Remote Sensing Based Analysis of Interactions between Tectonics and Landscapes in Rawanduz River, Northeastern Iraq

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Abstract

The study area along the northeast border of Iraq is a perfect location to test the notion of an index to predict relative tectonic activity, as well as being considered a very characteristic area as include three main tectonic zones (High Folded Zone, Imbricate Zone and Zagros Suture Zone). This study area has variable rates of active tectonics resulting from the collision of Arabian and Iranian plates. This study aims at highlighting the possibility of information systems programs in building a morphometric geographic database of the Rawanduz River Basin, which is one of the main basins of the Greater Zab River using Shuttle Radar Topographic Mission (SRTM), Digital Elevation Model (DEM 90 m) data to evaluate the drainage condition of this river with the help of Geographical Information Systems (GIS) and Remote Sensing. The morphometric analysis of the Rawanduz drainage basin has been executed during measurement of linear, areal and relief aspects as well as we offer a new process for estimate relative active tectonics according on geomorphic indices useful in evaluating morphology and topography. A total of 26 sub-basins were delineated in the Rawanduz River Basin. Geomorphic indices used include: drainage basin asymmetry (A_f), ratio of valley-floor width to valley height (V_f), index of drainage basin shape (Bs), and index of mountain front sinuosity (S_{mf}). Results from the analysis are accumulated and expressed as an index of relative active tectonics (Iat), which we divide into four classes from relatively low to higher tectonic activity.

Keywords: Geomorphic, Morphometric Analysis, Rawanduz river basin, GIS, DEM, SRTM.

Introduction

The series of tectonic and climatic forces has on essential and important role in determining the origin of landscape features, variable the elevation locally as well as on a regional scale, which in turn shape the landscape. Tectonic and geomorphological processes are closely related. In recent years ASTER derived digital elevation data and advances in GIS technologies have been widely used to determine the morphometric properties of tectonically active regions. In the tectonically active areas the morphotectonics it's considered as a tool to detect the intensity of tectonic activity [1]. The areas with relatively high activity, in the Holocene and Late Pleistocene, Its study is important for assessing the risk of earthquakes [2]. The aim of this paper is to quantify morphometric and several geomorphic indices of relative active tectonic and topographic growth to output a single index that can be used to characterize relative active tectonics. For this objective, we will present the tectonic geomorphic analysis of indices followed by a discussion of the active tectonics based upon recent field-based structural and geomorphic observation and analysis [3].

1. Regional setting and methods

Study area

The Rawanduz River Basin (RRB) is located in northeastern Iraq between longitudes and latitudes of (44°16'& 45°10'E) and (36°23'& 36°80'N), respectively. It covers a total area of 2,921 km^2 (Figure-1). According to the tectonic map [4], it lies within the High Folded Zone (HFZ), Imbricated Zone (IZ), which is a part of the Unstable Shelf and Zagros Suture Zone (ZSZ). It is located between longitudes and latitudes of (44°16'&45°10'E) and (36°23'&36°80'N), respectively. Rawandoz district is located northeast of the province of Erbil, 110 km between the two valleys Al-Sakheqin "Khrand and Kali Khalh spray". It is raised of 3591m above sea level and surrounded by the south of the Kork Mountain, from the east by the Handreen Mountain, from the north by the mountain of Zazik and from the west by the mountain of Bradost.

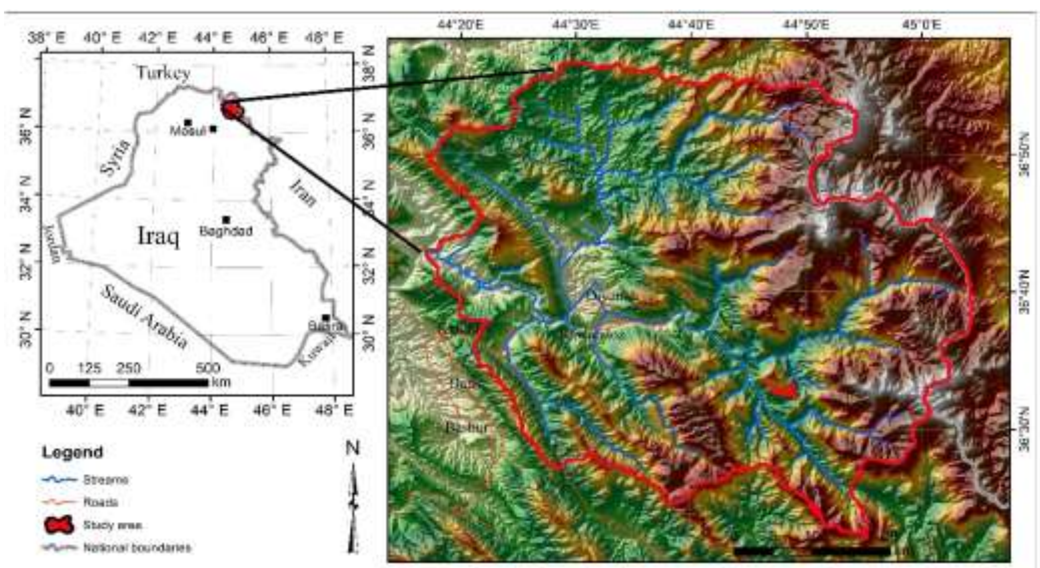


Figure- 1 Location map of the Rawanduz River Basin (RRB)

According to the Koppen-Geiger climate classification [5], as it stated that the most of the area located within the region of main arid climate, with steppe precipitation and hot arid temperature conditions. The emphasis was on the lithology and tectonic activity of the fact that the effect of climate on the evolution of geological forms is equal or semi- equal.

Structural Geology

According to [6] five major transversal blocks are specified bounded by major transverse faults. The three major fault systems are the N-S Nabitah (Idsas) System, the NW-SE Najd System and the NE-SW or E- W Transversal System (Figure-2). The studied area is located within the Imbricate, High Folded and Zagros Suture Zone, all of them belong to the Unstable Shelf of the Arabian Plate [7]and [8]. However, [9] considered the Unstable Shelf as the Outer Platform of the Arabian Plate, and introduced the Imbricate and Zagros Suture Zones. Many anticlines and synclines are developed within the studied area; they all are in NW – SE trend, however, in the extreme northwestern part of the area. The main anticlines: Bradost, Aqra, Korak, Zazik, Tanun, Handreen, Makook and Ranya (Figure-3). Some of the anticlines form water shades within the sub-basins, others form strike ridges and valleys, which have controlled the drainage pattern and basin's shapes. In addition to Thrust Fault of the Zagros Suture Zone also runs within the extreme northern and northeastern parts of the studied area, causing very complex structural frame work of the involved area.

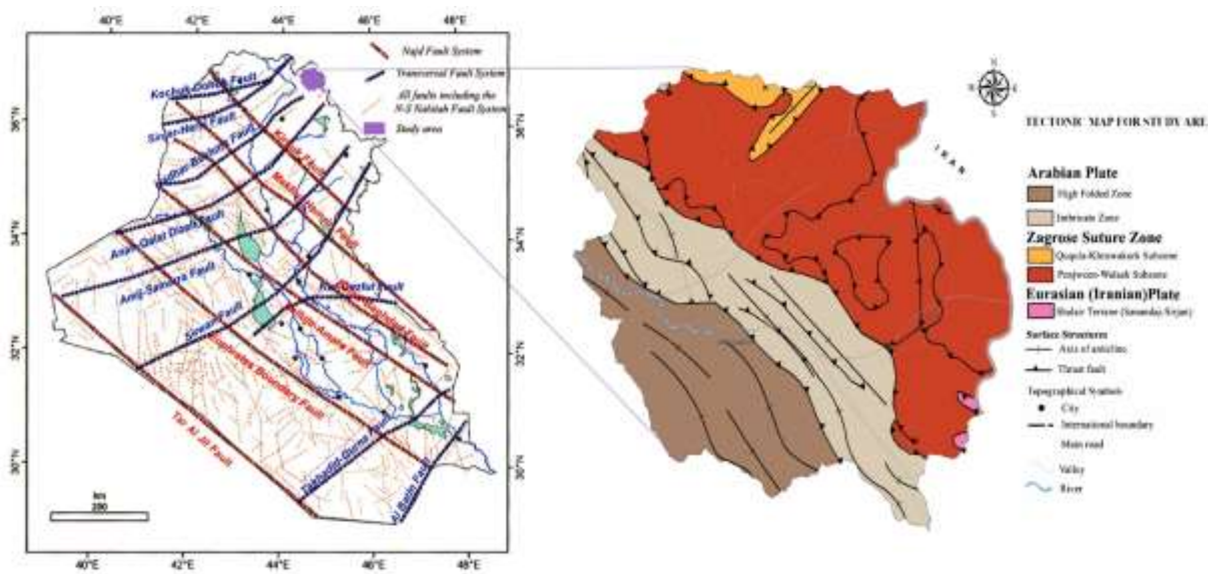


Figure-2 Main Tectonic Zones in Iraq (after [6]) and tectonic map of study area.

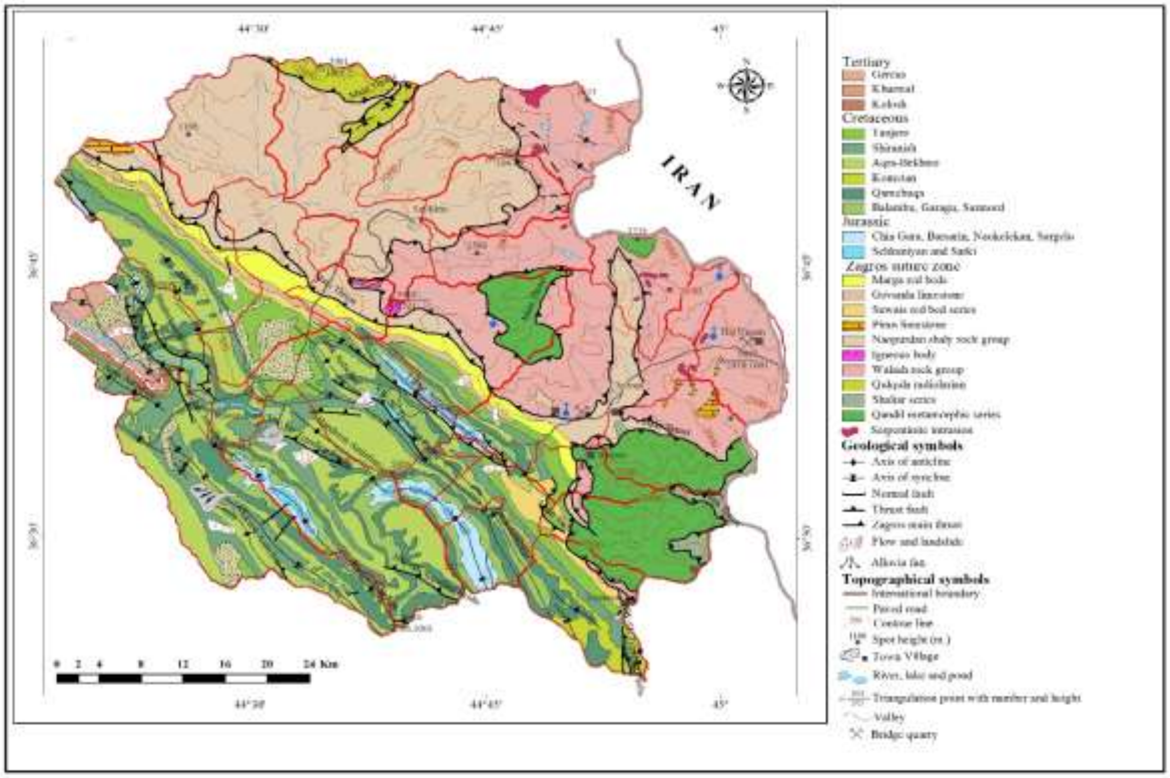


Figure-3 Structural map of the studied area (compiled from [8] and [9] (For the names of the anticlines).

Methodology

Morphometric characteristics such as linear, aerial, and relief aspect and some geomorphic parameters in the present study, have been prepared using digital satellite images and helpful data, this is because the manual extraction of during network and assigning the stream order from published topography map of Iraq and geo referenced satellite data for large area is a time taking tedious exercise. Geographic information system (GIS) and remote sensing techniques are used as suitable tools to produce spatial variation in morphometric variables. Remote sensing data obtained from sensors such as ASTER Global Digital Elevation Model (GDEM), with a 90-m grid spacing, other helpful data, such as topographic (scale 1:2,500,000) and geologic maps, were also used to determine the drainage network and the morphometric parameters of the RRB and sub-basins. ArcGIS 10.5 software was used to extract drainage networks, and to generate drainage basin characteristics. More specifically, the extracted of the RRB and its sub-basins and stream network are projected to the regional projection (WGS-1984, UTM Zone 38 N) and the hydrology toolbox of the ArcGIS software. According to the [10] the automated method for delineating drainage was done in GIS. Different morphometric parameters have been determined as shown in the (Table-1).

Table-1

Linear relief and areal morphometric parameters used for Rawanduz River Watershed

S.no.	Parameter	Formula	Reference
1	Stream order (*U*)	Hierachial rank	[10]
2	Stream length (*Lu*)	Length of the length stream	[11]
3	Mean stream length (*Msl*)	MSL = Lu/Nu	[10]
4	Stream length ratio (*RL*)	RL = Lu/Lu – 1	[10]
5	Bifurcation ratio (*Rb*)	Rb = Rb = Nu/Nu + 1	[35]
6	Mean bifurcation ratio (*Rbm*)	Rbm = Average of bifurcation ratios of all orders	[34]
7	Drainage density (*Dd*)	Dd = Lu/Ba	[16]
8	Stream frequency (*Fs*)	Fs = Nu/Ba	[11]
9	Drainage texture (*T*)	T = Dd × Fs	[17]
10	Elongation ratio (*Re*)	Re =2√((Ba/π)) / Lb	[35]
11	Circularity ratio (*Rc*)	$Rc = 4 \times \pi \times Ba/P^2$	[10]
12	Form factor (*Rf*)	$Rf = Ba/Lb^2$	[11]
13	Compactness coefficient (*Cc*)	$Cc = 0.2841 \times (P/Ba^{0.5})$	[36]
14	Basin relief (*R*)	$R = H_{max} - H_{min}$	[37]
15	Relief ratio (*Rh*)	Rh = H/Lb	[38]
16	Lemniscate shape ratio (*Ls*)	Ls = (Lb)2 * π/4 Ba	[39]
17	Drainage intensity (*Di*)	Di = Fs/Dd	[40]
18	Constant channel maintenance (*C*)	C = 1/Dd	[35]

Extraction of Rawanduz River Watershed

From the ASTER DEM data with a spatial resolution of 90 m, Rawanduz River Basin is automatically extracted. Different geological processing techniques in ArcGIS 10.5 have helped us in extracting the contributing basin area. The DEM and the pour point are the two input parameters required for the extraction purpose. A pour point is a user-supplied point to the cells of highest flow accumulation [12]. The systematic process wanted for the automatic extraction of the basin/watershed is shown in (Figure-4). The results of this process will lead to a watershed boundary polygon from the flow direction raster data.

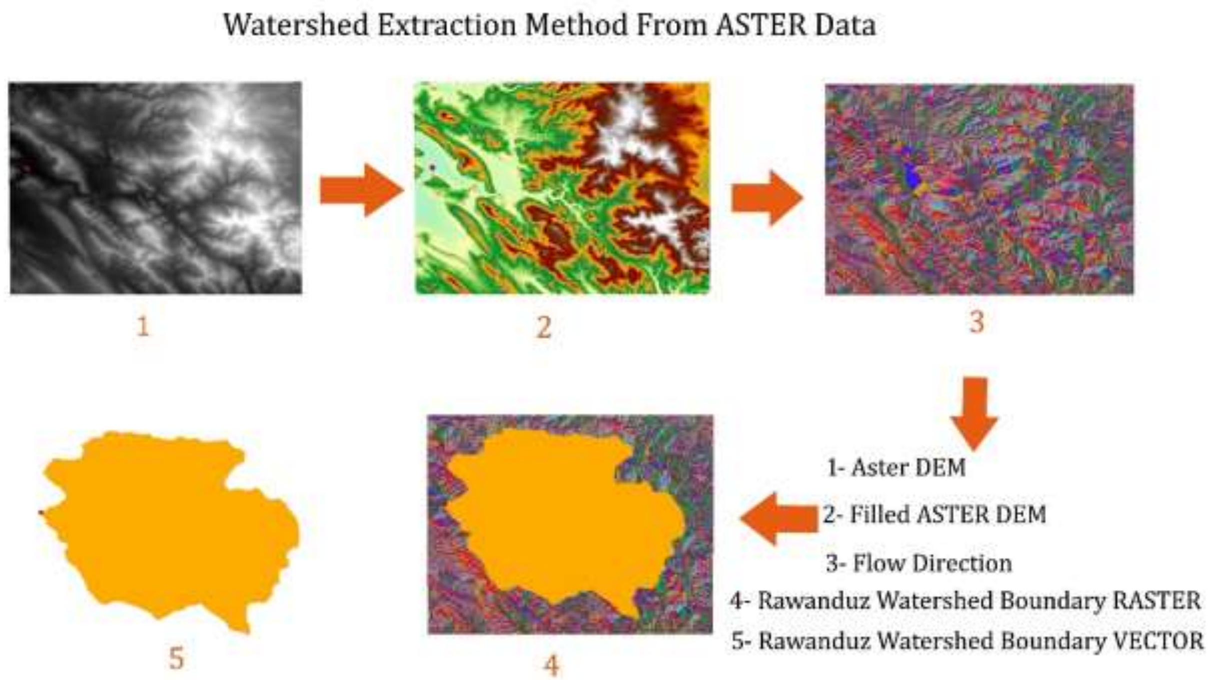


Figure-4 Extraction of Rawanduz River Basin boundary through ASTER data

Extraction of drainage network

In ArcGIS 10.5 the drainage network of the Rawanduz River Basin is extracted from a group of geo processing tools (Figure-5). According to [10] the output of this process is a basis to produce a stream/drainage network grid with stream order. In the Rawanduz River Basin the highest steam order was detected as sixth. Using the standard mathematical formulae given in (Table-1). has been analyzed the various parameters such as stream number, stream order, stream length, stream length ratio, bifurcation ratio, basin length, basin area, relief ratio, elongation ratio drainage density, etc., To assist the drainage morphometric basin, the aspect and slope map of the study area derived from the ASTER DEM using the aspect and slope tool in ArcGIS-10.5 spatial analyst module.

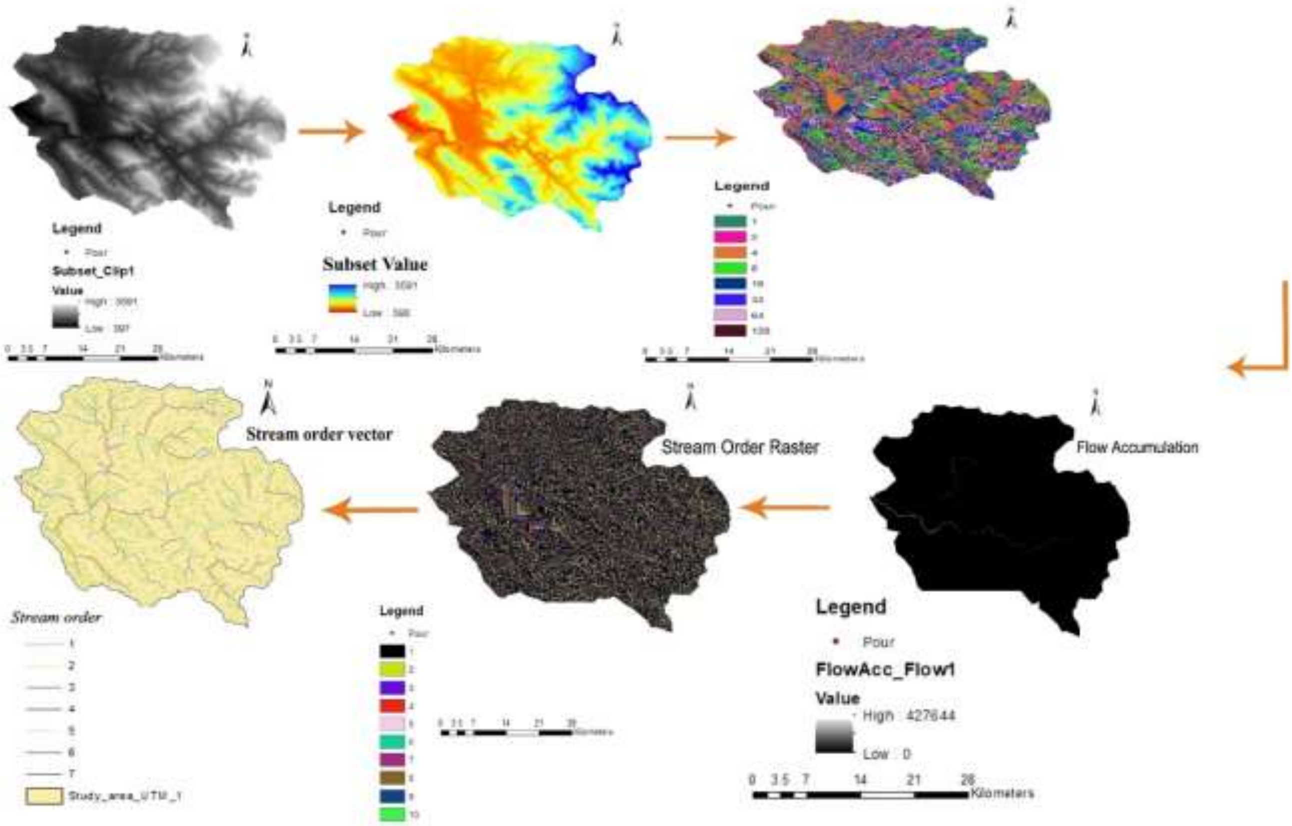


Figure-5 Automatic extraction of streams through ASTER data

Morphometric analysis and geomorphic indices of active tectonics
Morphometric Analysis of basin

Quantitative Morphotectonics parameters such as morphometric features are used to study the active tectonics and morphological relationships, According to [11], [10], [12], [13], [14] and [15].The drainage network of the watershed and stream ordering was analyzed as per The details of several formula used in this study are presented in (Table1), The morphometric parameters were classified into three groups, basic parameters, derived parameters and shape parameters. The basic parameters contain area (Ba), perimeter (P), basin length (Lb), stream order, and stream length. The derived parameters are bifurcation ratio, stream length ratio and drainage density. The shape parameters are elongation ratio, circulatory index and form factor.

Basic Parameters

According to (Table-2), the morphometric analysis of Rawanduz Watershed was carried out using the parameters. Basic parameters contain watershed area, perimeter, stream length, and stream order and basin length.

Table-2

Characteristics of the drainage basins

Sub - basin	Order	Stream number	Stream length (Km)	Basin areas (Km^2)	Perimeter (Km)	Basin length (Km)
1	4	67	100	90.440037	44.606436	9.576637
2	4	105	126	118.850307	49.90935	15.482854
3	4	98	99	111.657688	53.059538	18.290849
4	4	94	106	101.181792	51.424831	18.1065
5	4	25	29	25.934311	27.35938	9.015589
6	4	65	80	76.296642	43.738495	13.997789
7	5	175	207	204.836454	88.519393	22.124468
8	4	45	41	42.63546	36.712057	12.221843
9	5	58	63	62.025687	55.17385	13.908733
10	4	47	54	53.801482	32.750158	10.035859
11	4	75	80	71.786397	50.309419	17.16316
12	4	129	165	169.918909	63.664893	19.108943
13	4	26	24	26.137138	25.569273	8.738186
14	4	178	218	218.513987	82.762463	27.547324
15	6	125	149	162.365374	65.643613	19.363619
16	4	33	41	43.578592	31.936793	10.552775
17	5	93	104	96.809716	67.199934	16.465611
18	4	75	90	84.511879	42.780195	14.394312
19	4	166	206	197.503485	82.926871	27.370046
20	5	106	131	116.717357	58.284275	17.009115
21	4	26	25	22.565645	21.594334	6.168037
22	4	108	144	130.678161	61.323375	14.573639
23	6	99	169	127.074162	73.047774	21.126608
24	4	165	210	180.368262	67.475727	23.210354
25	4	201	258	228.071506	97.481968	34.541495
26	4	132	140	157.640959	79.730933	23.544423

Perimeter (P) and Area (A)

To obtain basic morphometric parameters, the Mini-watershed delineated layer is used such as area (A), perimeter (P), length (L), number of streams (N). Basin length (Lb) was calculated from stream length, while the bifurcation ratio (Rb) was calculated from the number of streams. Else linear and shape morphometric parameters were calculated using the equations (Table-3).

Table-3. Characteristics of the Rawanduz River Basin
(Lengths are in Km, areas in Km^2, height and width in m)

Coverage area	2.921
Coverage of half right basin area	1.669
Length of the basin	70.31
Width of the basin	57.88
Length of the stream	90.740
Width of the stream	95
Horizontal stream length	69.940
Highest point in basin	3591
Lowest point in basin	372
Perimeter of the basin	2.909
Channel Sinuosity: Before outlet/ After outlet	Regular

Stream Order (u)

To explain the basins in quantitative terms, idea of stream order was inserted by [11] and [10]. This idea is used with the linear dimension of the stream length. (Table-4) as shown Stream order, number of streams and total streams in Rawanduz River Basin.

A B

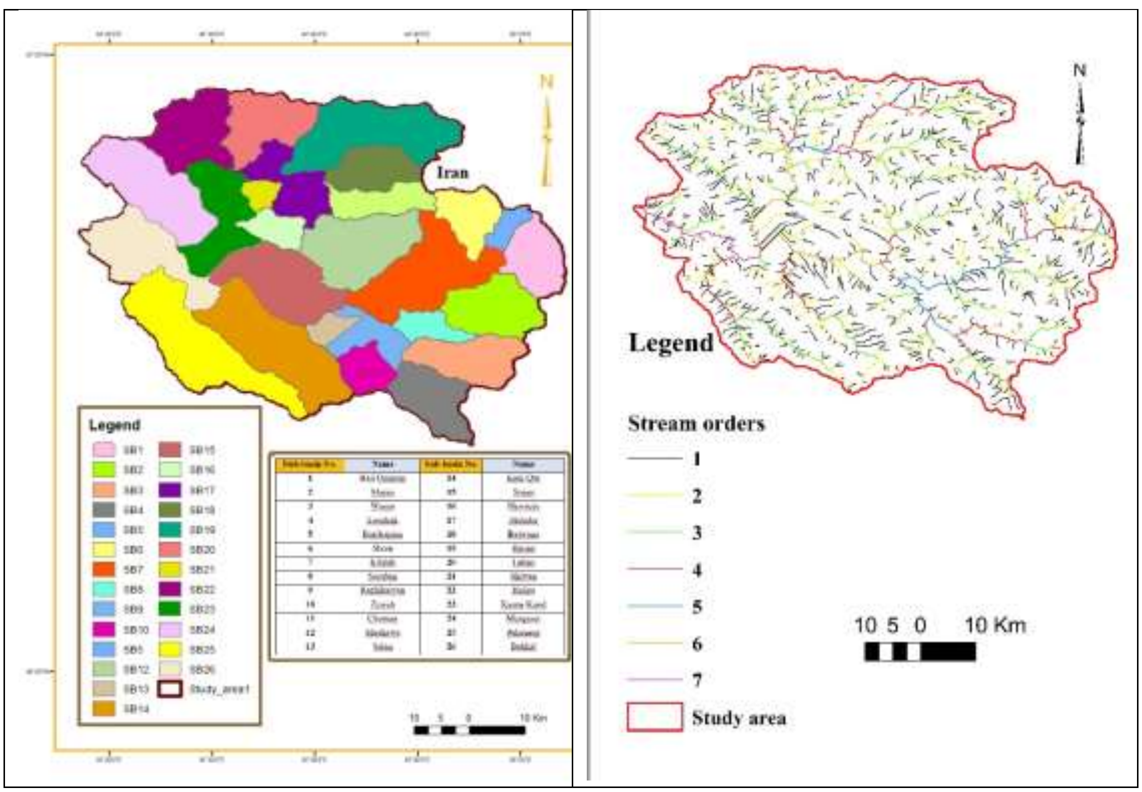


Figure-6 (A) - Sub-basin names of the Rawanduz River Basin, (B) - Watershed of the study area

Table-4
Stream order, number of streams and total streams in Rawanduz River Basin.

Sub - basin	I-order	II-order	III-order	IV-order	V- order	VI-order	Total No. of streams
1	51	12	3	1	0	0	67
2	77	20	6	2	0	0	105
3	75	17	4	2	0	0	98
4	72	16	4	2	0	0	94
5	16	5	2	2	0	0	25
6	51	9	3	2	0	0	65
7	127	33	4	9	2	0	175
8	33	8	2	2	0	0	45
9	43	6	2	6	1	0	58
10	35	8	2	2	0	0	47
11	58	13	3	1	0	0	75
12	101	22	4	2	0	0	129
13	16	6	2	2	0	0	26
14	138	33	5	2	0	0	178
15	98	16	3	4	2	2	125
16	25	4	2	2	0	0	33
17	68	15	3	5	2	0	93
18	55	14	4	2	0	0	75
19	127	29	8	2	0	0	166
20	80	18	3	2	2	0	105
21	16	6	2	2	0	0	26
22	85	19	3	1	0	0	108
23	73	13	3	5	4	1	99
24	129	32	3	1	0	0	165
25	163	32	5	1	0	0	201
26	97	27	7	1	0	0	132

Total Length of Stream (L)

Stream length is the addition of all stream lengths in special order. The numbers of streams of different orders in sub-basins were calculated and their lengths measured, which assist us to detect the drainage density, the results are in (Table-4).

Basin Length (Lb)

Basin length is generally defined as the distance measured along the major channel from the watershed outlet to the basin divide. The basin length (Lb) is one of the watershed feature of benefit and is important in hydrologic calculations and increases as the drainages increases and vice versa. The results of basin length analysis show that it varies between 6.16 km (Sub-basin 21) and 34.54 km (Sub-basin 25) in the Rawanduz watershed (Table-5).

Linear Parameters

Linear parameters contain bifurcation ratio, drainage density, stream frequency, texture ratio and length of overland flow.

Bifurcation ratio (Rb):

According to [10], in an area of uniform climate and period of development, the Rb tends to stay constant from one order to next order. The irregularities of the drainage watershed based upon lithological and geological development, leading to changes in the values from one order to the next. An elongated watershed has higher Rb than the circular watershed. The Rb values less than 5.00 indicate geomorpholgical control, while Rb values greater than 5.00 indicate structural control on the development of the drainage pattern.

Drainage Density (Dd)

It is the ratio of the total length of streams within a watershed to the total area of the watershed. The drainage density in the main river was considered low ranging from 0.84 (SB3) to 1.28 (SB23) (Table-6). According to [6] the lowest values of drainage density in the area could be due to the high permeability of the formations that outcrops in the high folded zone, as most of them consist of fractured limestone we noticed that the values tend to increase at almost sub-basins.

Stream frequency (Fs)

[16] Defined the Stream frequency as number of stream segments of all orders per unit drainage area. The (Fs) value of the main river basin is 0.88, and the values for the sub-basins range from 0.74 for sub-basin1 to 1.15 for sub-basin 21 (Table-5).

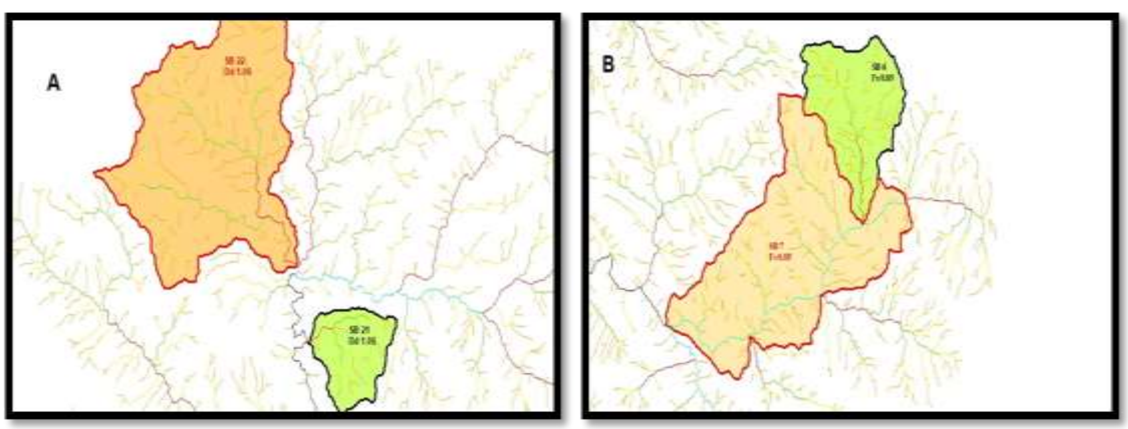


Figure-7 describing the difference between (Dd) and (Fs); (A) is showing two basins having the same (Dd) but different (Fs), while (B) is showing two basins having the same (Fs) but different (Dd).

Texture ratio (T)

According to [17] the texture ratio can be defined as the total number of streams of all orders per the basin perimeter, it can mirror the amount of space between the drainage networks. He classified the texture values as, coarse for values less than 2, moderate (2-6), and fine for values more than 6. He also mentioned that the drainage texture tends to be coarse in the early stages of basin growth and at its best in the stages of maturity. Within the study area, the texture ratio values were generally low and correspond to the very to the very coarse class, ranging from 0.91(sub-basin 5) to 2.44 (sub-basin 24), with an average of 1.62 (Table-**5)**.

Length of overland flow (Lg)

[11] Defined the length of overland flow as the length of flow path, design to a horizontal plane of the rain flow from a point on the drainage divide to a point on the neighboring stream channel. He also referred to the inverse relationship between values of the overland flow by the average channel slope. Considering it one of the most important independent variables affecting both the hydrologic and hydrographic development of drainage basins. The length of overland flow of the study area was ranging from 0.42 Km (sub-basin 3) to 0.64 Km (sub-basin 23) with an average value of 0.50 Km (Table-5). It was found that most of the sub-basins that acquired low values fall in the middle of the main river basins and the highest values regarding the lithology and the structural nature of the area.

Table-5

Results of some morphometric parameter in Rawanduz River Basin.

Sub - basin	(Lb)	(Rb)	(Dd)	(Fs)	(T)	(Lg)
1	9.57	3.52	1.00	0.74	1.50	0.50
2	15.48	3.39	1.01	0.88	2.10	0.50
3	18.29	3.55	0.84	0.87	1.84	0.42
4	18.10	3.50	0.92	0.92	1.82	0.46
5	9.01	2.23	0.98	0.96	0.91	0.49
6	13.99	3.38	0.96	0.85	1.48	0.48
7	22.12	4.25	1.03	0.85	1.97	0.51
8	12.22	3.04	0.87	1.05	1.22	0.43
9	13.90	4.12	1.00	0.93	1.05	0.50
10	10.03	3.12	0.98	0.87	1.43	0.49
11	17.16	3.39	1.03	1.04	1.49	0.51
12	19.10	4.03	0.96	0.75	2.02	0.48
13	8.73	2.22	0.89	0.99	1.01	0.44
14	27.54	4.42	1.03	0.81	2.15	0.51
15	19.36	3.04	1.13	0.76	1.90	0.56
16	10.55	3.08	0.89	0.75	1.03	0.44
17	16.46	3.15	1.07	0.96	1.38	0.53
18	14.39	3.14	1.06	0.88	1.75	0.53
19	27.37	3.99	0.96	0.84	2.00	0.48
20	17.00	3.23	1.04	0.89	1.80	0.52
21	6.16	2.22	1.06	1.15	1.20	0.53
22	14.57	4.6	1.06	0.82	1.35	0.53
23	21.12	3.15	1.28	0.77	2.44	0.64
24	23.21	5.89	1.11	0.91	2.06	0.55
25	34.54	5.49	1.03	0.88	1.65	0.51
26	23.54	4.81	1.02	0.83		0.51

Shape Parameters

According to the (Table-6) which that regarding to the results of Form factor (Rf),Shape Factor (Bs), Circulatory Ratio (Rc), Elongation Ratio (Re), Lemniscate shape ratio (Ls) (Ls) and Compactness Coefficient (Cc), their results were found to be similar and indicate that most of the sub-basins had an elongated nature (Figure-8). In Rawanduz river basin, values of elongation ratio ranged from 0.49(sub-basin 25) to 1.12(sub-basin 1) which indicates the highly elongated to near circular shape of the basins respectively. Majority of the elongated basins are present in the north-west and less elongated basins are present in the north-east part of the study area.

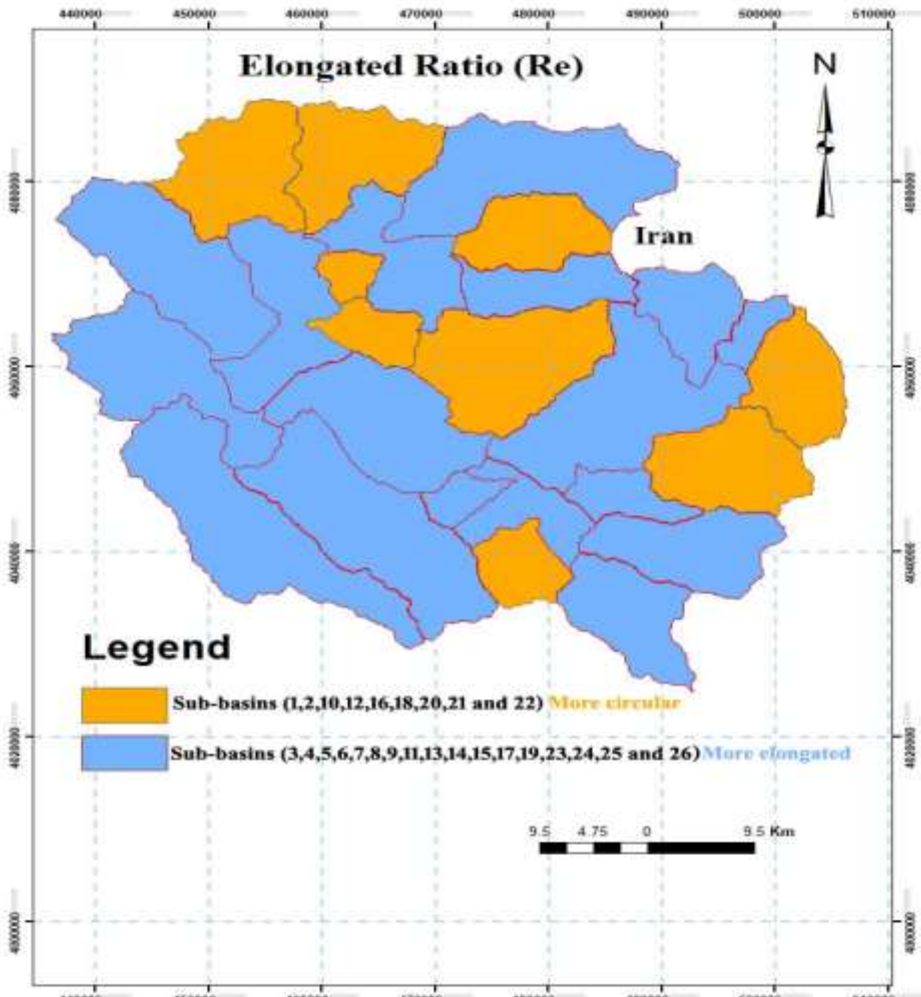


Figure-8 Distribution of (Re) throughout the study area.

Table-6
Detailed results of the shape and symmetry related indices

Sub - basin	(Rf)	(Re)	(Rc)	(Ls)	(Cc)
1	0.98	1.12	0.57	1.01	1.30
2	0.49	0.79	0.59	2.01	1.42
3	0.33	0.65	0.49	2.99	1.45
4	0.30	0.62	0.48	3.24	1.52
5	0.31	0.63	0.43	3.13	1.42
6	0.38	0.70	0.50	2.56	1.75
7	0.41	0.73	0.32	2.38	1.59
8	0.28	0.60	0.39	3.50	1.99
9	0.32	0.63	0.25	3.11	1.26
10	0.53	0.82	0.63	1.87	1.68
11	0.24	0.55	0.35	4.10	1.38
12	0.46	0.76	0.52	2.14	1.42
13	0.34	0.66	0.50	2.92	1.59
14	0.28	0.60	0.40	3.47	1.46
15	0.43	0.74	0.47	2.30	1.37
16	0.39	0.70	0.53	2.55	1.94
17	0.35	0.67	0.26	2.80	1.32
18	0.40	0.72	0.58	2.45	1.67
19	0.26	0.57	0.36	3.79	1.53
20	0.40	0.71	0.43	2.47	1.29
21	0.59	0.86	0.60	1.68	1.52
22	0.61	0.88	0.43	1.62	1.84
23	0.28	0.60	0.29	3.51	1.42
24	0.33	0.65	0.49	2.98	1.83
25	0.19	0.49	0.30	5.23	1.80
26	0.28	0.60	0.31	3.51	

Geomorphic parameters

According to [18], [19]. Most studies applied a mixture of two indexes (S_{mf} and V_f) to supply semi-quantitative data of relative degree of tectonic activity of mountain fronts. Two studies using these indices supply an assignation to different tectonic activity classes.

Mountain front sinuosity (S_{mf})

According to [20] is defined the (S_{mf}) it's the ratio of the total length of the mountain front as measured along the prominent break in slope along the foot of a mountain and the straight line length of the mountain front. And it is expressed by the following equation

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

(S_{mf}) index reflects a balance between the tendency of streams and slope processes to produce an irregular (sinuous) mountain front and vertical active tectonics that tends to produce a prominent straight front [18].

Table-7
Relationship between results and Tectonic activity

Class	Value	Tectonic activity
1	< 1.02	Extremely active
2	>1.02- 1.04	Moderately active
3	>1.04	Active

The S_{mf} index is especially attractive because it can be quickly and easily measured from aerial photographs, satellite or other high altitude imagery or topographic maps. Mountain fronts can be measured manually from the high resolution satellite images and topographic maps. For measurement of mountain front sinuosity in the Rawanduz river basin, digital elevation models (DEMs) generated by stereo image bands 3N and 3B of ASTER were used. 3-D surfaces using DEMs were generated in Global Mapper (version 11). Values of S_{mf} approach 1.0 on the most tectonically active fronts, whereas S_{mf} increases if the rate of uplift is reduced and erosional processes begin to form a front that becomes more irregular with time. S_{mf} values lower than 1.4 indicate tectonically active fronts [21], [22], while higher S_{mf} values (N 3) are normally associated with inactive fronts, S_{mf} values lower than 1.4 represented sub-basins (1,3,5,6,9,11,16,17,21,23 and 26).

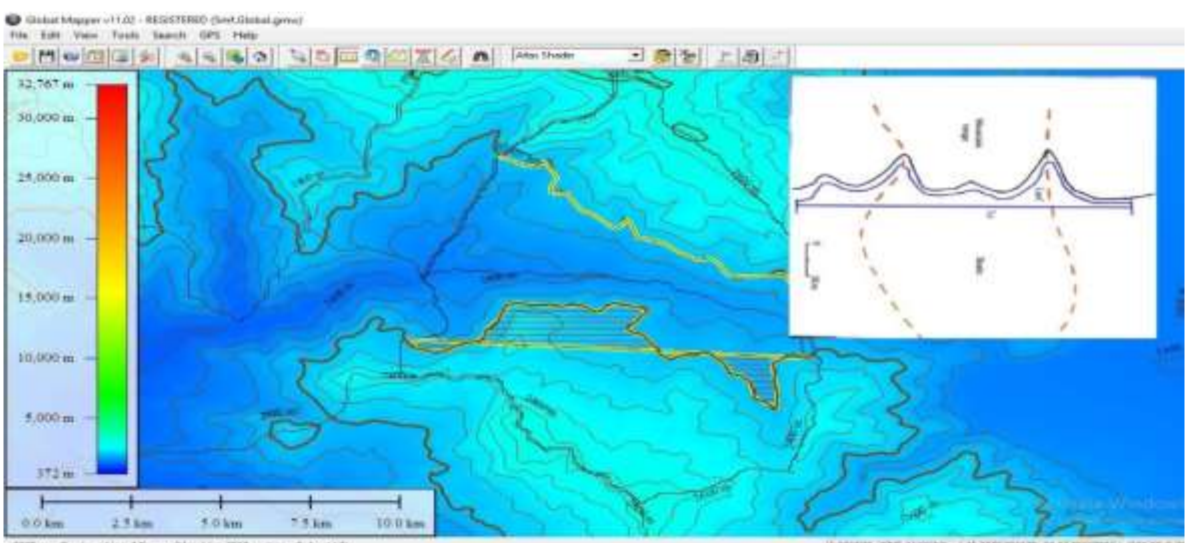


Figure-9 Calculating mountain front sinuosity (S_{mf}) index generated in Global Mapper (version 11).

Rawanduz River Basin has been divided into 26 sub basins and in each sub basin many fronts has been traced and measured, depending on the area of the basin. Mountain front can be calculated as one major front divided into segments of many fronts of same length or several continuous fronts of various lengths [23], [24], and [19]. In this study, later approach is adopted because this method was more suitable for the present research. And with this method we achieve better results about the tectonics of the area. Related the sub-basins within the study area, the ratio values were found to be ranging from 1.08(sub-basin 23) to 2.29 (sub-basin 8).

Valley floor width to valley height ratio (*Vf*)

The valley floor width to valley height ratio (*Vf*) is another index to estimate the area on the basis of the tectonic activity [18]. This index reflects the differences between the V-shaped valleys down cutting in response to active uplift, where the stream is governed by the influence of a base level fall at some point downstream that mention a relatively high tectonic activity, and the U-shaped broad-floored valleys with specially lateral erosion into the adjacent hill slopes in response to relative base level stability or tectonic quiescence that signifies a relatively low tectonic activity. Therefore, this index uses one vertical and one horizontal dimension at a given point along the stream in the erosional system. The ratio of valley floor width to valley height is defined as:

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

The floor width and the elevation values were acquired from the DEM of the study area by convert the main river for each sub-basin to Digital format and three engineering parts and drawing three profiles at points meeting of segments, (Upper, Middle and downstream) (Figure-10). According to [25] during this parameter the geometry of the transverse river profile can be described quantitatively and it possible tectonic influence on the river cross section shape can be assessed.

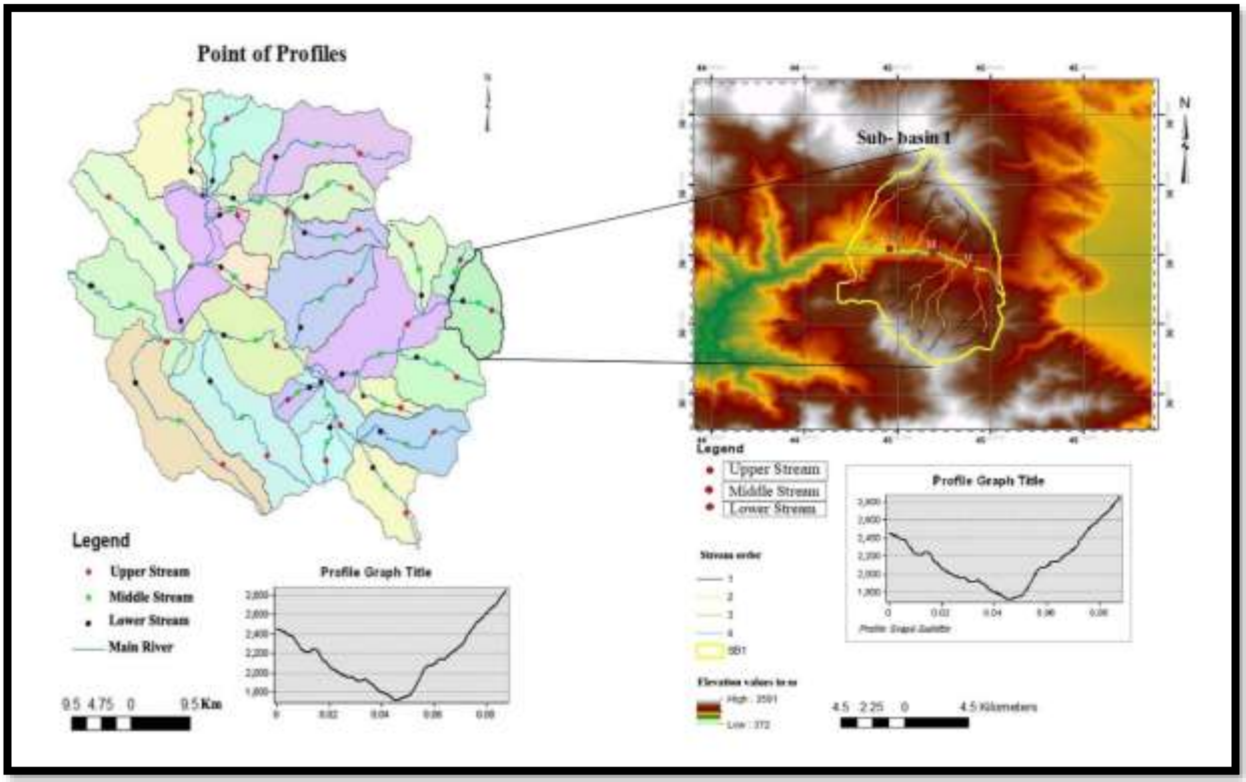


Figure-10 Profiling Locations for the calculation (*Vf*).

Related the sub-basins within the study area, the ratio values were found to be ranging from 0.09 (sub-basin 6) to 3.27 (sub-basin 17) (Table-7) with the lowest values falls within the sub-basin that cover the upper part of the main river (ZSZ). It was known that the values tend to increase for the sub-basin that cover the lower nearly of the main river basin (HFZ).

Table-8

Relationship between results and Shape of the Valley.

Class	Values	Shape of the Valley
1	0.05 – 0.12	indicates less eroded basin and v-shaped Valleys
2	0.12 – 0.24	indicates eroded basin
3	0.24 – 0.4	indicates highly eroded basin and U-shaped Valleys

For the purpose of calculating the four unknown heights of values elevations of E_{ld}, E_{rd}, E_{sc} and V_{fw} values that The digitization of the valley profiles serves it. Towards this, all the valley profiles will be converted into three dimensional profiles by using the 3D path profile/line of sight tool and viewed in the global mapper to measure the elevation values of each valley individually (Figure-11). The river and other minor streams cut the structures in V shape valleys, because the carved rocks are mainly of carbonates [26].

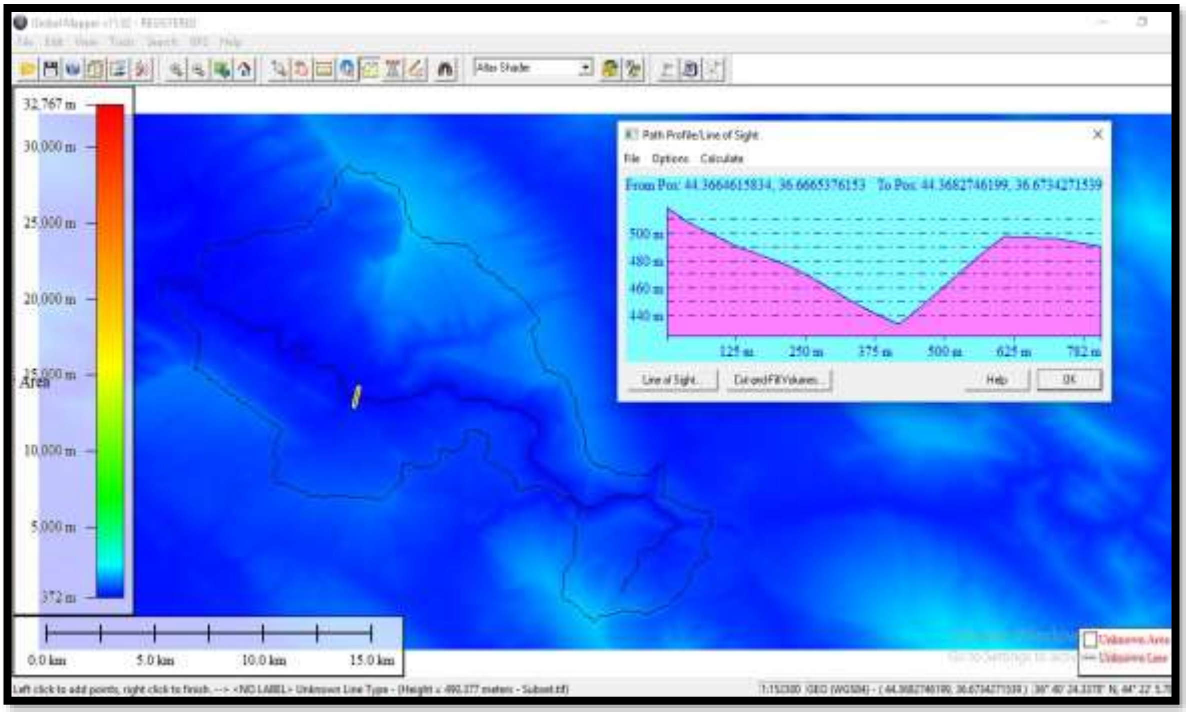


Figure-11 Map showing the valley profile of a basin (Generated in Global mapper).

Basin shape index (Bs)

The horizontal projection of a basin shape may be described by the basin shape index or the elongation ratio, Bs [27].

(Bs) was calculated by using the DEM and classified into three classes: class 1 (Bs≥4); 2 (3≤Bs≤4) and 3 (Bs≤3) [28]. Bs ranges from 0.55 (sub-basin 1) to 3.03 (sub-basin 25). Most of the studied sub-basins belong to classes 1 and 2 are elongated with higher (Bs) values as compared to class 3 with less (Bs) values and are nearly circular shapes (Figure-11). High values of (Bs) are associated with elongated basins, generally associated with relatively higher tectonic activity. Low values of (Bs) indicate a more circular-shaped basin, generally associated with low tectonic activity. Rapidly uplifted mountain fronts generally produce elongated, steep basins; and when tectonic activity is diminished or ceases, widening of the basins occur from the mountain front up [27].

Table-9.
Values of different geomorphic indices in Rawanduz River Basin.

Sub-basin No.	B_l (m)	B_w (m)	B_S	L_{mf} (m)	L_s (m)	S_{mf}	V_{fw} (m)	E_{ld} (m)	E_{rd} (m)	E_{SC}(m)	V_f
1	8,759	15,656	0.55	10841	8279	1.30	74	2575	2523	1632	0.45
2	15,146	11,130	1.36	9636	6001	1.60	300	2985	2206	1517	0.32
3	18,340	9,820	1.86	2470	2135	1.15	84	2191	2369	1422	0.48
4	17,858	11,136	1.60	17578	11873	1.48	154	2108	1858	1108	0.18
5	8,979	4,281	2.09	7268	5551	1.30	260	2300	2286	1831	0.56
6	14,012	8,997	1.55	6728	5824	1.15	70	2520	2384	1663	0.09
7	24,219	16,343	1.48	19979	11641	1.71	168	1715	2389	991	0.16
8	12,228	7,372	1.65	9614	4185	2.29	171	1784	1991	1450	0.39
9	13,018	8,953	1.45	15692	11327	1.38	299	1169	1234	802	0.75
10	10,121	9,503	1.06	12188	7311	1.66	213	1933	1272	1004	0.36
11	17,178	5,986	2.86	9286	6897	1.34	270	2238	1368	1673	2.07
12	19,104	13,591	1.40	14979	7283	2.05	220	1981	1933	1116	0.26
13	8,760	4,408	1.98	3720	2565	1.45	416	1479	1469	1062	1.009
14	27,123	10,516	2.57	14649	9081	1.61	374	1754	1926	1052	0.47
15	19,025	11,070	1.71	23372	13908	1.68	337	1270	1420	615	0.46
16	10,288	6,424	1.60	3938	3301	1.19	260	1066	1149	883	1.16
17	16,142	10,566	1.52	4410	3635	1.21	347	1016	982	893	3.27
18	14,306	8,705	1.64	9222	4700	1.96	387	1640	1836	1356	1.01
19	27,431	11,567	2.37	9128	6483	1.40	282	1827	1918	1348	0.54
20	15,297	12,994	1.17	6660	4710	1.41	55	923	931	843	0.65
21	6,287	6,063	1.03	2712	2054	1.32	41	1027	1032	888	0.29
22	14,645	11,429	1.28	7782	5511	1.41	39	904	887	826	0.56
23	21,078	7,134	2.95	7406	6853	1.08	84	678	940	618	0.44
24	22,891	10,212	2.24	20411	15787	1.29	80	1334	1640	714	0.1
25	34,285	11,306	3.03	24740	11254	2.19	115	1348	1578	963	0.23
26	23,059	12,025	1.91	18959	14213	1.33	88	1139	1235	463	0.12

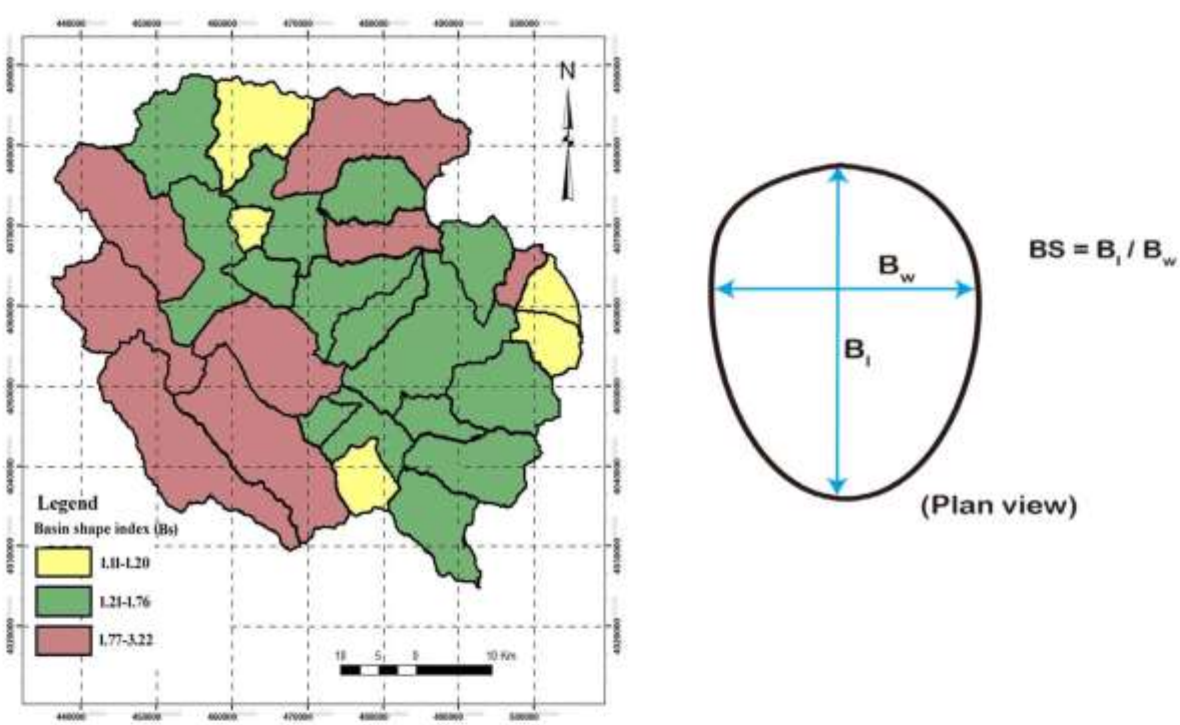


Figure-12 Distribution of (Bs) throughout the study area.

Basin asymmetry factor (A_f)

This index has been calculated for 26 sub basins. Results of the drainage basin asymmetry ranges between 25 (sub-basin 21) and 81(sub-basin 22), clearly suggest strong asymmetry. Results obtained show clear spatial variation of tectonic tilting at one side due to in-balance between incision and uplift. Ideally tectonically stable area should express the values 50, suggest no tilting and incision. Values of drainage asymmetry greater or less than 50 suggest tilting of the basin. It explains as values greater than 50 indicates that main river channel is shifted towards the left side of the basin looking downstream while values less than 50 indicates that the main river channel is shifting towards right side of the basin looking downstream. This index can be used to evaluate tectonic tilting at the scale of the drainage basin [2]. The Asymmetric Factor is classified into three

Classes: 1) ($Af \geq 65$ or $Af < 35$), 2) ($35 \leq Af < 43$ or $57 \leq Af < 65$) and 3) ($43 \leq Af < 57$)

To find the tilting intensity of the sub-basins, we calculated the area of the right bank (rBa). We applied the absolute value of (AF-50) to make it possible to compare with other indices.

The area has experienced a lot of tectonic activity that It was clear through as tiling intensity values for some sub-basins reached 81.70 (sub-basin 22) (Figure-13) (Figure-14). And the mean value for the area was 50.47 (Table-10).

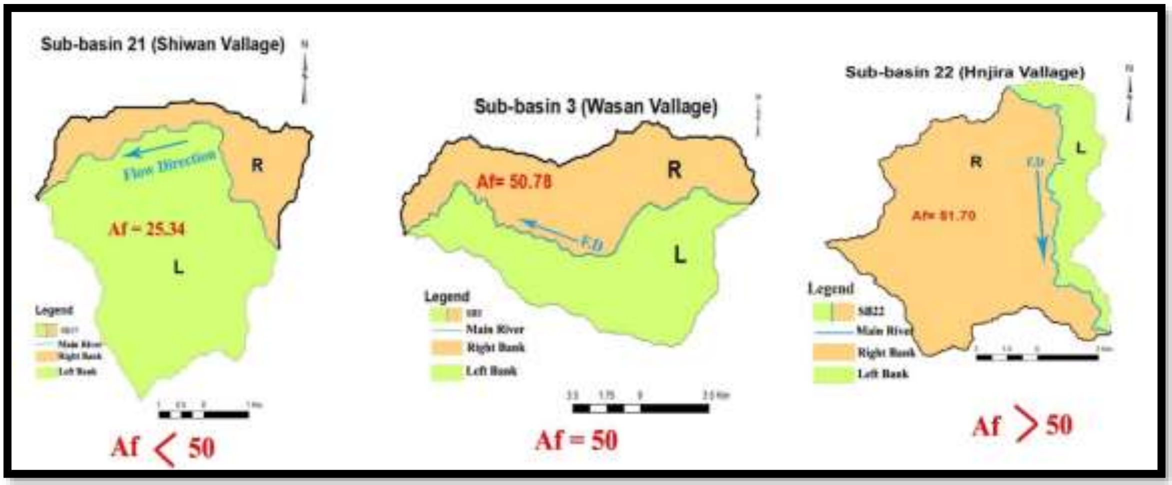


Figure-13 Examples of some sub-basins in the study area

Table-10. Asymmetry factor (A_f) values of the different basins of the study area. (Ar: area of the downstream right side of the basin; At: total surface of the basin)

Sub - basin	*Ar*	*At*	*Asymmetry factor (A_f)*
1	39.48	90.44	43.66
2	46.69	118.85	39.28
3	56.70	111.65	50.78
4	35.79	101.18	35.37
5	19.67	25.93	75.87
6	26.11	76.29	34.23
7	145.49	204.83	71.02
8	25.11	42.63	58.89
9	26.29	62.02	42.38
10	23.35	53.80	43.41
11	34.37	71.78	47.88
12	99.56	169.91	58.59
13	14.14	26.13	54.11
14	99.66	218.51	45.60
15	75.98	162.36	46.79
16	33.38	43.57	76.61
17	42.15	96.80	43.54
18	40.25	84.51	47.62
19	118.98	197.50	60.24
20	38.97	116.71	33.39
21	5.71	22.56	25.34
22	106.77	130.67	81.70
23	61.27	127.07	48.22
24	79.10	180.36	43.85
25	97.87	228.07	42.91
26	96.35	157.64	61.12

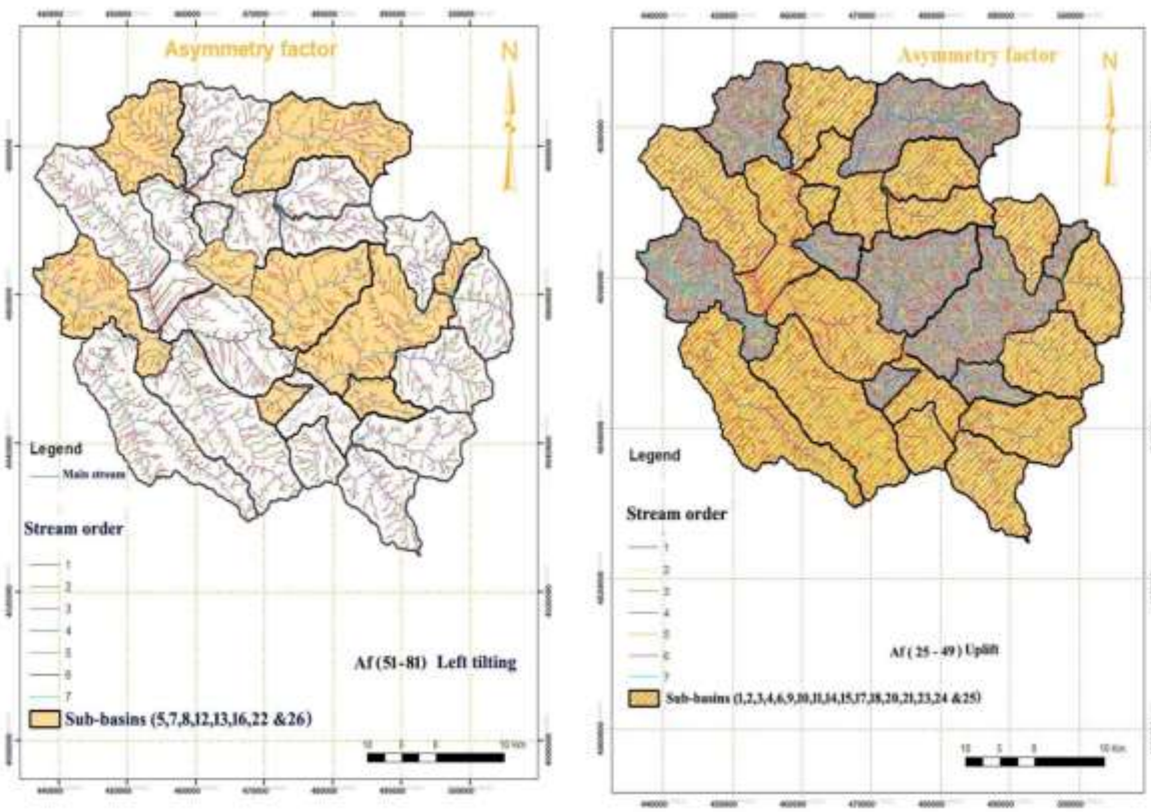


Figure-14 Map shows the Asymmetry in 26 sub basins of the Rawanduz Basin

Transverse topographic symmetry factor (T)

This factor mention migration of stream perpendicular to the drainage basin axis [29]. Transverse topographic symmetry factor is a vector with a bearing and magnitude from 0 to 1. We used the polygon centerline tool in ArcGIS to find the midline of a sub-basin (Figure-15), and then we calculated the parameters required in the equation mentioned above. For perfectly symmetrical basin, T = 0. As asymmetry increases, T increases and approaches a value of 1 [29], which leads to the displacement of the main stream in the direction of the cracked subsurface. Values of T are calculated for different segments of streams and indicate preferred migration of streams perpendicular to the drainage basin axis. In our study area (Figure-14), the results of the T factor were ranging from 0.17 (sub-basin 12) to 0.77 (sub-basin 7), the average value of T, is moderate (0.46), which indicates that this basin is asymmetrical [30]. Similar and can be correlated to the basin asymmetry factor results and that assures the tectonic effect within the area the detailed results see.

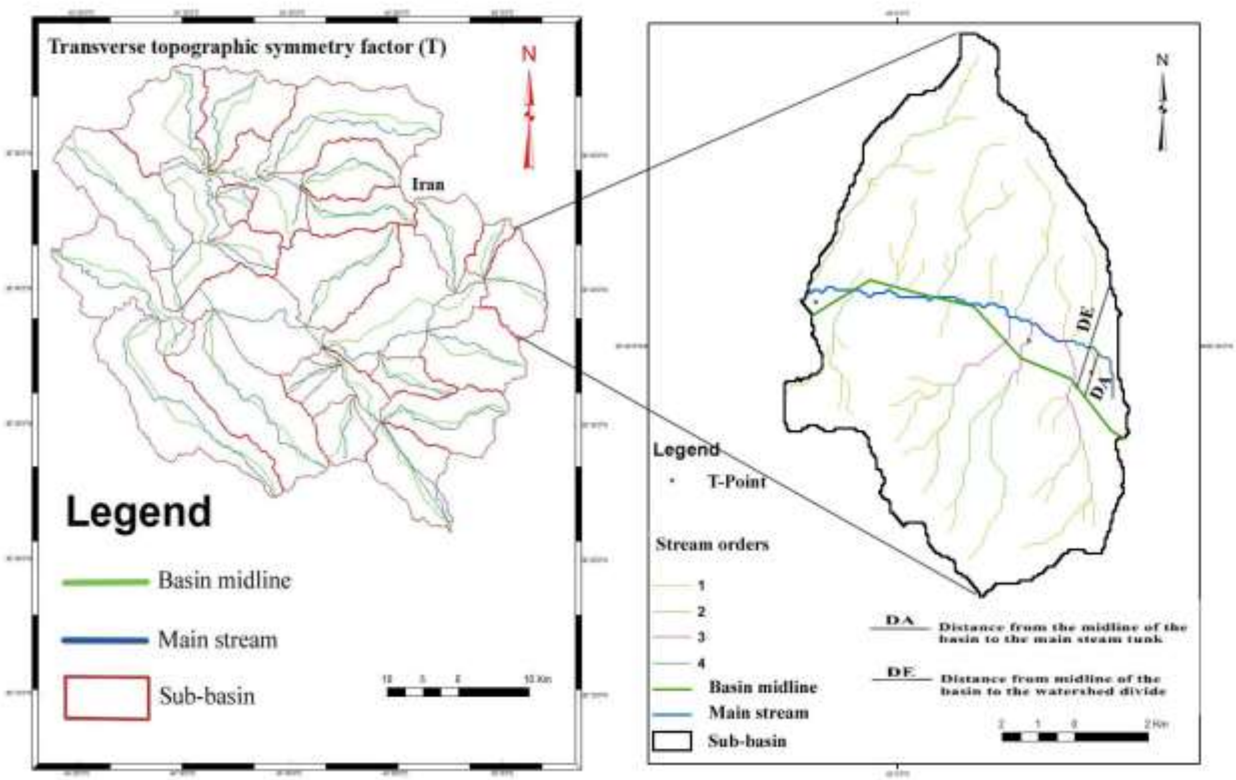


Figure-15 describing the midlines of the sub-basins within the study area

Sinuosity index (Si)

Rivers meander in order to maintain a channel slope in equilibrium with discharge and sediment load. On a meandering river, a river meanders when the straight-line slope of the valley is too steep for equilibrium-The sinuous path of the meanders reduces the slope of the channel [31]. It can be defined as the stream tendency to move back and forth across its floodplain, generally any tectonic deformation that affects the slope of the river valley results in a corresponding change is sinuosity to mountain the balance of the channel slope in an S-shaped pattern. The most sinuosity for a stream to reach usually happen in zones characterized by down tilt, while in uplifted zones the least sinuosity can be found [2]. [32] Suggest a classification to the sinuosity index. They described channel with values than 1.1 as straight, (1.1-1.5) as sinuous, and values more than 1.5 as meandering. (1.1-1.5) as sinuous, and values more than 1.5 as meandering (Figure-16).

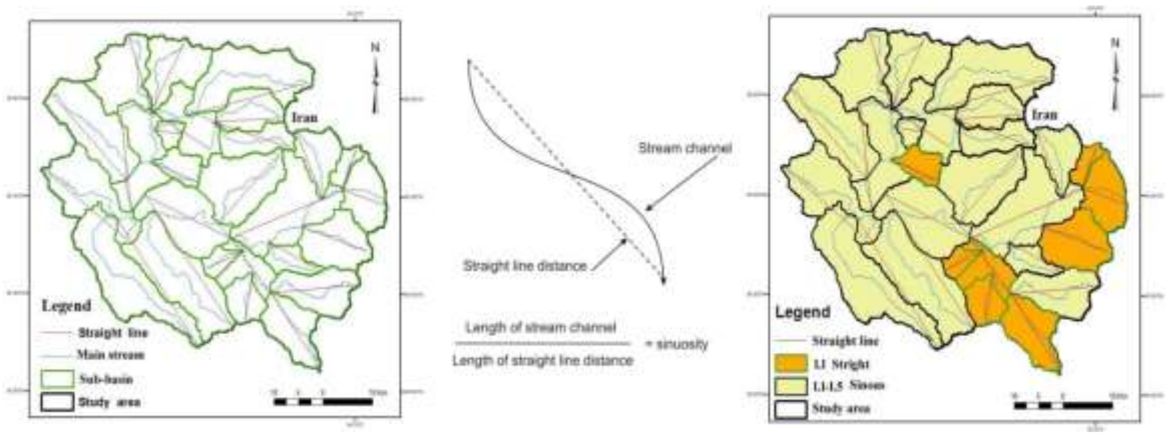


Figure-16 Distribution of (Si) throughout the study area.

In the Rawanduz River Basin, values more than 1.4 are indicating strong sinuosity that corresponds to the prevailing tectonic activity in the form of tectonic structures.

Discussion of relative tectonic activity based on morphometric and geomorphic indices

Geomorphic indices of active tectonics are helpful tools to analyze the influence of active tectonics. These indices have the characteristic of being calculated from GIS and remote sensing packages over large areas as a reconnaissance tool to identify geomorphic anomalies possibly related to active tectonics [3]. Based upon the shape related indices (Rc), (Rf), (Re), (Ls) and (Cc) their results were found to be similar and that for most sub-basins had an elongated nature. [18] Explained that the circularly shaped basins as basins connected with tectonically undisturbed environment, while elongated basins are connected with tectonically active regions. It so worth mentioning that some of these indices results can be caused by the form irregularities of the sub-basins. The lower part of the main river basin, especially in the High folded zone can be found many structures affecting the drainage system. The difference between the Zagros Suture Zone and High Folded Zone was very distinguished during the analysis of the (R) indicator, which is in turn can be related to higher incision rates and erosion. Regarding the geomorphic indices results, most studies used a mixing of two indexes (S_{mf} and Vf) to supply semi-quantitative data of relative degree of tectonic activity of mountain fronts. Two studies using these indices supply an assignation to different tectonic activity classes [18] [19]. A number of different mountain fronts were analyzed in 26 sub basins of the Rawanduz River Basin. Mountain front analysis shows the lowest result as 1.08 in (basin no.23) and highest result as 2.29 in (basin no.8). Therefore, on the basis of obtained results, all the mountain fronts in 26 sub basins of the Rawanduz Basin fall in „tectonically active front" class 1 (Figure-17).

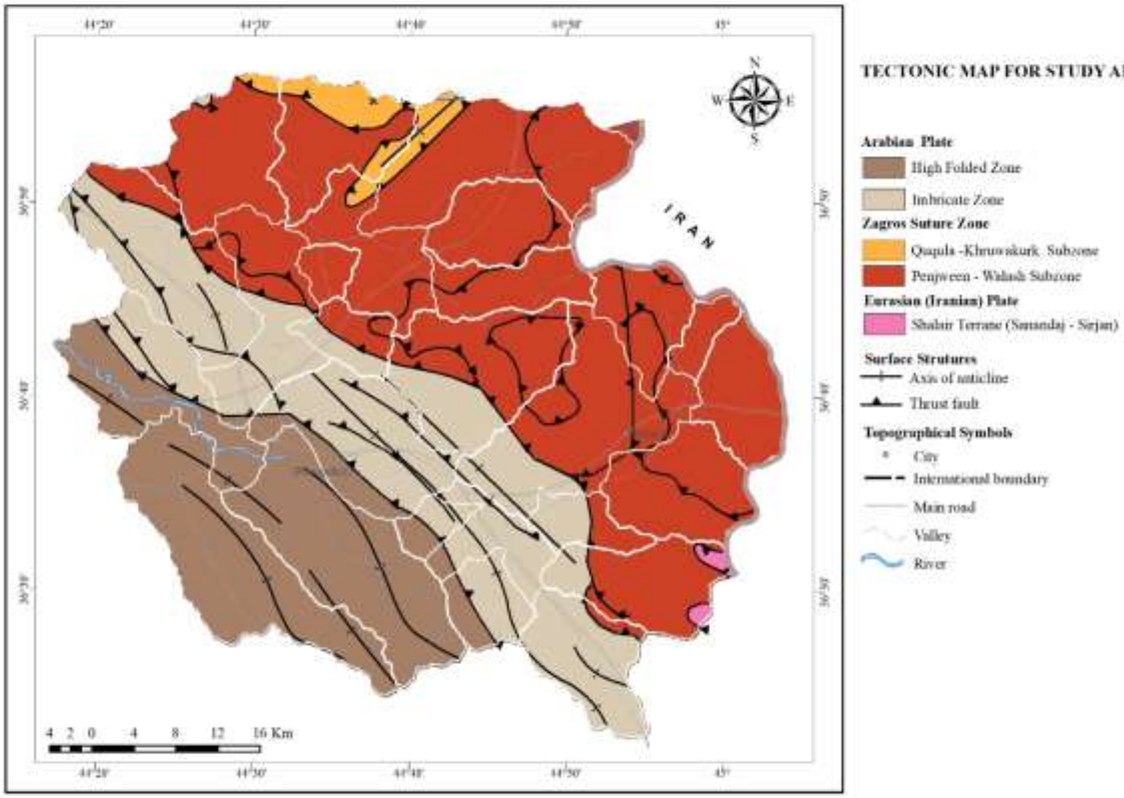


Figure-17 Tectonic map and distribution of sub-basins throughout the study area.

Table-11 Sub-basins location according to the Tectonic Zones

Tectonic Zones		
Zagros Suture Zone	Imbricate Zone	High Folded Zone
Sub-basins (1,2, 5,6,11,17,18,19,20,21 and 22)	Sub-basins (4 and 9)	Sub-basins (14 and 25)
Sub-basins (3,7,8,12,16,23 and 24)		
	Sub-basins (10,13,15 and 26)	

Results of the drainage basin asymmetry (Af) for 26 sub basins range between 25 (sub-basin 21) and 81(sub-basin 22), clearly indicate strong asymmetry. Obtained results express spatial variation of tectonic tilting at one side due to in-equilibrium between incision and uplift. Ideally tectonically stable region should express the values 50, suggest no tilting and incision. Values of drainage asymmetry greater or less than 50 suggest tilting of the basin. It is interpreted as values greater than 50 indicates that main river channel is shifted towards the left side of the basin looking downstream while values less than 50 indicates that the main river channel is shifting towards right side of the basin looking downstream. The rate of uplift and tectonic activity can also vary locally within a region. Among geomorphic indices, drainage systems are very sensitive to active deformation especially in the folded and thrust regions. Drainage basin asymmetry characterize that the sub basins in the near proximity of faults and thrusts, having relatively higher values while sub basins intersect with the main river channel and increasing distance from the main structures suggest relatively symmetric drainage system (Figure-19). In relation to the indicator (T), the values of its index are highly correlated with the (A_f) values and describe the high rates of asymmetry within the area, For the purpose of evaluating the relative active tectonics, the absolute difference is what is important, and values of A_f-50 range from about 1 to 31. In this study we presented the information on geomorphic indices that have been applied in other studies to assist the landscape in terms of potential tectonic activity. In general, the indices along a particular mountain front or area are discussed and a judgment made concerning relative tectonic activity [18], [21], [32], and [33].

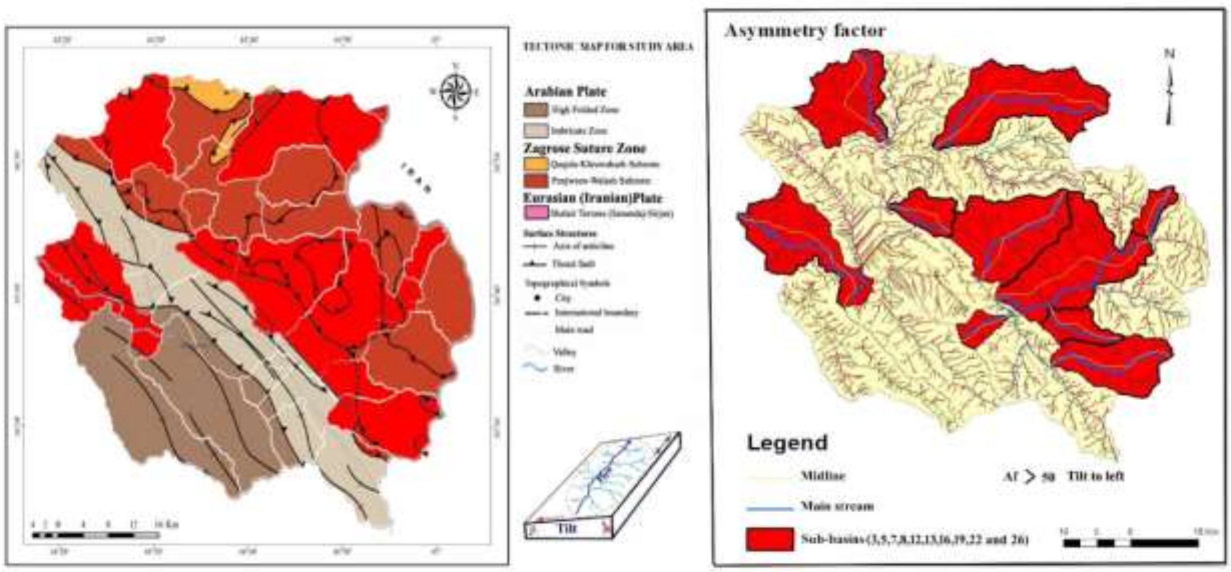
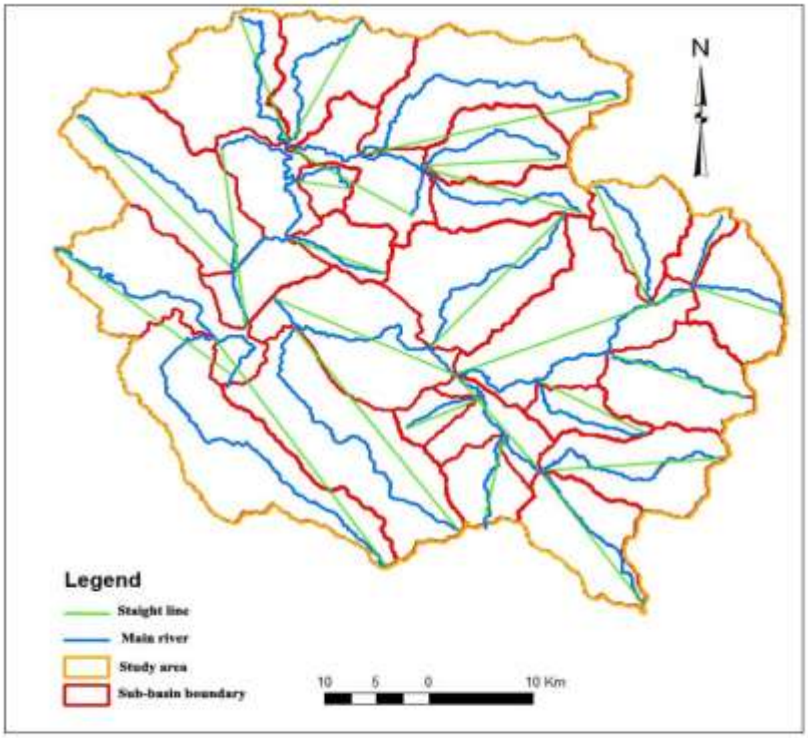


Figure-18 Map showing the Asymmetry in 26 sub - basins of the Rawanduz Basin.



(SL)	(VL)	Channel Sinuosity (S)
8.889075184	10.460502	1.176781812
13.97931291	16.761831	1.199045411
17.44158987	23.818855	1.36563554
16.63528925	19.198209	1.154065235
7.977925065	8.458298	1.060212766
13.55185447	16.268105	1.200433862
24.21914497	32.723568	1.351144644
11.62410708	14.280271	1.22850477
13.01842574	15.469524	1.18827916
8.781267672	10.44132	1.189044725
15.95745845	20.078683	1.258263217
18.23236981	22.877818	1.254791244
7.962305121	8.960863	1.125410652
27.03120569	35.630952	1.318141425
19.23825151	25.877141	1.345087987
10.0114795	11.429956	1.141685003
13.80019874	21.873162	1.584988913
13.17929161	17.405697	1.320685323
25.57993247	36.383246	1.422335499
14.37283334	20.26039	1.4096309
5.184121305	8.042678	1.551406213
14.11032659	20.376276	1.444068348
19.08176849	36.510685	1.913380567
22.17925268	27.402542	1.235503396
29.42560748	43.735013	1.486290913
21.34511205	33.534747	1.571073833

Figure-19 Map showing the Sinuosity in 26 sub basins of the Rawanduz Basin**.**

Conclusions

In this research, The study area is located in very perfect tectonic region of northern Iraq, which that include three tectonic zones (High Folded Zone, Imbricate Zone and Suture Zagros Zone), different morphometric and geomorphic indices such as mountain front sinuosity, Asymmetry factor, transverse topographic symmetry, channel sinuosity, Valley floor width to height ratio, and basin elongation ratio have been investigated in the Rawanduz River Basin to decipher the relative tectonic activity present in the study area by using satellite remotely sensed datasets. 26 sub basins have been selected for the detailed and precise study of these indices. Different geomorphic indices are showing different results in these sub basins. On the basis of the results each basin considered as a zone of tectonic activity. In addition to Results of Channel sinuosity indicates that sinuosity in the basins are the results of the tectonic activity. Rawanduz basin is easily classified in different tectonic zones based on the sub basins. According on the results of these indices have proven that geomorphic indices are very helpful in identifying regions on the basis of the tectonic activity. In this research, different morphometric indices that are regarding to the shape such as (Rc), (Rf), (Re), (Ls) and (Cc) their results were found to be similar and that for most sub-basins had an elongated nature. Asymmetry factor (Af) is sensitive to tilting and the values of Af significantly greater or less than 50 may suggest. In this study area were found the sub-basins (3, 5,7,8,12,13,16,19,22 and 26) (Figure-17), they have values greater than 50 which that mean tilting on the left side, the tributaries on the north (right) side of the main stream are long compared to tributaries on the south (left) side and in a drainage basin where the trunk stream flows west and tectonic rotation is down to the S-SE, If the tilting was in the inverse direction, then the larger streams would be on the left side of the main stream and the AF would be less than 50. Similar most geomorphic indices, the Af work alternative where each drainage basin is underlain by the same rock type. Another quantitative index to evaluate basin asymmetry is Transverse Topographic Symmetry Factor (T), Based on (Figure-13), Values of T are calculated for different segments of valleys and indicate mentioned migration of streams vertical to the drainage – basin axis. Regarding the results of the sinuosity index (Si), determine the river sinuosity values and classify the sinuosity into three classes according of tectonic movement that involved in the regions, through obtained the results the (Si) index between (1.06-1.91), that indicate active tectonics (Figure-16). Ratio of Valley Floor Width to Valley Height (V_f), calculated from the drawn cross Sections using DEM and Global Mapper, it was found that most of the sub-basins have class order no.1, This indicates that all tributaries have V-shaped valleys.

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Conflict of Interests.
There are non-conflicts of interest .

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الخلاصة

تعد منطقة الدراسة والتي تقع على طول الحدود الشمالية الشرقية للعراق موقعًا مثاليًا لاختبار فكرة وجود مؤشر للتنبؤ بالنشاط التكتوني النسبي. تُعتبر منطقة الدراسة هذه منطقة مميزة للغاية حيث تشمل ثلاثة أنطقة تكتونية رئيسية (نطاق الطيات العالية , نطاق التراكب ونطاق التصادم زاكروس) ، اضافة الى كونها تمتاز بمعدلات متغيرة من النشاط التكتوني الناتج عن تصادم الصفيحة العربية مع الإيرانية. تهدف هذه الدراسة إلى تسليط الضوء على إمكانية استخدام برامج أنظمة المعلومات في بناء قاعدة بيانات جغرافية مورفومترية لحوض نهر راوندوز، والذي يعد احد الأحواض الرئيسية لنهر الزاب الأكبر باستخدام نموذج الارتفاع الرقمي لبعثة المكوك الراداري (SRTM)) , بيانات لتقييم حالة تصريف هذا النهر بمساعدة نظم المعلومات الجغرافية (GIS) والاستشعار عن بعد. تم إجراء التحليل المورفومتري لحوض الصرف راوندوز أثناء قياس الجوانب الخطية والمساحية والتضاريس ، كما نقدم عملية جديدة لتقدير النشاط التكتوني النسبي وفقًا لمؤشرات الجيومورفيك المفيدة في تقييم التشكل والطبوغرافيا. تم تحديد 26 حوضًا فرعيًا في حوض نهر رواندوز. تشمل المؤشرات الجيومورفية المستخدمة ما يلي: عدم تناسق حوض الصرف (Af) ، ونسبة عرض أرض الوادي إلى ارتفاع الوادي (Vf) ، ومؤشر شكل حوض الصرف (Bs) ، ومؤشر تعرج الجبهة الأمامية الجبلية (Smf). يتم تجميع النتائج من التحليل والتعبير عنها كمؤشر للتكتونيات النشطة النسبية (Iat) ، والتي نقسمها إلى أربع فئات من النشاط التكتوني المنخفض نسبيا إلى العالي.

الكلمات الدالة : جيومورفك , تحليل مورفومتري , حوض نهر راوندوز, نظم المعلومات الجغرافية, نموذج الارتفاع الرقمي, مكوك البعثة الطوبوغرافية للرادار.