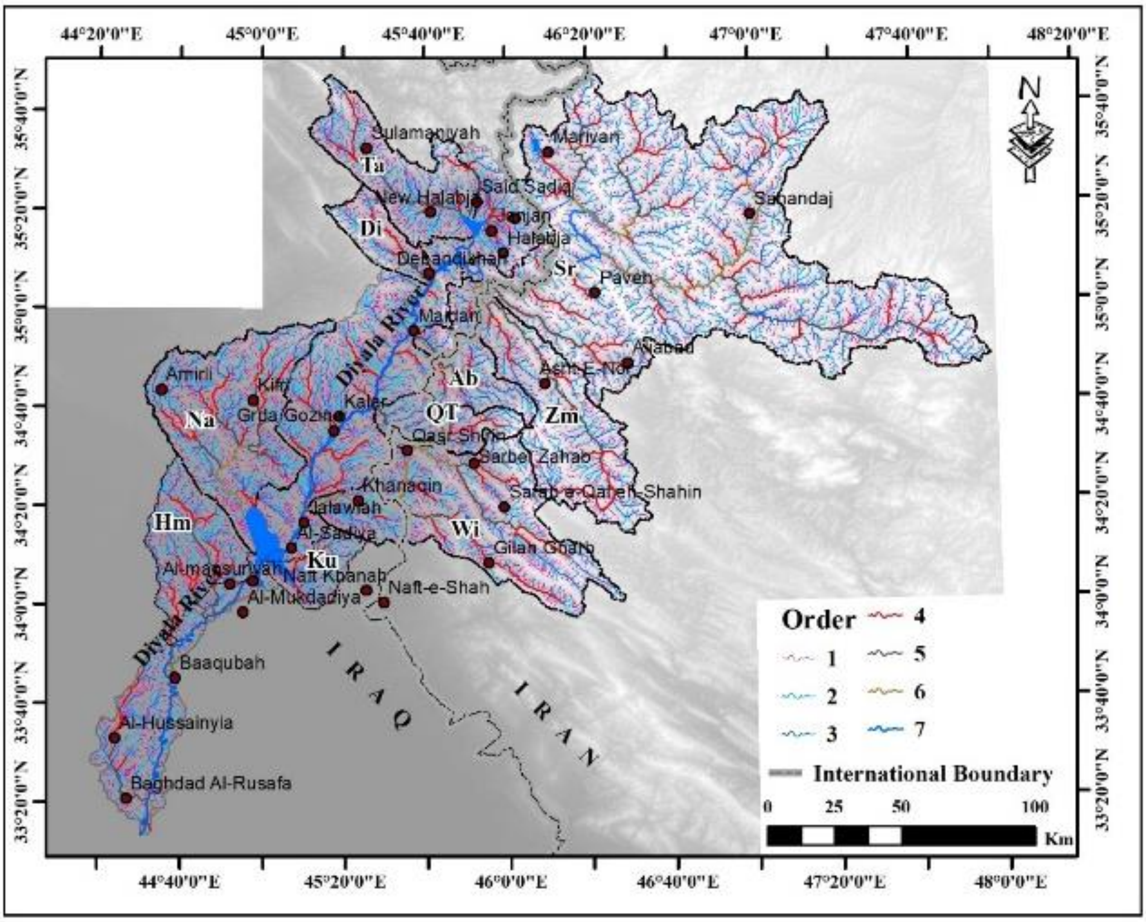

Figure 3: The DSM used in this study, showing the stream orders and boundaries of the DRB area and its sub-basins.

In table 5, the values of Bs, Bf, Be, Bt, Bc, Rp, Ri, Rr, Rg, Hi, Lb, S, Sl, and Di are directly proportional to the relative tectonic activity, but the values Rc, Af, At, Vf, Mr, are shown inversely proportional to the tectonic activity in the study area. These results correspond to the standard measurements to tectonic activity except for values of Lm, Dd, and Df, that are affected by lithological strength of the study area (Figure 4). The (MI) values of basin provide information pertinent to basin characteristics for relative tectonic activity in the study area. Uncertainty in (MI) values is overcomed by three methods; the first is assigning relative tectonic activity index numbers (RTI) to (MI) values based on their influence by tectonic activity. The second is assigning relative tectonic activity index numbers (RTI) based on lithological strength (Lit.) values based on their influence by tectonic activity (Table 6) and the latter is assigning fuzzy analytic hierarchy process numbers (FAHP) based on their influence by tectonic activity.

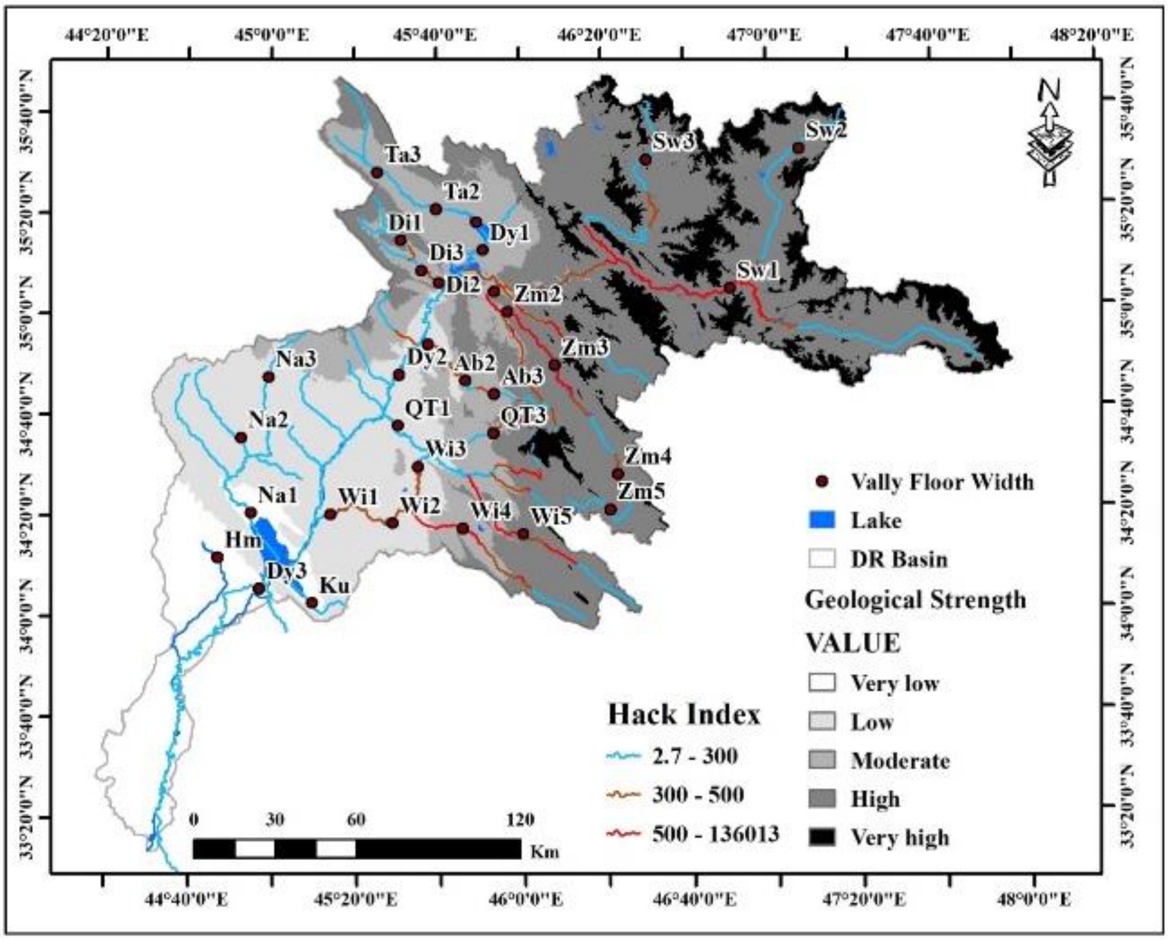

Figure 4: Distribution of Hack index (Sl) and location of Vf with Geological strength levels in the study area.

The Vf values are measured in the sub-basins of DRB by average of these values are located in each sub-basin and Vf value of DRB by the average of all points, table 5. While, their value at each point in Figure 4.

The five classes' numbers are used to assign weights (Table 3) for the Mi values. The weights numbers are introduce directly in Mi values matrix table 5 and results are shown in Table 7. Each (MI) values of DRB and every sub-basin are compared with standard class based on their tectonic activity (Table 5). The W-ratio of (MI) in each sub-basin is calculated in Table 7.

Four fuzzy numbers were used to give weights to the Mi (i.e., strongly important (2, 2.5, 3), moderate important (1.5, 2, 2.5), weakly important (1, 1.5, 2) and equal (1, 1, 1), the results of MAT weight are shown in table 6.

W. ratio has a direct relationship with tectonic activity such that the higher the value of W. ratio the greater the influence on tectonic activity. Hence, these values are directly in (MI) properties matrix table. Each (MI) of every sub-basins is compared with standard weight based on their Iat in Table 5.

The all results of Iat, lith. and w. classes are shown in table 8. And finally, the FAHP values are calculated for all results in table 8. Finally, the (LRTI) classes are average of (RTI), Lith, and W. classes for the DRB and its sub-basins (Table 8).

The methodology proposed of GIS allows a map showing of relative tectonic activity of the landscape to be produced. This method is linked to relative tectonic activity susceptibility mapping(El Hamdouni et al., 2008) in Sierra Nevada, Spain with widespread evidences of recent tectonic activity. The criteria for the different classifications produced previously by several authors, which are comparable with geomorphic indices in this study mentioned are summarized in Table 9. The classification used in this study for each geomorphic index is also included. The proposed integrated index (LRTI) has no antecedents in the available literature as it is determined by twenty-two geomorphic indices across the landscape.

Table 4: Characteristics of the DR and its tributaries and their sub-basins

	SR	**ZM**	**AB**	**QT**	**WI**	**TA**	**DI**	**NA**	**Ku**	**Hm**	**DR**
Hmax m.	3367	2564	2560	2567	2482	2199	1859	945	481	228	3367
Hmin m.	486	486	306	235	121	486	366	100	100	47	32
H*m*m.	1955	1537	915	725	1089	811	978	269	162	79	1199
Bl km	201	117	57	58	125	80	49	82	39	50	320
Bw Km	65	21	21	20	24	21	15	37	22	30	112
Per. Km	11343	2563	876	809	3493	1719	606	2922	177.58	305	2566
Ba(Km2)	1171	482	250	241	532	351	177	440	578.74	1410	32829
Stream order.											
Nu.1	3614	817	285	279	1170	564	211	962	200	450	10652
Nu.2	773	176	68	67	275	135	48	223	47	90	2363
Nu.3	162	47	19	15	59	31	5	48	9	25	526
Nu.4	41	9	4	4	13	7	2	15	2	8	126
Nu.5	9	2	1	1	4	3	1	5	1	1	32
Nu.6	4	1			1	1		1			8
Nu.7	1										1
Total	4604	1052	377	366	1522	741	267	1254	259	574	13708
Bifurcation ratio (Rb)											
Nu1/Nu2	4.68	4.64	4.19	4.16	4.25	4.18	4.40	4.31	4.25532	5	4.51
Nu2/Nu3	4.77	3.74	3.58	4.47	4.66	4.35	9.60	4.65	5.22222	3.6	4.49
Nu3/Nu4	3.95	5.22	4.75	3.75	4.54	4.43	2.50	3.20	4.5	3.125	4.17
Nu4/Nu5	4.56	4.50	4.00	4.00	3.25	2.33	2.00	3.00	2	8	3.94
Nu5/Nu6	2.25	2.00			4.00	3.00		5.00			4.00
Nu6/Nu7	4.00										8.00
Average	4.03	4.02	4.13	4.10	4.14	3.66	4.62	4.03	3.99439	4.93125	4.85
Stream Length											
Nu.1	4450	1078	420	368	1746	935	283	1546	341.52	741.8	15238
Nu.2	2014	406	161	188	766	506	128	807	158.78	377.8	7120
Nu.3	990	269	120	90	319	147	38	327	85.73	229.2	3320
Nu.4	481	144	52	40	196	82	33	188	42.9	162.6	1648
Nu.5	330	99	36	45	94	101	23	97	11.8	51.5	981
Nu.6	170	19			117	23		74			549
Nu.7	112										327
Total	8546	2016	789	731	3238	1792	505	29163	640.73	1562.9	29183
Stream length ratio											
Nu1/Nu2	2.21	2.65	2.61	1.95	2.28	1.85	2.22	1.92	2.1509	1.96347	2.14
Nu2/Nu3	2.03	1.51	1.34	2.09	2.40	3.45	3.36	2.47	1.85209	1.64834	2.14
Nu3/Nu4	2.06	1.87	2.29	2.26	1.62	1.79	1.15	1.74	1.99837	1.40959	2.01
Nu4/Nu5	1.46	1.45	1.45	0.88	2.10	0.81	1.45	1.94	3.63559	3.15728	1.68
Nu5/Nu6	1.94	5.10			0.80	4.46		1.31			1.79
Nu6/Nu7	1.51										1.68
Average	1.87	2.52	1.93	1.79	1.84	2.47	2.04	1.87	2.40924	2.04467	1.91

Table 5: Mi values of the DR and its tributaries and their sub-basins

	SR	ZM	AB	QT	WI	TA	DI	NA	KU	HM	DR	W.
Bs	2.77	5.55	2.69	2.91	5.19	3.80	3.25	2.44	1.77	1.67	2.87	0.02
Bf	0.35	0.19	0.27	0.24	0.22	0.27	0.25	0.23	0.56	0.60	0.32	0.02
Be	0.60	0.49	0.58	0.55	0.53	0.58	0.57	0.74	0.70	0.85	0.64	0.02
Bt	0.41	0.41	0.43	0.45	0.44	0.43	0.44	0.43	1.46	1.88	5.34	0.03
Bc	3.12	2.71	2.40	2.41	2.56	2.40	2.04	2.31	2.10	2.31	4.02	0.02
Rp	3.10	2.69	2.38	2.39	2.54	2.39	2.03	2.29	2.08	2.29	4.00	0.05
Rc	0.10	0.14	0.18	0.18	0.16	0.18	0.24	0.19	0.23	0.19	0.06	0.06
Af	42.85	66.49	94.26	69.26	27.36	76.13	95.18	60.70	44.50	63.69	49.46	0.06
At	0.18	0.28	0.27	0.38	0.59	0.46	0.31	0.65	0.73	0.43	0.28	0.08
Rl	2881	2078	2254	2332	2361	1713	1493	845	381	181	3335	0.05
Rr	14.32	17.82	39.47	40.05	18.86	21.38	30.39	10.29	9.77	3.62	10.42	0.06
Rg	0.68	0.74	0.41	0.31	0.46	0.47	0.66	0.32	0.43	0.44	0.36	0.06
Vf	0.33	0.43	2.40	0.86	3.16	5.53	0.57	13.68	11.13	5.15	17.46	0.08
Hi	0.51	0.51	0.27	0.21	0.41	0.19	0.41	0.20	0.16	0.18	0.35	0.08
Mr	0.56	0.44	-0.77	0.35	0.58	0.66	0.15	41.85	25.00	44.50	1.77	0.08
Lm	1.86	1.92	2.09	2.00	2.13	2.42	1.89	23.26	2.47	2.72	2.13	0.03
Lb	4.03	4.02	4.13	4.10	4.14	3.66	4.62	4.03	3.99	4.93	4.85	0.02
S	1.93	1.89	1.49	1.70	1.93	1.29	1.57	1.56	1.40	1.50	1.50	0.08
Sl	1183	13197	233	400	1860	154	184	40	14	15	162	0.08
Dd	0.75	0.79	0.90	0.90	0.93	1.04	0.83	9.98	1.11	1.11	0.89	0.02
Df	0.41	0.41	0.43	0.45	0.44	0.43	0.44	0.43	0.45	0.41	0.42	0.02
Di	0.54	0.52	0.48	0.50	0.47	0.41	0.53	0.04	0.40	0.37	0.47	0.03
Lat.	1.36	1.45	1.91	1.82	1.59	2	1.82	2.36	2.50	2.64	2.18	-
RTI.class	1	1	2	2	2	2	2	2	3	3	2	-

Table 6: Lit. Index in each sub-basins

subbasins	**SR**	**ZM**	**AB**	**QT**	**WI**	**TA**	**DI**	**NA**	**Ku**	**Hm**	**DRB**
Lith.	1.2	1	2.1	2.3	1.8	2.4	1.4	3.6	4	3.9	2.2
Lith. Class	2	1	2	2	2	2	1	3	4	4	2

Table 7: Weight of morphometric indices based on active tectonic

MI	**SR**	**ZM**	**AB**	**QT**	**WI**	**TA**	**DI**	**NA**	**Ku**	**Hm**	**DR**
Bs	0.06	0.11	0.05	0.06	0.10	0.08	0.07	0.05	0.04	0.03	0.06
Bf	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.01	0.01
Be	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Bt	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.06	0.08	0.21
Bc	0.06	0.05	0.05	0.05	0.05	0.05	0.04	0.05	0.04	0.05	0.08
Rp	0.19	0.16	0.14	0.14	0.15	0.14	0.12	0.14	0.12	0.14	0.24
Rc	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.01
Af	3.43	5.32	7.54	5.54	2.19	6.09	7.61	4.86	3.56	5.10	3.96
At	0.02	0.03	0.03	0.04	0.06	0.05	0.03	0.07	0.07	0.04	0.03
Rl	172.86	124.68	135.24	139.92	141.66	102.78	89.58	50.70	22.86	10.86	200.10
Rr	1.15	1.43	3.16	3.20	1.51	1.71	2.43	0.82	0.78	0.29	0.83
Rg	0.05	0.06	0.03	0.02	0.04	0.04	0.05	0.03	0.03	0.03	0.03
Vf	0.03	0.04	0.24	0.09	0.32	0.55	0.06	1.37	1.11	0.52	1.75
Hi	0.05	0.05	0.03	0.02	0.04	0.02	0.04	0.02	0.02	0.02	0.04
Mr	0.06	0.04	-0.08	0.04	0.06	0.07	0.01	4.19	2.50	4.45	0.18
Lm	0.07	0.08	0.08	0.08	0.09	0.10	0.08	0.93	0.10	0.11	0.09

Lb	0.08	0.08	0.08	0.08	0.08	0.07	0.09	0.08	0.08	0.10	0.10
S	0.19	0.19	0.15	0.17	0.19	0.13	0.16	0.16	0.14	0.15	0.15
Sl	118.30	1319.70	23.30	40.00	186.00	15.40	18.40	4.00	1.42	1.50	16.20
Dd	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.20	0.02	0.02	0.02
Df	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Di	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.00	0.02	0.01	0.02
Wat	13.49	66.00	7.73	8.62	15.12	5.79	5.40	3.08	1.50	1.07	10.19

Table 8: Classification of the (LRTI) (Lithological strength and Weight of morphometric indices for relative tectonic activity index) in the DRB and their sub-basins

Basin	**SR**	**ZM**	**AB**	**QT**	**WI**	**TA**	**DI**	**NA**	**Ku**	**Hm**	**DR**
lat. Class	1.00	1.00	2.00	2.00	2.00	2.00	2.00	2.00	3.00	3.00	2.00
Lith. class	2.00	1.00	2.00	2.00	2.00	2.00	1.00	3.00	4.00	4.00	2.00
W. class	1.00	1.00	3.00	3.00	1.00	4.00	4.00	5.00	5.00	5.00	2.00
RTI	1.33	1.00	2.33	2.33	1.67	2.67	2.33	3.33	4.00	4.00	2.00
(LRTI).class	1.00	1.00	2.00	2.00	2.00	3.00	2.00	3.00	4.00	4.00	2.00

Table 9: The comparison between the geomorphic indices classification in this study and other studies

	Present study	**El Hamdouni et al., 2008.**	**Silva et al., 2003**	**Cooke et al., 1985.**	**Bull and McFadden, 1977.**
Class 1	S < 1.1 Vf < 0.5 SL High anomalous values |Af-50| > 15 Bs >4 Other indices shows in table 2	Smf < 1.1 Vf < 0.5 SL High anomalous values |Af-50| > 15 Bs >4	Smf < 1.53 Vf < 0.60	Uplift rate: N 0.4–0.5 m/ka Smf < 1.4 Vf < 1	Smf 1.2–1.6 Vf 0.055–0.5 –Unentrenched alluvial fans –Elongated drainage basins with narrow valley
Class 2	S 1.1-1.5 Vf 0.5-1 SL Low anomalous values |FA-50| 7–15 Bs 4–3 Other indices shows in table 2	Smf 1.1-1.5 Vf 0.5-1 SL Low anomalous values |FA-50| 7–15 Bs 4–3	Smf 1.8–2.3 Vf 0.3–0.8	Uplift rate 0.5–0.05 m/ka	floors and steep hillslopes even in soft materials Smf 1.8–3.4 Vf 0.5–3.6
Class 3	S > 1.5 Vf > 1 SL no anomalous values |Af-50| < 7 Bs >4 Other indices shows in table 2	Smf > 1.5 Vf > 1 SL no anomalous values |Af-50| < 7 Bs >4	Smf 2.8–3.5 Vf 0.8–1.2	Uplift rate < 0.05 m/ka Smf > 1.4 Vf > 1	–Entrenched alluvial fans –Large drainage basin that are more circular than class 1 Smf 2–7 Vf 2–47

DISCUSSION

Many studies have used a set of indices to provide semi-quantitative information of the relative mark of tectonic activity for the mountain fronts. Two studies used these indices to provide a support to different classes of tectonic activity (Bull and McFadden, 1977, El Hamdouni et al., 2007).

Bull and McFadden, 1977 and Silva et al., 2003 used a combination of Smf and Vf values to provide a construction of diagrams to attribution for different categories of tectonic activity, such as frequency distribution diagrams and diagrams illustrate these values distribution along the mountain front and streams. The Vf and Smf values are plotted on a same diagram to produce a relative mark of tectonic activity and discrimination of three different classes. These authors defined the "active fronts" with low values of Vf (< 0.5) and Smf (< 1.6) indices, characterized by the existence of steep, untrenched fans receiving Holocene sediments at the apex, caused by uplift rates ranging from 1 to 5 m/ka. Rockwell et al. (1984) suggested that the lower uplift rates of 0.4–0.5 m/ka were enough to keep Vf values down to 1 and Smf values down to 1.4, therefore to generate active fronts (Class 1). These studies are assessment of tectonic activity based on along Smf only.

El Hamdouni et al., (2007) used the geomorphic indices data to assess the landscape in terms of potential tectonic activity. They provided a method to assess an index of an area that is a relative tectonic activity (RTI) , which it divided indices (Sl, Smf, At, Bs, Hi) values into three classes: the first is class 1 characterized by high activity, the second class 2 moderate activity and class 3 low activity. Lat is derived by different classes' average of morphometric indices, and separated into four classes which are very high, high, moderately and low tectonic activity.

These studies are focused on tectonic activity assessment based on along Smf, and Vf only, and El Hamdouni et al., (2008) focused on Smf and some aerial morphometric indices (At, and Bs), relief (Hi), and linear (Sl). El Hamdouni et al., 2008 classified the Iat into 4 classes and they are: class 4 (>2.5) is low of Iat class, class 3 (2.5 > class3 > 2) moderate of Iat class, class 2 (2 > class3 > 1.5) high of Iat class, and class 1 (1.5 > class3 > 1) very high class of Iat. Theses classification are not equal limited boundaries between them and not involved of very low class.

The obvious question is how useful the (LRTI) and other indices can do to assess relative tectonic activity compared to field evidence related to tectonic activity? The vertical rates of tectonic activity in eastern Iraq are all unknown due to the lack of a chronology of the Quaternary sediments. There is abundant evidence about the vertical displacement amounts, but the lack of absolute dates has made it difficult to interpret tectonic activity. What is known is that rates along the border of the Zagros suture vary from about 20 to 24 mm/y (Vernant et al. 2004). However, these rates are predominating based on displacement over several million years. The neotectonic of the DRB is divided into parts: they are, down-warped areas are located in the southwestern part, and the up-warped areas are located the northeastern part of DRB, the rates of Down-warping and up-warping are -1.06 and 0.8 cm/100y, respectively (sissakian and dekran, 1998). Arabian and Eurasian plates that has produced linear northwestern–southeastern anticlinal forms, as well as extension with variable vertical rates of main collision zone (Zagros Suture Zone) to about -0.9 mm/y and horizontal moves towards northeastern anticlockwise direction about 24-29 mm/y (Sella et al.,2002).

This study presents the data on geomorphic indices, which are used in other studies to assess the landforms in relationships with relative tectonic activity. Now this study provides a method to develop of (RTI) index using lithological index level and weight of (Mi). The lithological index level is divided the various lithology into three classes are class 1 being low activity and class three being high activity (Table 5).

In this study focuses on, aerial, linear, relief, and network drainage morphometric indices with their weight, and lithological strength to develop of relative tectonic activity (RTI) , which are used in other studies to assess the landforms in relationships to relative tectonic activity.

Generally, the indices along a river sinuosity or area were discussed and a decision made regarding relative tectonic activity (Keller and Pinter, 2002). Now this study provides a method to develop of (RTI) to (LRTI) using lithological index level and weight of (Mi). The lithological index level and weight of (MI) are divided into 5 classes, from class 1 being V. High activity to class 5 being V. Low activity (Table 3).

The boundaries of the various classes change for what index is being evaluated; and for our purpose here, we chose the boundaries that generally agree with changes in the range of the values of the various indices. Admittedly, the boundaries chosen for the various indices could be improved were rates of uplift or other indications of tectonic activity known.

Unfortunately, very few studies to determine the relative tectonic activity of the landscape (mountain blocks, basins, and mountain fronts) have been attempted. Therefore, in order to develop an aerial index, we have made arbitrary, best estimate decisions. (LRTI) is obtained by the average of the different classes of geomorphic indices, lithological strength and weighted of geomorphic indices, which are divided into five classes, where class 1 is very high tectonic activity; class 2 is high tectonic activity; class 3 moderately tectonic activity; class 4 low tectonic activity; and class 5 very low tectonic activity. The (LRTI) are summarized in Table 8 for 10 drainage sub-basins in DRB and 1 main basin of DR (table 8 and figure. 5).

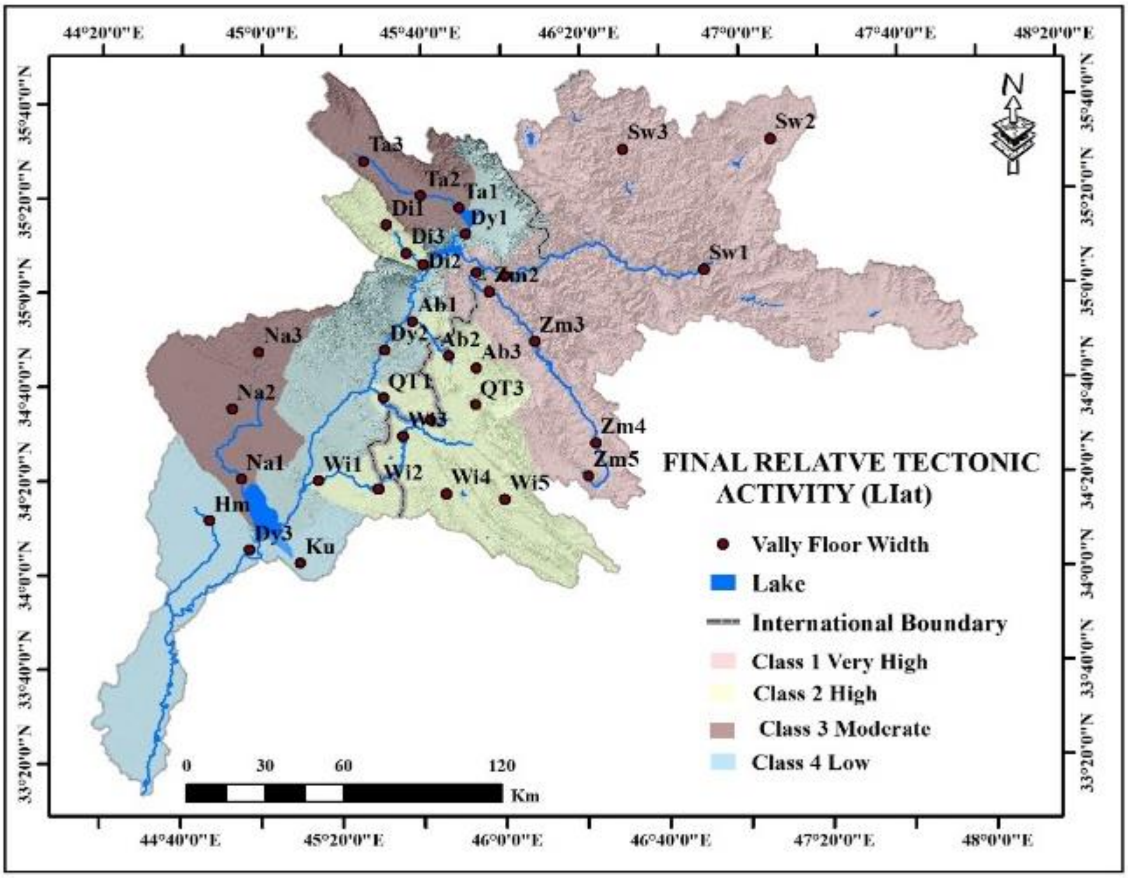

Figure 5: Distribution of the (LRTI) index of relative tectonic activity in the DRB.

Class 1 (very high tectonic activity) for (LRTI) mainly occurs in the northeast of DRB (Sr and ZM subbasins), class 2 (high tectonic activity) for (LRTI) mainly occurs in the middle part of lift side of DR (AB, QT, and WI subbasins and Diewana subbasins is located NE right side of DR), class 3 (moderate tectonic activity) for (LRTI) mainly occurs in the right side of DR

(TA,and NA subbasins), and class 4 (low tectonic activity) for (LRTI) mainly occurs in the SE part of lift and right side of DR (KU, and HM subbasins). While, class 2 (high tectonic activity) represent the rest of the DRB.

CONCLUSION

Metamorphic indices (MI) are suitable tools to analyze the effect of relative tectonic activity. These indices (Mat) have the characteristic of being calculated from remote sensing and GIS packages cover large areas as an exploration tool to identify (MI) anomalies probably related to tectonic activity. This is predominantly valuable in DRB where relatively little work is available on tectonic activity based on absolute dates. Based upon values of the Bs, Bf, Be, Bt, Bc, Rp, Ri, Rr, Rg, Hi, Lb, S, Sl, and Di that are collected with (Lith.) to developed an overall index (LRTI) which is a combination of the other indices that divides the landscape into five classes of relative tectonic activity.

The KU and HM sub-basins are represented by very low tectonic activity class 5 of (LRTI), which is located in the SE of DRB. While the NA sub-basin is represented by low tectonic activity class 4 of (LRTI), which is located in the middle SE of DRB. The AB, QT, DI and TA sub-basins are represented by moderate tectonic activity class 3 of (LRTI) (AB and QT sub-basins are located in the left side of DR and NE of the DRB, and by TA DI sub-basins are located in the right side of DR and NW of DRB). The SR and WI sub-basins are represented by high tectonic activity class 2 of (LRTI), which is located in the left side of the DR, the SR sub-basin is located in NNE of DRB and WI sub-basin located in the middle part of the DB. The ZM sub-basin is represented by very high tectonic activity class 1 of (LRTI), which is located in NEE of the DRB and left side of DR.

A comparison of field observations of tectonic activity along the western and eastern sides of the DR clearly correspond with the values and classes of relative tectonic activity indices and the whole (Mi). That is, areas with moderate to high and very high relative tectonic activity index correspond with areas where prominent fault scarps, triangular facets, hanging valleys, deformed alluvial fan deposits, and deep Narrow River gorges incised near mountain fronts exist. The high class 2 of (LRTI) of (MI) is mainly in the whole DRB.

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