Bulletin of Pure and Applied Sciences.
Vol.39F, Geology (Geological Science), No.1
January-June 2020: P.15-31

Print version ISSN 0970 4639
Online version ISSN 2320 3234
DOI: 10.5958/2320-3234.2020.00002.5

Original Article

Available online at ww.bpasjournals.com

Geomorphic Processes and Active Tectonics Evaluation in Diyala River Basin (Iraq-Iran) Using the Hypsometric Curve Moment Statistical Analysis Method and Its Density Function

[1]Talal Hasan Kadhim*, [2]Manal Al-kubaisi

Author's Affiliations:
[1]PhD. Student, Geology Department, College of Science, University of Baghdad Baghdad Iraq and Information Department, Iraqi Geological Survey, Baghdad, Iraq.
E-mail: talalkazem@yahoo.com
[2]Professor, Geology Department, College of Science, University of Baghdad, Baghdad Iraq
E-mail: manalalkubaisi@yahoo.com

***Corresponding Author: Talal Hasan Kadhim,** PhD. Student, Geology Department, College of Science, University of Baghdad Baghdad Iraq and Information Department, Iraqi Geological Survey, Baghdad, Iraq.
E-mail: talalkazem@yahoo.com

(Received on 14.11.2019, Accepted on 17.02.2020)

ABSTRACT

The main work of this study is to provide geomorphic indices and active tectonics in the Diyala River Basin of Iraq and Iran. The hypsometric curve (HC) analysis method and its statistical moments were adopted to use for the assessment. These methods have been widely used for the assessment of geomorphic processes and active tectonics in many areas in the world showing promising results. A total of 26 watersheds of the Diyala River is analyzed. The result shows that 3 curve-types such as "straight- shape", "S- shape", and concave were found; with the concave curve being the dominant and widely distributed in the west side and in the east of the southwestern side of the study area. The hypsometric integral (HI) values are rather small with the largest value is 0.53 and the smallest one is 0.16. Moment's statistical analysis of the hypsometric curve, skewness, kurtosis, skewness, and density kurtosis functions are showed in great values, which increased in the south direction of the Diyala river Basin. Based on that, the recent active tectonics (uplift) in the study area is generally moderately; however, they are also not completely homogeneous and can be distinguished by different levels. The northeastern side is being lifted higher than the southwestern side. The northern part is being lifted larger than the southern part. In the region, the uplift activities were increased gradually in the Pliocene- Quaternary and could have been continued at present time. The current geomorphic processes are mainly headward erosion in the upstream.

KEYWORDS: *Hypsometric curve, and Hypsometric Integral, Statistical moments analysis; skewness, kurtosis, density skewness, and density Kurtosis. Active tectonics.*

INTRODUCTION

The Diyala River extends over a length 420 Km along the Sirwan fault zone from Debendikhan Lake to its intersection with Tigris River in Baghdad. The Sirwan fault extends into central and SW Iraq). The Mesopotamian and Central Iraq transversal block are NW and SE side along the Diyala River (Sirwan fault zone). The Diyala River Basin across three Najad fault system from SW to NE are Tikrit-Amara, Makhul-Himrin, and Kirkuk fault zones in iraq (Jassim and Goff, 2006). The Diyala River Basin is divided into four tectonic zones: Mesopotamian foredeep Basin, Zagros Fold Belt, Zagros thrust zone, and Central Iran Basins (Buday and Jassim, 1987; Gorbani, 2013) figure (1).

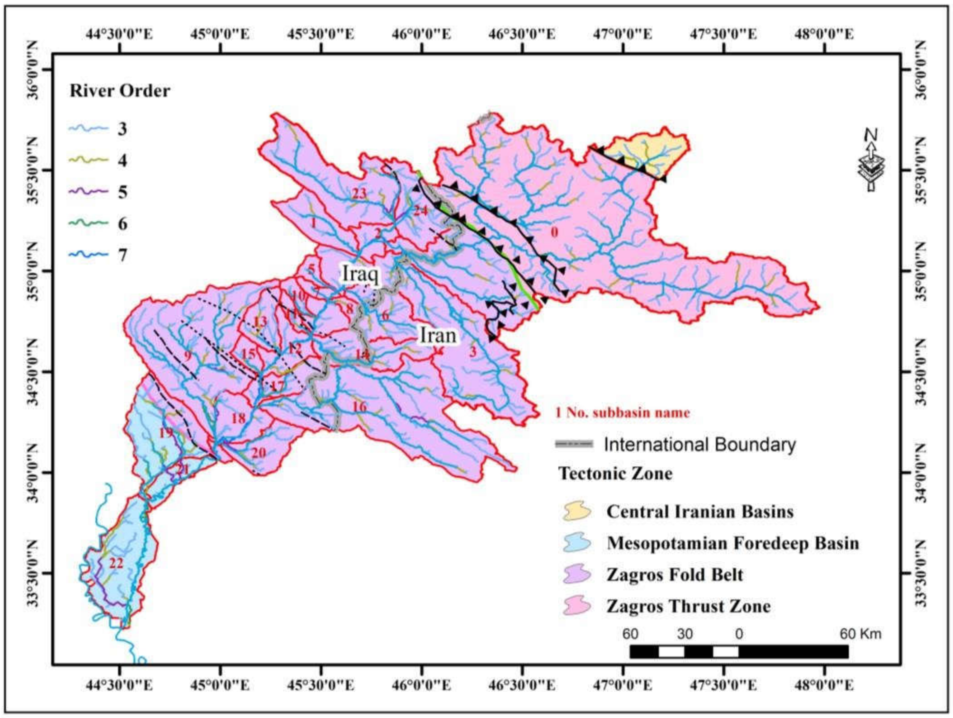

Figure 1: The Diyala River Subbasins.
Source: data derived from DSM (JAXA version 1.1, 2017), authors' processing.

This area has received attention of many geoscientists and seen as key to understand the geodynamic of Arabian –Iranian plates. The achieved results have contributed to the explanation and clarification of many issues in geology, tectonics and geomorphology. However, some points are not consistent and disputable (Leloup et al., 2001). Studies of tectonics in this area have not paid much attention to the role and significance of geomorphology; especially, the lack of quantitative analyses of landscapes using various geomorphic indices.

In Iraq, despite some initial Geomorphic indices also to be used quite successfully in several studies such as (Al-Jebouri,1991; Ibrahim,2009; Obaid, 2018) but they were did not calculated the HC, HI, and statistical moments of the hypsometric curve in their studies. However, most of the calculations in these studies were manually carried out based on topographic maps and satellite images; so the results often depend on the ability to estimate, sight and experience of experts who conducted these studies. Therefore, the analysis and assessment of geomorphic indices have not show their clearly roles, the significances, and its relationship to the geomorphological processes and active tectonics.

The aims in this paper, we present quantitative Analyses and assessments of the hypsometric curve (HC) and its statistical moments in relationship between geomorphic processes and active tectonics in the Diyala River Basin. The HC index is one of the geomorphic indices that has been considered as a powerful tool for quantifying the topographic features and differentiate zones deformed by active tectonics (Keller and Pinter, 2002; Pedrera et al., 2009; Mahmood and Gloaguen, 2012). However, in Iraq, this is the first time to adopt this method for the assessment of the active tectonics in the Diyala River fault zone and the zagros fold-and-thrust zones.

MATERIALS AND METHODS

Materials

Climate, Tectonic, Geologic, and Geomorphic Settings

The climate data of Diyala river basin are collected from five stations from FAO geodatabase is Sulaimaniya, Sanadaj, Kanaqin, Kermanshah, and Baghdad stations. Sulaimaniya, Kanaqin, and Baghdad stations are located in Iraq, Sanadaj, and Kermanshah stations are located in Iran. The air temperature, precipitation, relative humidity, and potential evaporation parameters are used to climate classification of the study area based on modified Köppen climate classification system (Arnfield, 2018), by New LocClim V. 1.10 software. The climate elements are gathered from five stations, table (1), and figure (2). The Diyala river basin is located within the northern temperate zone with high semistatic air pressure and has acquired from this site a semi-continental climate affected by the Mediterranean climate.

The climate of The Diyala river basin is characterized by a very hot summer and a short cold winter. The Diyala river basin climate is divided into three types The Temperate (Mediterranean Sea) climate Csa in Sanandaj station: It prevails in the mountainous region in the northeast and is characterized by cold sowing and snow falls over the peaks of the mountains and moderate summer temperatures do not exceed 35 degrees Celsius in most parts.

The steppe climate, Bsk in Sulaymaniyah, and Kermanshah with Bsh in Khanaqin, stations. A transitional climate between the mountainous region and the warm desert climate in the south. It is mostly within the confines of the wavy region. Its annual rainfall ranges between 400-800 mm. The hot desert climate Bwh in Baghdad station: The annual rainfall ranges between 32-200 mm, and characterized by the large temperature between night and day, summer and winter and in winter prevail the warm atmosphere and the temperature remains above freezing and does not fall below. The Diyala River Basin is less than 5-120 km wide and more than 550 km long, extending from Baghdad to Derbendikhan Lake, and appearing as an elongated NW-trending core of clastic rocks (Sissskian, 2014). The altitude of the mountain is peaked at Khuh-Shahu of 3367 m, then descending to the northwest and southeast. The Diyala River basin is characterized by three main strips, with the NW-SE direction and separated by the perpendicular lines with the Diyala River. Which it derived from digital surface model (DSM), and topographic maps, figure (2): The High mountains area covers north and northeast parts and small parts of the northwest part, such as the mountain between Diewana and Tanjero subbasins, and central part of Diewana subbasin, the elevation of these mountains are about (1000-3367 m.a.s.l.). The high mountains characterized by anticline folds mountain series, where syncline folds are located between them (Al-Jebouri, 1991), most parts of these mountains are located in Iran.

The wavy area covers the central parts of the study area, and central part of Diewana and Tanjero subbasin, and the elevation of these areas about (200-1000 m. a. s. l.). The wavy area are tills anticline folds, which are located between syncline folds (Al-Jebouri, 1991), most parts of these tills are located in Iraq.

Table 1: The Climate Data of Diyala River Basin.

Station Name		Baghdad				Station Name		Khanaqin			
	Longitude	44.23					Longitude	45.43			
Coordinat	Latitude	33.23				Coordinat	Latitude	34.3			
Altitude	34 m.					Altitude		212			
months	T_Mean	T_Max	T_Min	preci.	pet. Eva.	months	T_Mean	T_Max	T_Min	precipition	pet. Eva.
Jan.	10.3	16.2	4.8	26	59.1	Jan.	10	15.6	4.5	56	44.7
Feb.	12.8	19.7	7.3	13	70.2	Feb.	11.8	17.6	5.6	47	62.9
Mar.	18.1	24.7	11.3	13	129.2	Mar.	15.8	21.2	8.3	80	97.2
Apr.	23	29.7	16	13	169.6	Apr.	21.8	27.6	13.6	40	139.6
May	28.8	36.5	21.5	5	223.8	May	28.2	34.9	18.7	19	197.6
Jun.	34.4	41.7	25.8	0	299.4	Jun.	34	40.7	22.3	0	241.9
Jul.	36.5	44	28.2	0	326.2	Jul.	36.2	43.7	25.2	0	252.2
Aug.	35.7	43.7	26.7	0	297.4	Aug.	35.9	43.2	24.8	0	240.7
Sep.	32.5	40.5	23.7	0	229.5	Sep.	31.7	39.2	20.6	0	182
Oct.	25.7	33.2	18.2	5	165.3	Oct.	25.5	32.9	15.8	3	139.1
Nov.	17.8	24.8	11.6	11	94.3	Nov.	17.5	24.6	10.3	23	77.7
Dec.	11.6	18.2	6	10	64	Dec.	11.6	17.5	5.8	49	44.3
Average	23.93	31.08	16.76	8	177.33	Average	23.3	29.9	14.6	26.4	143.3
Station Name		Sulimaniya				Station Name		Sanadaj			
	Longitude	45.45					Longitude	47			
Coordinat	Latitude	35.55				Coordinat	Latitude	35.33			
Altitude	853 m.					Altitude	1373 m.				
months	T_Mean	T_Max	T_Min	precipition	pet. Eva.	months	T_Mean	T_Max	T_Min	precipition	pet. Eva.
Jan.	3.2	7.5	-0.4	116	31.1	Jan.	0.1	5.3	-5	75	25.3
Feb.	5.3	10.1	1.2	150	38.8	Feb.	2	7.6	-3.5	58	34
Mar.	10.1	15.3	5.4	127	68.2	Mar.	7.4	13.5	1.3	71	66.7
Apr.	15.3	20.5	10.3	111	87.4	Apr.	11.1	17.3	4.9	99	87
May	21.2	28	14.8	53	137.8	May	17	24.5	9.6	41	138.2
Jun.	28.6	34.7	21	0	198.4	Jun.	22.7	31.6	13.8	1	192
Jul.	32	38.4	24.2	0	239.9	Jul.	27.2	35.7	18.7	1	217.3
Aug.	31.8	38.5	24.6	0	214.8	Aug.	26.2	34.7	17.6	1	206.6
Sep.	27.5	34.4	20.3	0	160.5	Sep.	21.6	30.8	12.3	0	163.7
Oct.	21.1	27.8	14.8	13	121	Oct.	15.1	23.5	7	24	109.2
Nov.	12.8	18.3	8.1	68	62.8	Nov.	8.3	15.1	1.7	52	54.1
Dec.	6	10.8	2.5	100	36.1	Dec.	3	8.6	-2.5	47	31.1
Average	17.9	23.7	12.2	61.5	116.4	Average	13.5	20.7	6.3	39.1	110.5
Station Name		Krmanshah									
Coordinat	Longitude	47.11									
	Latitude	34.26									
Altitude	1322 m.										
months	T_Mean	T_Max	T_Min	precipition	pet. Eva.						
Jan.	0.6	6.5	-4.4	67	26.9						
Feb.	2.5	8.8	-3	62.9	35.4						
Mar.	7.6	14.3	1.2	88.9	71.8						
Apr.	12.6	19.7	5	69.9	101.6						
May	17.6	25.7	8.1	33.7	147.1						
Jun.	23.6	33.2	11.3	0.5	200.3						
Jul.	28.2	37.7	16.1	0.3	231						
Aug.	27.2	37	15.3	0.3	219.8						
Sep.	22.3	32.5	10.6	1.2	169.1						
Oct.	16	25	6.4	29.2	113.7						
Nov.	8.8	16.7	1.7	54.2	54.2						
Dec.	3.5	9.6	-1.8	70.3	33.5						
Average	14.2	22.2	5.6	39.8	117						

Source: data derived from DSM (JAXA version 1.1, 2017), authors' processing.

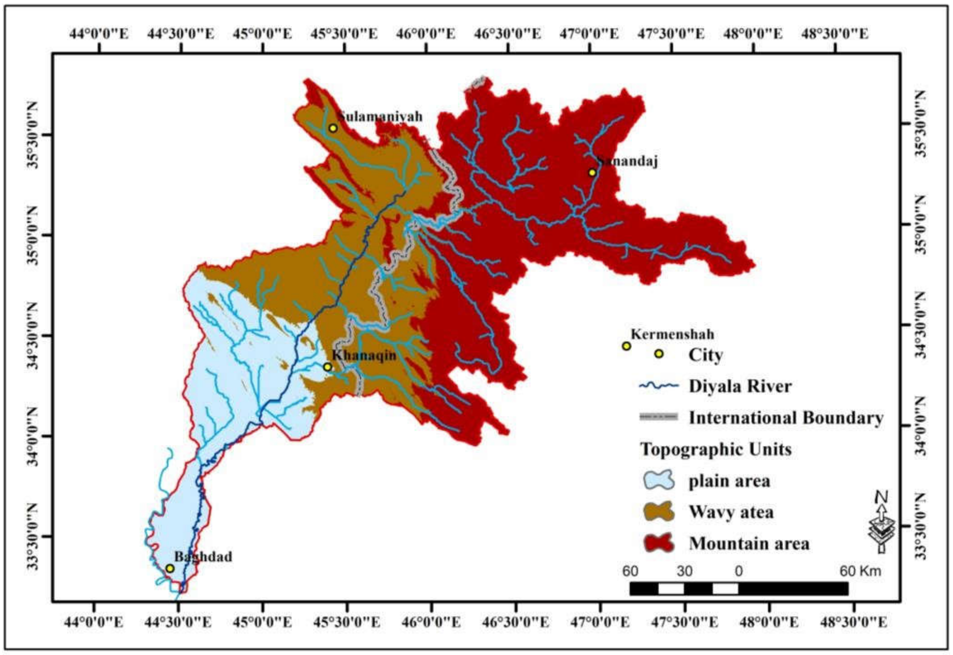

Figure 2: Topographic map of Diyala River Basin. derived from DSM.
Source: data derived from DSM (JAXA version 1.1, 2017), authors' processing.

The plain area covers the southern parts of the study area, and the elevation of these areas about (200-21 m.a.s.l.). The plain area is a flat area. Therefore, the riverbed is wide and shallow, this area represented by Mesopotamian plain. The plain area is located in Iraq.

Tectonically, the diyala river basin is a part of outer Platform at Arabian plate and Central Iran zone at Eurasian (Iranian) plate (Fouad, 2012). The Diyala River Basin is located in four tectonic zones and they are: Sanandaj-Sirjan, Zagros suture (Zagros thrust belt), unstable (Zagros fold belts), and stable zones (Alavi 1994; Jassim and Goff, 2006).

The Sanandaj-Sirjan zone is located in northeast part of the study area, which is enormous presence for magamatic and metamorphic rocks of Paleozoic and Mesozoic eras (Gorbani, 2013). Depended on tectonostratigraphy features, (Aghanabati, 2004) thinks that of Sanandaj-Sirjan is a part of the central Iran zone, and some authors deem the Sanandaj–Sirjan Zone similar to Zagros; although, the differences exist in orogenic events and rock types, magmatism, metamorphism. The Zagros suture zone represented by extreme folded and overthrusted faults in north and northeast of the study area, this zone is divided into two tectonic zones in the study area is Qulqulq-Khwakurk, and PenjweenWalash zones in Iraq, which is equivalent to Zagros thrust zone in Iran. The Zagros fold-thrust belt zone occupies the largest part of the study area which is divided into three tectonic zones: are imbricated, High folded and low folded zones in (Jassim and Goff, 2006; Fouad, 2012), which is equivalent to Zagros fold belt basin in Iran. The later zone is stable represented by Mesopotamian zone, this zone includes Tigris subzone only in the study area.

Diyala River Basin is built up by geological formations ranging in age from Triassic up to Recent, figure (3).

The studied area consists of mountainous, hilly and flat terrains, with many ridges as most prominent morphological features. Besides, presence of some hillocks which form dense network of small valleys. Main ridges provide long wide watersheds to the internal plains and also of second order watersheds, Figure (2). The main Stratigraphic sequence in the Diyala River Basin consists of

Avroman limesone, Sarki, Sehkanyian, Sargelu, Naokeledan Avanah, Pilaspi, Qulqula Series, Shiranish, Balambo, Tanjero Oligocene group, Euphrates-Jerebi, Fatha, Injana, Mukdadiyah, Bai Hassan, Bamu Conglomerate Formations and Quaternary deposits as shown in figure (3).

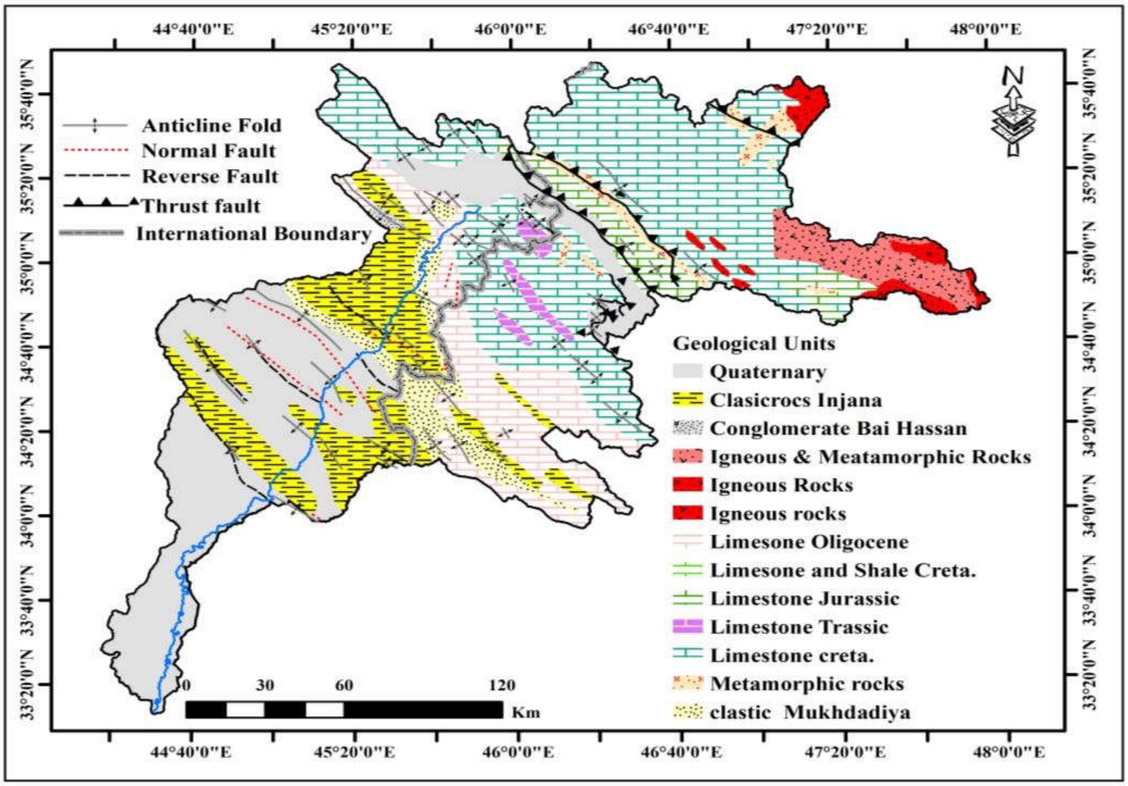

Figure 3: Geological Map of Diyala River Basin.
Source: geological map of Iraq (Sissakian, 2014), and geological map of Iran (Gorbani, 2013), authors' processing.

Structurally, the area is a part of three zones, the Zagros suture zone, the high Folded Zone (north eastern part), and the majority of the area belongs to foothill zone of the Outer platform at NubioArabian Platform. Tectonically, the foothill zone here is divided into Hemrin-Makhul and Chemchemal-Butmah subzones. Chia Surakh, Ali Mire, Kiria Pika, Pulkhana, Naodoman are the main structural elements, they are asymmetrical and thrusted anticlines, separated by broad and asymmetrical synclines filled by Tertiary sediments.

Satellite and map Data
To determine the hypsometric curve and its statistical moments for the study area, Digital Surface Model (DSM) is used with 30 m spatial resolution, which is provided by the Japan Aerospace Exploration Agency (JAXA), (JAXA Version 1.1, 2017). The seismic focus map has been drawn, (figure 4), from information seismic (USGS website https://earthquake.usgs.gov/ earthquakes/map/).

The DSM is analyzed by ArcGIS software; it is useful tools to ensure accuracy, quick and less expensive in the calculation of morphology parameters. The calculation in this study is carried out automatically using the extension tools of TecDEM, 2014 software (Shahzad, 2009) for subbasins (No. subbasins Sb1, sb2). Geological map of the study area was constructed using the geological maps at the scale of 1:1,000,000, Geological survey of Iraq (Sissakian, 2014), and the geological maps at the scale of 1:1,000,000, Geological Survey Iran (Gorbani, 2013).

Methods

The DSM used to prepared HC and H_i maps the Hc map (figure 5) was drawn by DSM divided into 10 bins then accumulative distribution function (C.D.F) for these bins, and H_i map (figure 4) was drawn by DSM convert to three raster datasets are minimum, maximum, and mean using by focal analysis toolbox and function (1). Active faults are taken from the (Jassim and Goff, 2006).

The first used of the hypsometric analysis in fluvial geomorphology is by Langbein et al., 1947 anticipated hypsometric of area altitude analysis to distinct the overall slope of drainage watersheds. The hypsometric curve shows the distribution of elevations across an area of land with different scales from one drainage watersheds to the entire region. The curve is created by plotting the proportion of total basin height (h/H = relative height) against the proportion of total basin area (a/A = relative area) (Strahler, 1952; Keller and Pinter, 2002) (Figure 6). The form of the hypsometric curve is related with the stage of geomorphic development of the watershed. The three forms of hypsometric curve are convex hypsometric curve which relates to typical of a youth stage, S-shaped curve relates to a maturity stage, and concave curve indicatives to oldest stage or a peneplain stage (Strahler, 1957; 1990; Delcaillau et al., 1998; Keller and Pinter, 2002; Pérez-Peña et al., 2009) (Figure 6).

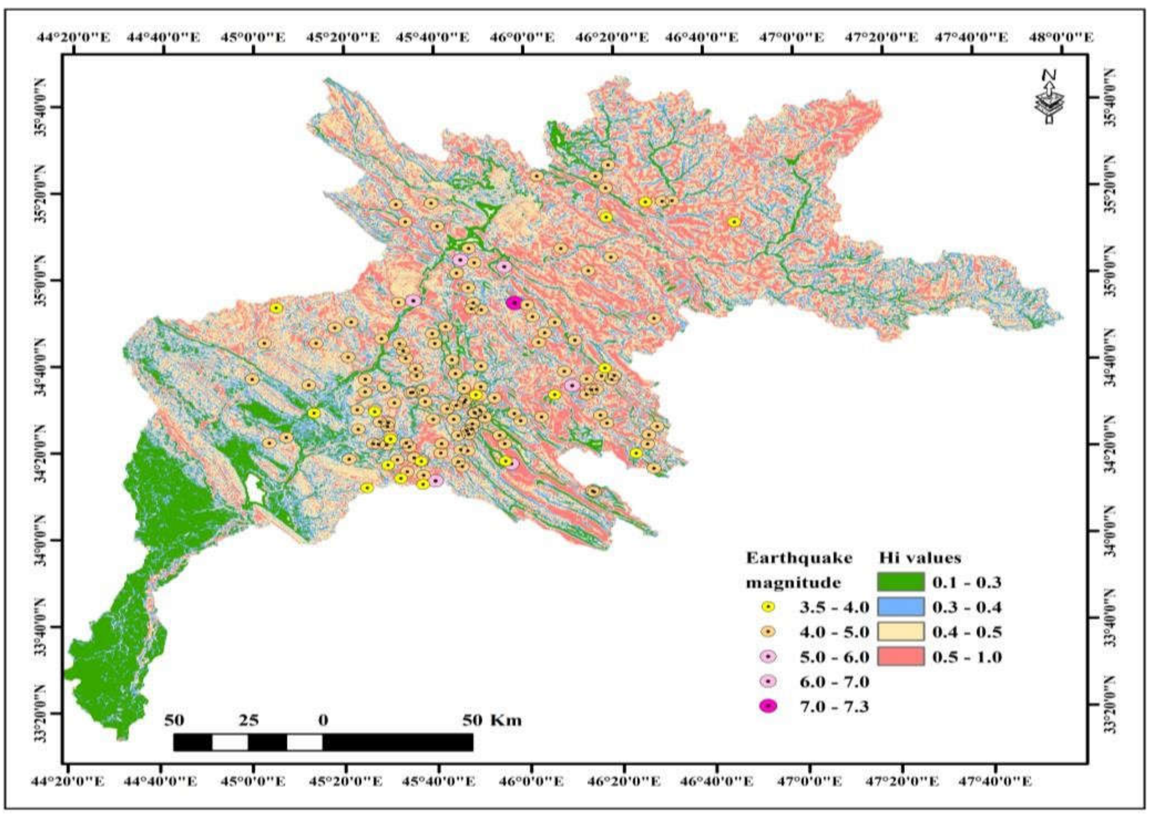

Figure 4: The seismic focus and H_i map of the Diyala River Basin. Source: data derived from DSM (JAXA version 1.1, 2017), and (USGS website https://earthquake.usgs.gov/ earthquakes/map/) authors' processing.

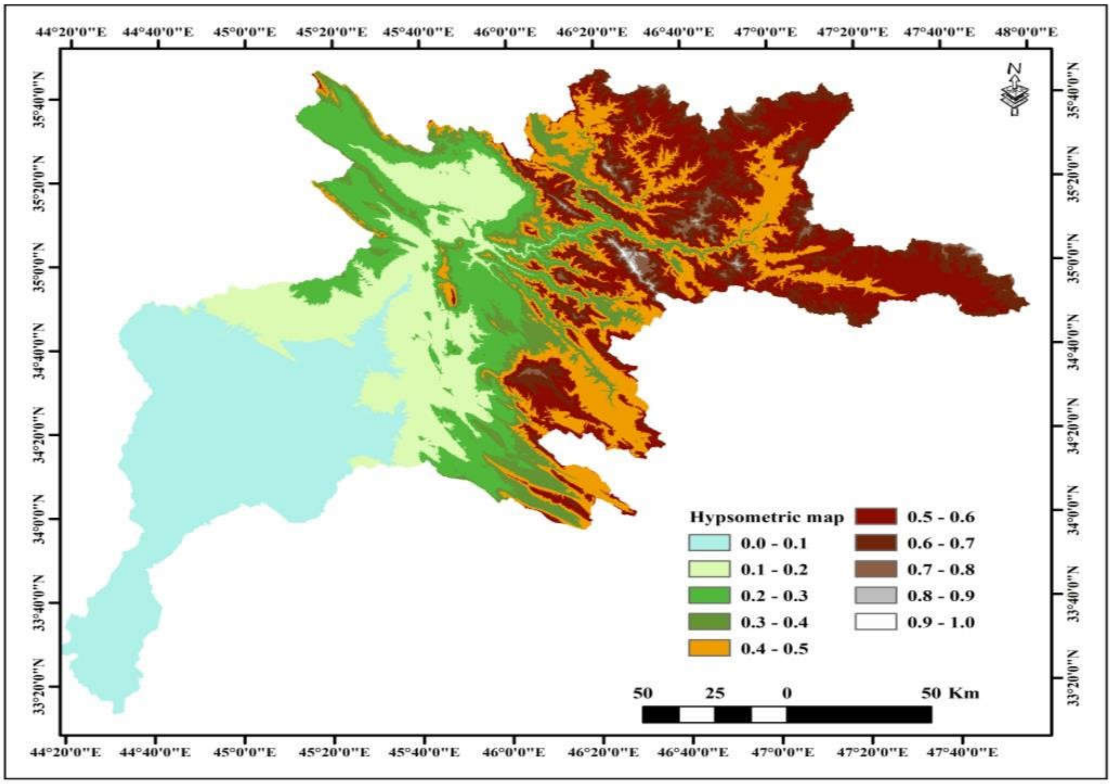

Figure 5: The HC map of the Diyala River Basin.
Source: data derived from DSM (JAXA version 1.1, 2017), authors' processing.

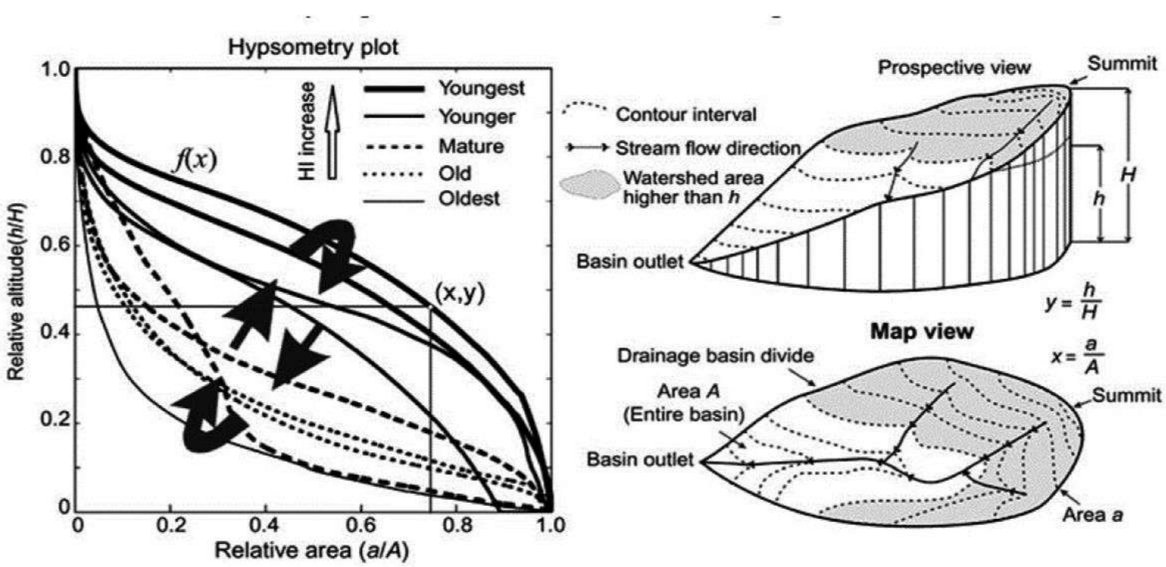

Figure 6: Basic hypsometric curves and its geomorphological development cycles
Source: after Strahler, 1952; Keller and Pinter. 2002)

The hypsometric integral (H_i) is a simple way to characterize the shape of the hypsometric curve for a given drainage watershed is to calculate its. The definition of hypsometric integral is as the region under the hypsometric curve and can be calculated (Keller and Pinter, 2002):

***Hi = (Hmean - Hmin) / (Hmax - Hmin)**……….(1)*

H_{max}: maximum elevation, H_{min}: minimum elevation and H_{mean}: mean elevation.

The parameters in the formula (1) can be calculated by analyzing the DSM with the GIS, SagaGIS and TecDEM softwares. The H_i index has been used, as well as the hypsometric curve, to infer the stage of development of a watershed. The values of the Hi always vary from 0.0 to 1.0 Values near 1.0 indicate a state of youth and are typical of convex curve. However, in the mature stage of the basin, it has a lot of S-shape and concave shape but the H_i values often similar. Meanwhile, to distinguish or assessment correlate between the watersheds, we often base on the statistical indices are given below. Beside to importance of hypsometric integral (H_i) analyses, we are also determine and analyze other parameters of hypsometric curve (HC): the hypsometric curve skewness (SK), the hypsometric curve kurtosis (K), the hypsometric curve density skewness (DS), and the hypsometric curve density kurtosis (DK). These parameters are developed a technique that dealt the hypsometric curve as a cumulative probability distribution and used its statistic moments to describe it quantitatively, which it consists of the hypsometric curve by a continuous polynomial function with the form by (Harlin, 1978) (Figure 7).

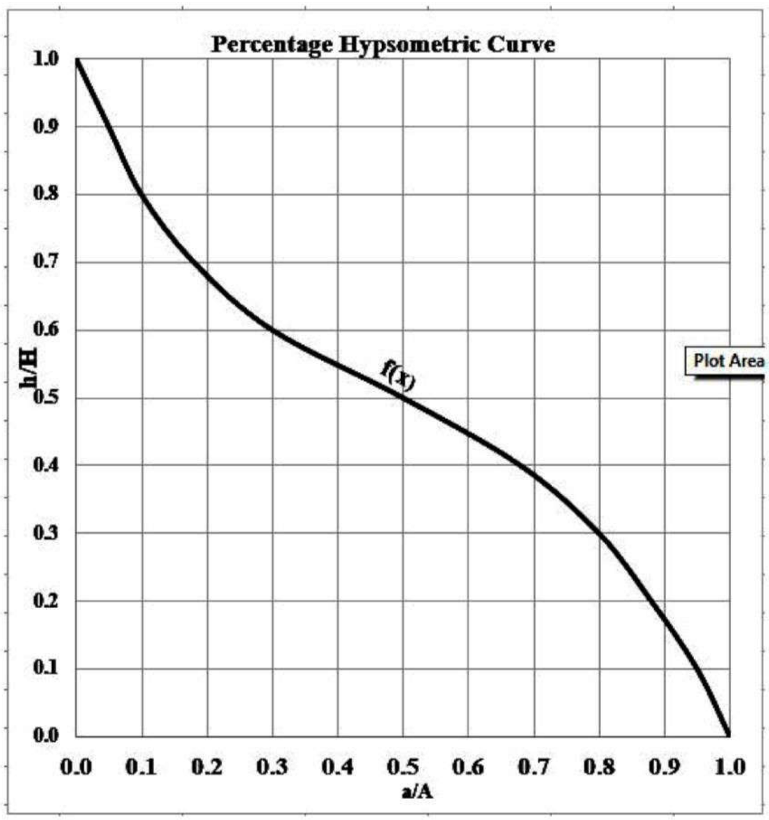

Figure 7: **Hypsometric curve Function.**
Source: modified from Strahler, 1957, and Harlin, 1978).

***f(x) = a0 + a1x+ a2x2+... + anxn**.........(2)*

A = $\iint_R$ ***dxdy**…………………………. .(3)*

A: area, ***R:*** area under the hypsometric curve, ***x*:** relative area, and ***y*:** relative height.

Hypsometric curve skewness is calculated by:

$SK = \mu_3 / (\mu_2^{1/2})^3$………………..…(4)

μ_3 and μ_2 **:** third order and second order about x.

Hypsometric curve kurtosis is calculated by:

$K = \mu_4 / (\mu_2^{1/2})^4$……………………….(5)

μ_4 and μ_2 **:** fourth order and second order about x.

Density skewness (DS) and density kurtosis (DK) are calculated similarly of skewness and kurtosis, but that except y is the first derivative of the hypsometric curve (example, the density function of the hypsometric curve (replacing y with y′) (Liem, et al., 2016). The DS and DK calculations are chosen so which they are identical with Harlin's original work (Harlin, 1978).

Skewness and kurtosis statistics are describing of the distribution relative to the normal distribution and are dimensionless shape. Skewness properties the asymmetry degree of a distribution around its mean. When the SK is zero (SK=0), the diversified distribution becomes symmetric, S is a positive x (SK>0) refers an asymmetric distribution becomes skewed to the right, and S is a negative x (SK>0) refers an asymmetric distribution becomes skewed to the left. Kurtosis measures the relative peaked flat (peakedness or flatness) of a distribution, relative to a normal distribution.

These statistics are applied to the distribution function of the hypsometric curve order to explain the erosion and slope watersheds and has been checked by (Harlin., 1978; Luo, 2000; Pérez-Peña et al., 2009). Accordingly, the hypsometric skewness represents the amount of headward erosion in the upper reach of a watershed (Figure 8); DS indicates slope change; a large value of kurtosis signifies erosion on both upper and lower reaches of a watershed, and DK determines mid watershed slope. These statistical can be used to describe and characterize the shape of the hypsometric curve and, hence, to quantify changes in the morphology of the drainage watersheds. In many cases, these parameters are very useful for the hypsometric analysis, especially in watersheds with similar hypsometric integrals but different shapes (Pérez-Peña et al., 2009; Liem et al, 2016).

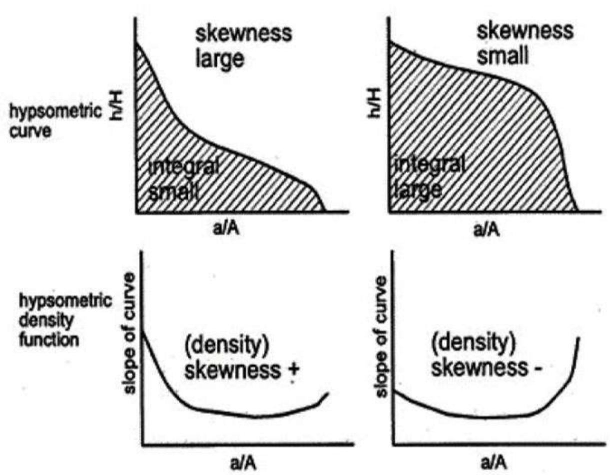

Figure 8: Schematic diagram showing the relationship between the shape of the hypsometric curve and its integral, skewness, and density skewness.
Source: from (Luo, 2000).

RESULTS

The Diyala River Basin area consists of 25 watersheds. The hypsometric curve analysis method and its statistical analysis are used to assessment for 8 watersheds which are 0, 3, 6, 8, 14, 16, 17, and 20 at eastern part of Diyala River, 11 watersheds are 1,5,7.9.10,11,13,15,19,23, and 24 at western part of Diyala River, and 3 watersheds at southern part of Diyala. The results are shown on Table 2, Figures 9A, B,,and C. The largest watersheds area is the eastern part. In addition to that, there are 6 watersheds 2, 4, 12, 18, 21, and 22. The watersheds 2, 18 represented by Derbendikhan and Hemrin lakes, respectively, and 4, 12, 21, 22 watersheds rare located within the Diyala River.

At Diyala River Basin area, the hypsometric curve is divided into four curves; convex shape, straight shape, S- shape, and concave shape Figures 9. The convex shape (3/24 Sirwan, Zamkan, and W1) subbasins, the concave shape curve has the biggest proportion (12/24 Abasan, QaraToo, Tanjero, Derbendikhan, Himreen, Kurdarah, Narin, D12, D17, D19, D21, D22 subbasins), the S-shape (6/24 watersheds), and the final is straight-shape (1/44 basins). The H_i values range between small to medium(0.16 to 0.53) are also consistent with watersheds, the biggest value of the hypsometric integral in the watersheds no.3 (Zamkan River) equal to 0.53, and the lowest of the hypsometric integral in the watershed no. 8 (HI = 0.50) with convex shape. The H_i values of watersheds with straight- shape curve are bigger than 0.41 (Al-Wind River), the H_i values of S-shape curve are bigger than 0.47 and the concave curves with biggest H_i value is 0.29, table 2.

The results shown in Table 2 show that the SK values are from -0.42 to 2.88 and these values do not change much in the basins with straight-shape of the hypsometric curve (the SK values range from 0.22 to 0.36) and the "S-shape" of the hypsometric curve (0.51 $<SK<$1.24). In contrary, the SK values have considerable variability in the basins with concave shape of hypsometric curve (the SK values range from 1.36 to 2.88). In the basins with straight-shape and s-shape of hypsometric curve, the density skew values range from 0.30 to 0.98, and the basins have concave curve, this values range from ~ 1.04 to 2.01.

Table 2: The statistical moments of the hypsometric curve in the DNCV area (HI - Hypsometric integral, SK - Skew; KUR - Kurtosis, DSK - Density skew and DKUR - Density kurtosis

Basin No.	SubBasin	MIN	MAX	MEAN	HI	SK	KUR	DSK	DKUR
all	Diyala	32	3367	1199.25	0.35	0.80	2.91	1.58	7.06
dsm0	Sirwan	486	3367	1955.31	0.51	-0.42	3.42	-0.04	4.11
dsm3	Zamkan	486	2564	1587.34	0.53	-0.09	1.32	-0.08	1.09
dsm6	Abasan	306	2560	914.58	0.27	1.36	4.62	1.15	4.24
dsm8	D8	285	949	517.40	0.35	0.71	5.29	0.74	5.72
dsm14	Qara Too	235	2567	724.72	0.21	1.95	7.01	1.64	6.52
dsm16	Al-Wind	121	2482	1089.01	0.41	0.36	-1.58	0.30	-1.58
dsm17	D17	133	651	283.22	0.29	0.60	-0.45	0.50	-0.63
dsm20	Kurdarah	100	481	187.63	0.23	1.86	7.54	1.59	7.06
dsm23	Tanjero	486	2199	811.47	0.19	1.62	3.62	1.39	3.27
dsm1	Diewana	366	1859	978.13	0.41	0.51	1.77	0.43	2.05
dsm5	D5	300	1189	744.50	0.50	-0.05	1.74	-0.04	1.48
dsm7	D7	285	1098	602.07	0.39	0.62	-0.45	0.51	-0.63
dsm10	D10	262	1109	643.15	0.45	0.22	-0.55	0.18	-0.78

dsm11	D11	237	917	488.60	0.37	0.71	1.45	0.60	1.21
dsm13	D13	193	934	430.12	0.32	0.81	1.13	0.68	0.91
dsm9	Narin	100	945	269.00	0.20	2.15	8.60	1.82	8.80
dsm15	D15	160	404	233.20	0.30	1.24	4.64	1.04	4.28
dsm2	MDerbend	366	1606	713.20	0.28	1.20	3.01	1.09	2.68
dsm4	MDer 1	299	1798	733.71	0.29	1.23	3.27	1.04	2.96
dsm12	D12	121	763	320.02	0.31	1.00	2.08	0.98	1.80
dsm18	MHimrin	100	281	136.20	0.20	2.16	9.55	1.86	9.20
dsm21	D21	47	195	72.16	0.17	2.88	9.59	2.43	9.62
dsm19	D19	47	228	86.82	0.22	2.05	7.21	1.76	6.72
dsm22	D22	32	109	44.32	0.16	2.20	7.39	2.01	6.87
dsm24	D24	486	2863	1056.48	0.24	1.80	8.24	1.55	8.80

Source: data derived from DSM (JAXA version 1.1, 2017), authors' processing.

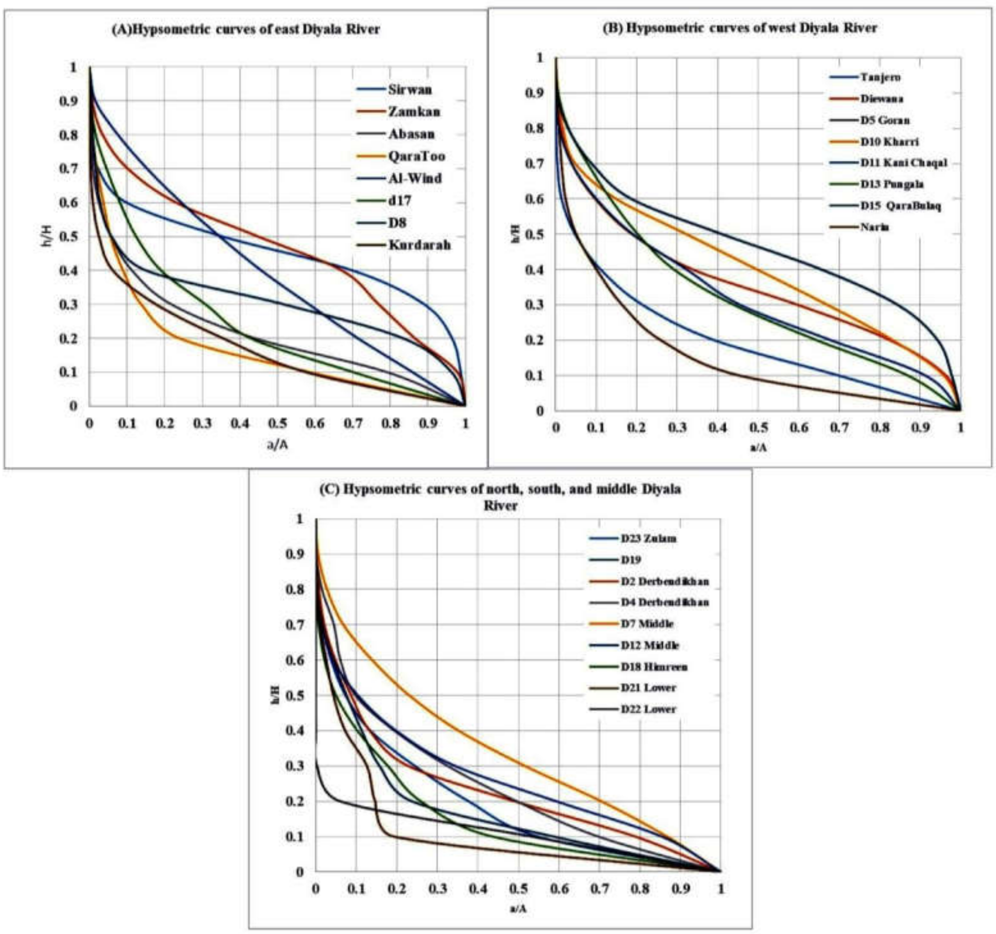

Figure 9: Hypsometric curve of Diyala River Subbasins A) eastern side, B) western side, and C) southern Northern side.

Source: data derived from DSM (JAXA version 1.1, 2017), and Table 2, authors' processing.

The kurtosis values range from ~9.59 to -1.58; while, the basins have the hypsometric curve with the "straight" and "S" shape, the kurtosis values are less than 5.29 (the kurtosis of a normal distribution is 3.0). The density kurtosis values range from -1.58 to 9.62. As the SK values, the density kurtosis values are not change much in the hypsometric curve basins with the "straight" and "S" shape, and quite change in the concave shape basins. The variation values of the main statistical analyses indices in the DRB are showed on Figure 10.

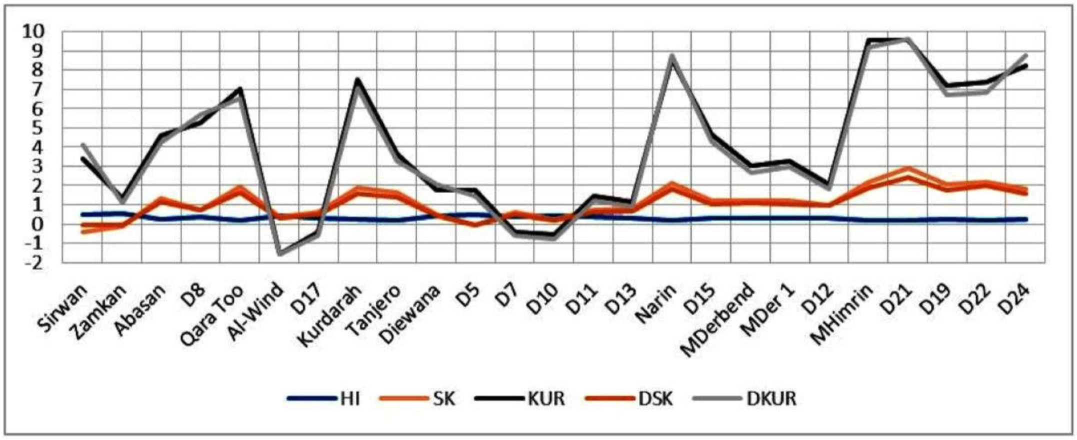

Figure 10: The variation of statistical moments of diyala river basin.
Source: data derived from DSM (JAXA version 1.1, 2017), and Table 2, authors' processing.

DISCUSSION

The hypsometric curve, integral and its statistical analyses effectiveness by active tectonics, are also influenced by geological and regional climatic characteristics (Moglen and Bras, 1995; Willgoose and Hancock, 1998; Huang and Niemann, 2006; Pedrera et al., 2009).

The tectonic map of Iraq shows that the NE trending subsurface Sirwan fault extends from Halabja to Iraq-Saudi Arabia border, and it runs along the Diyala River in north Iraq (Jassim and Goff, 2006). The Diyala river Basin is located in the collision zone between Arabian and Iranian plates. Therefore, the area in the upper part is represented by narrow structures with thrusted, while the central part represented by a broad structures with less thrusted than the upper part, with NW-SE trending except at Khanaqin fault which is dextral strike slip-fault with N-S trending (Ibrahim, 2009; Al-Hachim, 2012), and flat area in lower part. The regional climate includes three types: they are Temperate (Mediterranean Sea), steppe, and transitional. The geology of the study area shows that the sedimentary, igneous, and metamorphic rocks are identical (Figure 2). Therefore, any anomalies in geomorphic indices in the Diyala river area are mainly reflections of the recent tectonic activity.

The difference in the indices values of these basins (D2, D4, D12, D18, D19, D21, and D22) results from the construction of Derbendikhan and Himrin hydropower dams. Therefore, these basins in the calculations are not used. On the other hand, since the relief features of the Diyala River with their slopes in the eastern side is greater than the western side, therefore, area of the watersheds in the eastern side usually larger than the western part. The number of watersheds in the eastern side is less than that on the southwestern side. This may reflect the cause of the higher activity in northeastern side. This will be clarified by the hypsometric curve, hypsometric integral and its statistical analyses as in table 2.

In the study area, the hypsometric curves are of 4 types: convex, straight- shape, S- shape, and concave curves. The hypsometric curves are almost concave curves (13/24 basins). The H_i maximum values are mainly medium is 0.51 (Figure 9 and Table 2). Accordingly, the basin in this study area is mainly in the youth, mature, and oldest stages. Therefore, the watersheds (Sirwan, Zamkan, and D5) are youth stage, which are distinguished by deep incision and rugged relief, watersheds (Al-wind, Diewana, Kaarri, kani Chaqal, Pungala, QaraBulaq, and D8) are the mature, which are reached the equilibrium, and watersheds (Abasan, QaraToo,Kurdarah, Tanjero, Zulam, and D19) are oldest stages, which are distinguished by landscape near base level in the longitudinal profiles of the stream (or river) . In these watersheds, the dominant geomorphological processes usually are vertical erosion and lateral erosion. Another word, the active tectonic (uplift) in these watersheds is weak to moderate. However, the hypsometric curves are still as convex straight-shape and S-shape and distributed in different parts of the study area and concentrated mainly in the northern part to the center of the eastern side of the Diyala River. Whereas, in the lower part of the Diyala River Basin, the hypsometric curve is concave curve (Figure 9c, subbasins D19). Tectonic activity in the study area is not consistent. The uplifting activity in the eastern side basically is greater than that in the western side of the Diyala River. Some parts of the northeastern segment are uplifted greater than southern segment.

According to (El Hamdouni et al., 2008), the hypsometric curve often has convex curve when H_i index more than 0.5; intermediate form between the concave and convex shape is straight shape or S-shape when the H_i value in the range of 0.4 to 0.5, and the H_i- value smaller than 0.4, the hypsometric curve has a concave shape. In the Diyala River area, as in the Table 2, Figure 9 a, b, and c the H_i values of the hypsometric curve with convex shape are more than 0.50, straight- shape and S-shape are less than 0.45, and H_i- value of concave shape are less than 0.35. Thus, when using and analyzing the H_i index in different areas, need to be combined with its hypsometric curve. Since in many cases, the subbasins with similar hypsometric integrals and different shapes, in such cases, the statistical moments are indispensable to consider for the hypsometric analysis (Figure 10) (Pérez-Peña et al., 2009).

According to the results in Table 2, Figure 9 (a, b, c) in the Diyala River area the H_i index the values decrease from northaest to southwast direction, other statistical moments of the hypsometric curve are likely to increase in both watershed systems of the Diyala River. The skewness, kurtosis, density skewness, and density kurtosis values are in particular seem to be more unique to specific curve shapes than the hypsometric integral. There is no typical linear relationship between statistical moment and hypsometric integral values (Harlin, 1978). The skewness value results range from 0.45 to 1.3 (SK>0), this means that the subbasins in the study area with the geomorphological processes almost are represent the amount of headward erosion in the upper reach of the basin (Harlin, 1978; Luo, 2000; Pérez-Peña et al., 2009). This trend basically increased in the direction from northeast to southwest in the basin of the Diyala river area. Consistent with SK index, the DSK index also reflects a larger slope in the upper reach of the basin and also showed increase in the trend from northeast basins to the southwest subbasins. In addition, a larger value of kurtosis almost the concave shape in the southern of the Diyala river area and Narin subbasin in southwest and in both the northeast and southwest sides; Table 2 and Figure 7. Signify erosion on both upper and lower reaches of a basin as indicated by (Harlin, 1978; Luo, 2000). These results also showed that large Kurtosis and Density Kurtosis values, in the subbasins (D7, D19, D21) (Table 2 and Figure 9). This means that, these subbasins have also large slope in the middle part of the basin (Harlin, 1978; Luo, 2000; Pérez-Peña et al., 2009). What makes this area contain these features erosion process in the both of the upstream and middle part area, in addition to large slope in the downstream part is the lithology composed of fluvial sediments and clastics rocks , according to (Al-Kubaisi, 2000; Al-Jebouri, 1991), the regional topography has stepped clearly. This stepping is due to the raising activities and the active fault branches of the Diyala River with the main Zagros fault, and khanaqin fault on the east side of the Diyala River. The increasing values of the KUR and DKUR indexes often show upward trend of recent tectonic activity (Pérez-Peña et al., 2009). Therefore, in the study area, the higher anomalies of the Kurtosis and Density kurtosis indexes still lie in the basins with the hypsometric curve showing concave shape (Table 2 Figure 9). Thus, if only individual subbasins with concave curve shapes are considered, subbasins with larger KUR and DKUR values will show stronger tectonic activity. If subbasins of the Diyala River with the higher anomalies of Kurtosis and Density kurtosis indexes with concave curve shape may suggest the following remarks: According to basic hypsometric curve, model and geomorphological development cycles shown by the changes of the hypsometric curves

(Figure 3), the hypsometric concave curve shapes in the study area are the oldest stage of geomorphological cycles. The final stage of the faulting cycle passed through a new tectonic activity cycle that means the tectonic activity in the southern study area is possibly the last period of stabilization tectonic cycle and the beginning of a new tectonic activity cycle. The hypsometric S-shape and straight shape in most of Diyala River Basin that means the tectonic activity in the middle study area is the moderate stabilization tectonic cycle and the reactivated of a new tectonic activity cycle. The hypsometric convex shape in northeast of Diyala River Basin means that the tectonic activity in the northeastern study area is possibly due to the low of stabilization tectonic cycle. If so, the above assumption is appropriated in anticipation to repeat the cycle of large earthquakes in the study area since 1958 A.C., while in the Zamkan Subzone strong earthquake had occurred with 7.3 magnitude on the Richter scale and occurred approximately 2 years ago. In summary, the hypsometric curves in the study area are mainly concave, straight and S-shapes with some curves with convex shape. H_i index is basically medium and tends to decrease to the west side. The SK and KUR and their density function are small and decreasing in the northeast trend. The recent tectonic activity (low uplifting) is generally weak in the southwestern part, while it is medium uplifting in the middle part of the study area, and the high uplifting in the northeast part of the study area. The uplifting is higher in northeastern part than the southwestern part of the study area and eastern side is being lifted higher than the western side of Diyala River.

The northern part is being lifted larger than the southern part. In the region and surrounding area, the strong uplift activities are increased gradually in the Pliocene-Quaternary. The current geomorphic processes are mainly headward erosion in the upstream.

CONCLUSION

The hypsometric curves and its statistical moments are tools to assess the geomorphological processes and active tectonic of the region as well as the comparison between different zones.

The Diyala River area has revealed 4 curves they are convex, S- shape", straight-shape, and concave curves. The S- shape", straight-shape curve are the most common and widely distributed in the middle part of the study area. The hypsometric integral (H_i) values are rather different; the largest value is 0.48 whereas the smallest one is 0.09. Other statistical moments of the hypsometric curve such as skewness (SK), kurtosis (KUR), and the density function (density skewness - DSK and density kurtosis-DKUR) have different values and increase in the southwest direction of the study area.

The recent active tectonic activities are strong (uplift-high) in northeastern part, moderate (uplift-medium) middle part, and weak (uplift-low) in southern part of the study area. However, they are also not completely homogeneous and can be distinguished by different levels. The eastern side is being lifted higher than the western side of Diyala River, and the northern part is being lifted larger than the southern part. In the region, the uplift activities were decreased gradually in the Pliocene-Quaternary and could have continued at present time. The current geomorphic process is mainly headward erosion in the upstream.

REFERENCES

1. Alavi, M., 1994. Tectonic of the Zagros Orogenic Belt of Iran: new data and interpretation. tectonophysics 229. Doi: 10.1016/0040-1951(94)90030-2.
2. Al-Hachim, A.E., 2012. The fault at Khanaqin Area at Its Effect on Hemrin South Structure. Unpublished M. Sc. thesis, College of Science, University of Baghdad, Iraq, 114 p.
3. Al-Jebouri, TH., 1991. Hydrology and Geomorphology of Diyala River. Unpublished Ph. D. thesis, College of Science, University of Baghdad, Iraq, 222 p. (in Arabic).
4. Al-Kubaisi, M.Sh, 2000. Morphotectonic of Tigris River and its Tributaries in the folded zone of Iraq. Unpublished Ph. D. Thesis College of Science, University of Baghdad, Iraq, 164 p. (in Arabic).

5. Arnfield, A.J., 2018. Köppen Climate Classification. Encyclopaedia Britannica. Website https://www.britannica.com/science/Koppen-climate-classification.
6. Azor, A., E.A. Keller and R.S. Yeats, 2002. Geomorphic indicators of active fold growth: South MountainOak Ridge anticline, Ventura basin, southern California. Geological Society of America Bulletin 114, 745-753. Doi: 10.1130/0016-7606(2002)114.
7. Delcaillau, B., B. Deffontaines, L. Floissac, J. Angelier, J. Deramond, P. Souquet, H.T. Chu and J.F. Lee, 1998. Morphotectonic evidence from lateral propagation of an active frontal fold; Pakuashan anticline, foothills of Taiwan. Geomorphology 24, 263-290. Doi: 10.1016/S0169-555X (98)00020-8
8. El Hamdouni, R., C. Irigaray, T. Fernández, J. Chacón and E.A. Keller, 2008. Assessment of relative active tectonics, southwest border of the Sierra Nevada (southern Spain). Geomorphology 96, 150-173.Doi:10.1016/j.geomorph.2007.08.004.
9. Font, M., D. Amorese and J.L. Lagarde, 2010. DEM and GIS analysis of the stream gradient index to evaluate effects of tectonics: the Normandy intraplate area (NW France). Geomorphology 119, 172180. Doi:10.1016%2Fj.geomorph.2010.03.017
10. Fouad, S.F., 2012. Tectonic Map of Iraq Scale 1:1,000,000, third edition, Iraqi Geological Survey, Baghdad, Iraq.
11. Gorbani, M., 2013. A summary of geology of Iran. The economics of geology of Iran mineral deposits and natural resources, p45-64, 978-94-007-5624-3. Doi: 10.1007/978-94-007-5625-0
12. Harlin, J.M., 1978. Statistical moments of the hypsometric curve and its density function.
13. Mathematical Geology 10, 59-72. Doi: 10.1007/BF01033300.
14. Howard, A.D., 1990. Role of hypsometry and planform in basin hydrologic response. Hydrological Processes 4, 373-385. Doi: 10.1002/hyp.3360040407.
15. Huang, X.J. and J.D. Niemann, 2006. Modelling the potential impacts of groundwater hydrology on longterm drainage basin evolution. Earth Surface Processes and Landforms 31, 1802-1823. Doi:10.1002/esp.1369.
16. Ibrahim, A.O., 2009. Tectonic style and Evolution of the NW Segment of the Zagros Fold-Thrust Belt, Sulaimaniya Governorate Kurdistan Regipon NE Iraq. . Unpublished Ph. D. thesis, College of Science, University of Sulaimaniya, Iraq, 222 p.
17. Ibrahim, S.A., 2018. Hydrogeological and morphometric study of diyala river basin Iraq Geological Survey, Baghdad, Iraq.
18. Jassim, Z.S. and J.C. Goff, 2006. Geology of Iraq. Dolin, Prague, Czech Republic, 341 p.
19. Joshi, P.N,. D.M. Maurya and L.S. Chamyal, 2013. Morphotectonic segmentation and spatial variability of neotectonic activity along the Narmada-Son Fault, Western India: Remote sensing and GIS analysis. Geomorphology 180-181 (2013) 292-306. Doi.10.1016%2Fj.geomorph.2012.10.023.
20. Keller, E.A. and N. Pinter, 2002. Active Tectonics. Earthquakes, Uplift and Landscape. New Jersey: Prentice Hall press.
21. Leloup, P.H, N. Arnaud, R. Lacassin, J.R. Kienast, T.M. Harrison, P.T. Trinh, A. Replumaz and P. Tapponnier, 2001. New Constraints on the Structure, Thermochronology, and Timing of the Ailao Shan-Red River Shear Zone, SE Asia, Journal of Geophysical Research, B, Vol. 106, 6683-6732. Doi: 10.1016/S1367-9120(01)00034-7.
22. Liem, V.L., N.P. Dat, B.T. Dieu, V.V. Phai, P.T. Trinh, H.Q. Vinh and T.V. Phong, 2016. Assessment of Geomorphic Processes and Active Tectonics in Con Voi range Area (Northern Vietnam) using Hypsometric Curve and curve Analysis Method. Vietnam Journal of Earth Sciences, vol. 38(2), 2202-216. Doi:10.15625/0866-7187/38/2/8602.
23. Luo, W., 2000. Quantifying groundwater- sapping landforms with a hypsometric technique. Journal of Geophysical Research, Vol. 105, No. El, Pages 1685-1694, January 25. Doi: 10.1029/1999JE001096.
24. Mahmood, S.A. and R. Gloaguen, 2012. Appraisal of active tectonics in Hindu Kush: Insights from DEM derived geomorphic indices and drainage analysis. Geoscience Frontiers 3(4), 407-428. Doi: 10.1016/j.gsf.2011.12.002.

25. Moglen, G.E. and R.L. Bras, 1995. The effect of spatial heterogeneities on geomorpHic expression in a model of basin evolution. Water Resources Research 31, 2613-2623. Doi: 10.1029/95WR02036.
26. Pedrera, A., J.V. Pérez-Peña, J. Galindo-Zaldívar, J.M. Azañón and A. Azor, 2009. Testing the sensitivity of geomorphic indices in areas of low-rate active folding (eastern Betic Cordillera, Spain). Geomorphology 105, 218-231. Doi:10.1016/j.geomorph.2008.09.026.
27. Pérez-Peña, J.V., J.M. Azañón and A. Azor, 2009. CalHpso: An ArcGIS extension to calculate hypsometric curves and their statistical moments. Applications to drainage basin analysis in SE Spain. Computers & Geosciences 35, 1214-1223. Doi:10.1016/j.cageo.2008.06.006.
28. Shahzad, F. and R. Gloaguen, 2011. TecDEM: AMATLAB based tool box for tectonic geomorphology, Part 1: Drainage network preprocessing and stream profile analysis. Computers & Geosciences 37, 250-260. Doi: 10.1016/j.cageo.2010.06.008.
29. Sissskian, V.K., 2014. Geology of Khanaqin Quadrangle sheet NI-38-7, scale 1,250,000 second editions, Iraq Geological Survey, Baghdad, Iraq.
30. Strahler, A.N., 1952. Hypsometric (area-altitude) analysis of erosional topography. Geological Society of America Bulletin 63, 1117-1142. Doi: 10.1130/0016-7606(1952)63.
31. Strahler, A.N., 1957. Quantitative analysis of watershed geomorphology. Transactions of the American Geophysical Union 38, 913-920. Doi: 10.1029/TR038i006p00913.
32. Willgoose, G. and G. Hancock, 1998. Revisiting the hypsometric curve as an indicator of form and process in transport- limited catchment. Earth Surface Processes and Landforms 23, 611-623. Doi: 10.1002/(SICI)1096-9837(199807)23.