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Quantitative morphometric analysis of the watershed of Baki Basin, Eastern Anatolian using GIS methods

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After a brief presentation of the Baki catchment, the drainage network is analyzed using the Horton – Strahler classification system. From the amount of morphometric parameters, the drainage and the surface patterns, like relief and slope, are taken into consideration for the entire Baki watershed. Based on the analyzed patterns, a series of morphometric parameters specific to the stream network in the Eastern Anatolia which is part of Uluova stream and also Euphrates River were calculated and analyzed. All the values used in parameters equations and quantitative characterizations were extracted using ArcGIS 10.2.

Key words: GIS, Morphometric analysis, Elazığ, Baki Stream

1. Introduction

Morphometric analysis of drainage basins is highly complex and requires a large amount of work and attention. Nowadays, GIS technology enables us to make geographic research more objective by using these types of analyzes and large databases. The morphometric properties of hydrological basins and drainage networks are the result of a continuous evolutionary process. The size of the basins is directly related to the flux and energy circulating in the basin due to geographical conditions.

The numerical analysis approach of drainage basin morphology was first discussed by Horton (1945). Horton's law of flow lengths, consecutive flow sequences, found a geometric relationship between the number of flow arms. The basin laws indicated that the average basin area of the sequentially regulated flows had a graphically linear relationship. The laws of Horton, later Strahler (1952, 1957, 1958 and 1964, Schumm (1956), Shreve (1967), as research tools for making inferences about tectonic activity, hpsometric integral, drainage basin asymmetry, flow length slope index, It is developed by adding some geomorphological indices such as front folds.

Today, the determination of how the basin geometry changes against the processes has been one of the important issues of modern geomorphology. The drainage basin is the basic science of river geomorphology, which examines the relationships between surface shapes and the processes that change them (Singh, 1992). Morphometry, rivers, soil erosion, floods, droughts, river flows change, rivers' branching habits, flow characteristics and performance of the drainage lines are related to the hydrological and geomorphological responses (Garde, 2005; Mohd et al., 2013).

The bifurcation rate in the homogeneous host rock affects the morphometry of the surface and the current provides a significant control over the "peak" of the hydrograph (Chorley et al., 1957). It is expected that there will be low flood periods from long narrow basins with high forks, whereas floods are expected to be high in round basins with low bifurcation rate.

In basin studies, the characteristics of the basin are generally examined in three categories: linear (one dimension), area directions (two) dimensions and relief shapes (three dimensions). The data in the first category include the maximum order of flows, the number, length, area, circumference, and relief content of each of the basins in each row. In the second category, bifurcation rates, extension coefficient, circularity index, shape factor, drainage density, flow frequency, texture ratio, relief rate, length of surface flow, number of fixed channel maintenance and infiltration. In the third category, there are features such as channel slope, basin rate, relief ratio, hipsometry curve and longitudinal profile.

The morphometric analysis of the watershed provides a quantitative description of the drainage system, an important aspect of the characterization of watersheds (Strahler, 1964). As it can contain important information about morphometric characteristics, formation and development of the watershed scale, the development of hydrological and geomorphic processes in the basin carries explanatory information (Singh, 1992). GIS techniques are now widely used to evaluate the various terrain and morphometric parameters of drainage basins and water basins. The main objectives of this study are to explore basin drainage characteristics by using morphometric evaluation and to help the basin to reveal geomorphological development stages.

2. Study Area

The Basin of Baki River is 162.05 km² and is located between 38°59'56''- 39°11'54'' E longitude and 38°32'36''- 38°23'28'' N latitude. It is situated in the south-eastern part of Turkey (Eastern Anatolia), an important geographical region. More specific, Baki basin is located in the Elazig Province of Turkey, very close to Elazig city (Figure 1). Also, it is part of Uluova stream, which flows into Keban Dam Lake, a hydroelectric dam on the Euphrates.

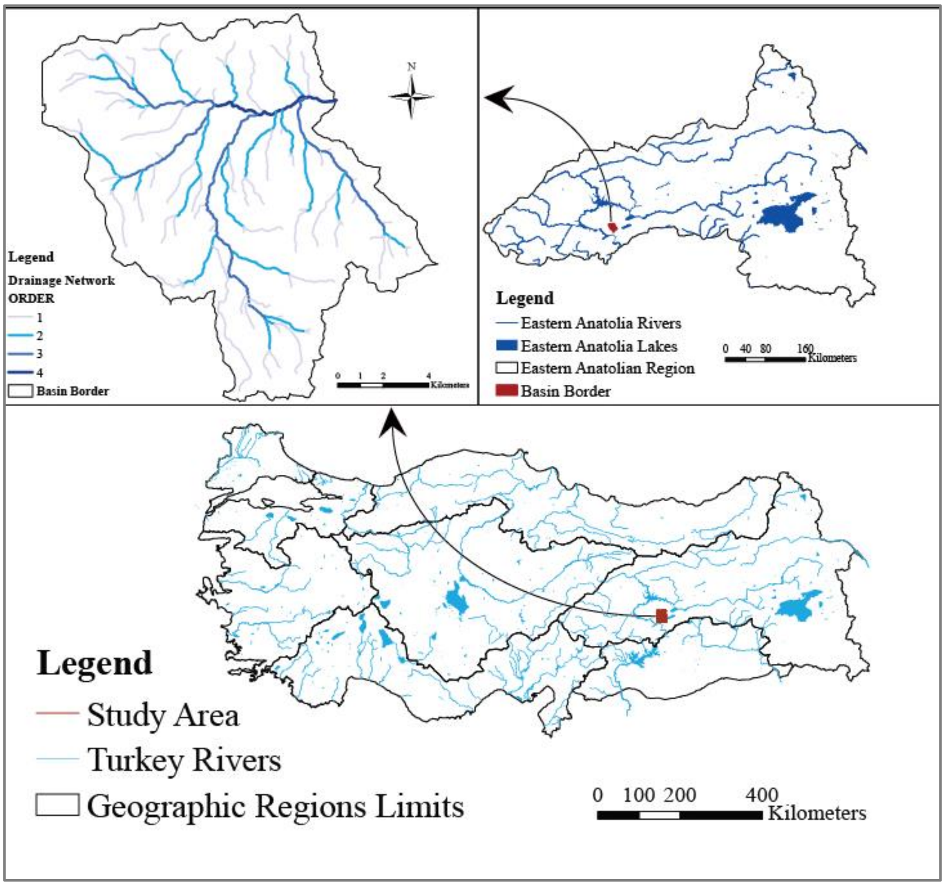


Figure 1. Localization of Baki basin in Turkey

3. Methodology

GIS software was used to determine the morphometric features of the hydrographical network in the Baki catchment. Thematic maps have been created using ArcGIS 10.2. The relief analysis of the Baki watershed required digitizing contours from the following topographical maps: Elazig region, no. L42-A1, L42-A2, K42-D3, K42-D4 at a scale of 1:25000. The Digital Elevation Model has a 10 m spatial resolution in order to better visualize the drainage network, basins and watersheds and was generated by using as an input, the contours in 3D Analyst Tools – Topo to Raster. In the present study, the surface analysis is based on the relief characterization, hypsometric and slope analysis. For the hypsometric analysis, the altitude range from the Digital Elevation Model has been reclassified in 6 classes using the Reclassify tool, calculating for each class the height from the lowest point and spread area. The values are presented in Table 4. Slope Analysis is divided in 2 parts, the basin slope analysis and the stream slope analysis, both are based on the Slope map, which was created using Spatial Analyst Tools – Surface – Slope. The watershed delimitation was carried out on the Digital Elevation Model. The flow direction, flow accumulation, stream order, watershed boundary and basin delimitation have been created using Spatial Analyst – Hydrology tools. The values for the calculation of the morfometrical parameter were automatically generated using the Calculate Geometry tool. As an overview on the quantitative morphometric analysis, the morhometrical parameters which have been calculated are presented in the last table (Table 5).

4.Findings

The morphometrical analysis has four parts. In the first part, parameters that describe the drainage network have been calculated. The second part describes drainage texture and drainage density. The third part shows the values of basin geometry specific parameters. The last part is about surface analysis like relief, hypsometry and slope characterization. All parameters were calculated using the methods of Horton (1945), Strahler (1957), Mueller (1968), Schumm (1956), Smith (1950), Black (1972), Faniran (1968), Langbein (1947), Miller (1953), Luchisheva (1950), Zăvoianu (1985), Pareta (2011).

A.Drainage Network

For Baki's drainage network the Horton- Strahler classification system was used. The result is a total of 5 orders, with the maximum frequency in the first order (Figure 2). This ordering method started from the simplest and smallest fingertip tributary and progressed to the largest and most complex watercourse. Thus, a river segment of second order appears as a result of the junction of two first-order streams. In order to obtain a higher order it must unite with another stream segment of the same order, and so on.

Table 1. Ord: Stream Order, Nu: Number of streams, Rb: Bifurcation Ratio, Nu-r: Number of streams used in the ratio, Rbwm: Weighted mean bifurcation ratio

Ord	Nu	Rb	Nur	Rb*Nur	Rbwm
I	355				***4.17***
II	86	4.13	441	1820.41	
III	21	4.10	107	438.19	
IV	4	5.25	25	131.25	
V	1	4.00	5	20.00	
Total	467	17.47315	578	2409.84	
Mean		***4.37***			

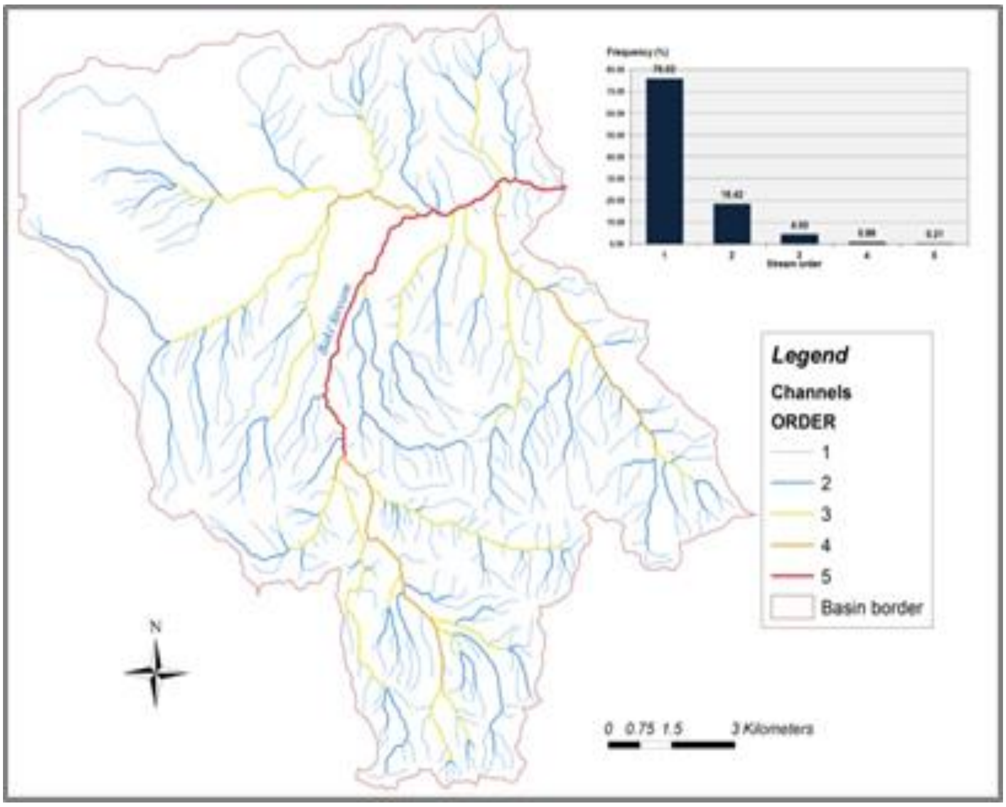


Figure 2. Baki's Drainage Network map Strahler and in Eastern Anatolia; Classification

According to Horton, the morphology of stream channel networks is characterized by three laws: the law of stream numbers, the law of stream lengths and the law of stream areas. The first law states that "the numbers of streams of different orders in a given drainage basin tend closely to approximate an inverse geometric series in which the first term is unity and the ratio is the bifurcation ratio" (Horton, 1945). In table 1 the bifurcation ratio has been calculated by dividing the number of streams of a given order by the number of streams of next higher order (Table 1). Stream Number (Nu) represents the number of stream segments for each order. Horton (1945) mentioned that "the bifurcation ratio ranges from about 2 for flat or rolling drainage basins up to 3 or 4 for mountainous or highly dissected drainage basins." The values which have been calculated during this research show that the mean bifurcation ratio is 4.37. This denotes the fact that Baki basin is comprised mostly of mountainous and fragmented hilly surface.
The weighted mean bifurcation ratio (Rbwm) is an index of more representative bifurcation ratio of each successive pair of orders. It is obtained in 3 steps. The first step is to find out the number of stream segments involved in each pair of orders used in bifurcation ration calculation (Nu-r). The second step is to multiply the bifurcation ratio for each successive pair of stream orders by the total number of stream orders involved (Rb*Nu-r). And the last step is to divide the total numbers for these columns (Rb*Nu-r / Nu-r). In the present study of Baki basin the weighted mean bifurcation ratio is 4.17 whereas the mean bifurcation ratio is 4.37.
The second law holds the fact that "the average lengths of streams of each of the different orders in a drainage basin tend closely to approximate a direct geometric series in which the first term is the average length of streams of the 1st order" (Horton, 1945).

Table 2. Ord: Stream Order, Nu: Number of streams, Lu: Stream length, Lum: Mean stream length, Lur: Stream length ratio,Lur-r: Stream length used in the ratio, Luwm: Weighted mean stream length ratio.

Ord	Lu (km)	Nu	Lum	Lur	Lur-r	Lur*Lur-r	Lump
I	241.50	355	0.68				***2.21***
II	90.49	86	1.05	1.55	1.73	2.68	
III	56.35	21	2.68	2.55	3.74	9.53	
IV	17.74	4	4.44	1.65	7.12	11.77	
V	10.88	1	10.88	2.45	15.32	37.57	
Total	416.96	467.00	19.73	8.20	27.90	61.54	
Medie				***2.05***			

Length ratio (Lur) is the ratio of the mean (Lum) of segments of order (Su) to mean length of segments of the next lower order (Lum-1) (Table 2). Length means (Lum) were obtained by multiplying stream segments (Nu) of each order with steam segment length (Lu). In the present study, the mean length ratio is 2.05. Weighted mean stream length ratio has been calculated by dividing the totals of the last 2 columns (Lur*Lur-r/Lur-r). The result is 2.21.

Table 3. Ord: Stream Order, Nu: Number of streams, A: Basins Area, Am: Mean Area, Ar: Area ratio, Ar-r: areas used in the ratio, Arwm: weighted mean aria ratio

Ord	A(km²)	Nu	Am	Ar	Ar-r	Ar*Ar-r	Arwm
I	90.15	355	0.25				***2.68***
II	37.11	86	0.43	1.70	0.69	1.16	
III	20.03	21	0.95	2.21	1.39	3.06	
IV	7.98	4	1.99	2.09	2.95	6.16	
V	6.10	1	6.10	3.06	8.09	24.76	
Total	161.37	467.00	9.73	9.06	13.11	35.15	
Medie				***2.26***			

Aria ratio (Ar) is the fundamental parameter for Horton's third law. This supports the fact that "the average areas of drainage basins of successively higher orders tend to form an increasing geometric progression in which the first term is the average area of first-order basins and the ratio of successive average areas". For calculation of this parameter it's necessary to follow a few steps (Table 3). First step is to define basins for each segment and extract the area values (A). In the next step the mean aria was calculated by dividing the areas of basins for the stream segments by the number of streams (Nu). In the last step, the value of mean aria (Am) for each order was divided to the value of mean aria of smaller order resulting aria ratio (Ar). Baki basin mean aria ratio is 2.26 and weighted mean aria ratio is 2.68. Total basin area is 161.37 km².

Theoretically, the drainage basin area increases at the same rate as the increase of stream length. This statement is related to another parameter called Length Area Relation (Lar). For the calculation of this relationship, Hack (1937) has found that the two variables are related according to the formula Lar = 1.4 A0.6, where, A is basin area. This means that the length of a given stream is proportional to the respective area to the power of 0.6 (Zăvoianu, 1985). The value for this parameter for Baki basin is 29.57.

The Rho coefficient (ρ) is an important parameter relating drainage density to physiographic development of a watershed which facilitates evaluation of storage capacity of drainage network and hence, a determinant of ultimate degree of drainage development in a given watershed (Pareta, 2011). The result for Rho coefficient Baki watershed is 0.47.

Calculation of the sinuosity coefficients requires knowledge of the main channel length (Cl), measured along the river course on a map projection, the minimum aerial distance (Adm) and the length of the valley axis (Vl). Main Channel Length is 20 km; the Valley Length is 13.1 km, while the Minimum Aerial Distance is 12.82 km. All these values have been generated by ArcGIS 10.2.

Coefficient of topographical sinuosity (Ts) is obtained as the quotient between the valley length (Vl) and the straight line distance between the two extreme points (Adm) (Mueller, 1968, Zăvoianu, 1985). Topographical sinuosity is the result of the interaction of geological and geomorphologic factors from which the undulating course of valleys has resulted in the course of time. The result for Baki watershed is 1.02.

Coefficient of hydraulic sinuosity (Hs) is determined by the laws of hydrodynamics, water courses, under the influences of slope, of the nature of the rock below the river bed, and also of suspended load, tend to meander along valley bottoms, resulting in sinuous courses which may deviate to a greater or lesser extent from the valley axis" (Zăvoianu, 1985). This is the result of the ratio of the channel length (Cl) to the valley length (Vl). The result for Baki watershed is 1.53. Leopold (1964) showed that the coefficients of hydraulic sinuosity can reach values lower than 1.5 for sinuous rivers and higher than 1.5 meandering rivers up to 4.

Coefficient of river sinuosity (Ks) is also a dimensionless value, given by the ratio of the main-channel length (Cl), to the straight-line distance (Adm) between the two extreme points (Luchisheva, 1950, Zăvoianu, 1985). The result for Baki watershed is 1.56.

Forward, Mueller (1968) suggested the following formula for calculating the proportions of Topographical Sinuosity Index (TSI) and Hydraulic Sinuosity Index (HSI). This percentage indicates the river deviation from a straight line to hydraulic sinuosity in the first case and to topographical sinuosity in the second (Zăvoianu, 1985). The value for Baki watershed of Topographical Sinuosity Index is 3.90 % and the value of Hydraulic Sinuosity Index is 96.10%.

B. Basin Geometry

Basin perimeter (P) of a drainage basin is the linear length of a drainage basin perimeter. The perimeter of Baki watershed is 70.56 km. This value has been offered by the Geometry Calculation function in ArcGIS 10.2. The relative perimeter (Rp) has been calculated dividing the basin area by the basin perimeter, as such, the value for Baki basin is 2.29.

The basin length (Lb) has been calculated using Measure tool in ArcGIS 10.2, representing the distance between the watershed mouth to the upper limit of the watershed near the main river source (Horton, 1945). The Baki basin length is 13.10 km.

Mean width of the basin (Wb) is considered to be the ratio of the area (A) and the maximum length (Lb) (Chebotarev, 1953, Zăvoianu, 1985). The value for Baki basin mean width is 12.32km.

Form factor (Ff) is a quantitative description of basin shape introduced by Horton (1945), which represents the "dimensionless ratio of the area a drainage basin to the square of its maximum length". The form factor for Baki basin is 0.94 which means that the form tends to be a rectangle, whereas 1.273 is the value for a perfect circle.

The compactness coefficient (Cc) represents the ratio of the actual basin perimeter (P) to the perimeter of a circle of equal area (P') (Luchisheva, 1950, Zăvoianu, 1985). The value of compactness coefficient for Baki basin is 1.57, which means that the shape is approximately a rectangle, while the value for basin with perfect circle form is 1.00.

Miller (1953) introduced the circularity ratio (Rc), which represents the quotient between the area of a basin (A) and the area of a circle whose circumference is equal to the basin perimeter (P) (Zăvoianu, 1985). Circularity ratio for Baki basin is 0.41, which is the next proof that the basin shape tends to be a rectangle, because the circle form has value 1.00.

Schumm (1956) proposed a unique parameter, elongation ratio (Re), to describe basin shape, by dividing the diameter (Dc) of a circle of area equal to that of the basin, and the maximum basin length (Lb)

(Zăvoianu, 1985). The resultant for Baki basin is 1.09 that means that the basin shape is a rectangle. For a perfect circle the value should be 1.275.
Rotundity coefficient or elipticity index (Ie) provides an indication of the shape of a basin. When equal to unity the basin form tends to be a perfect circle, the value increasing to 1.27 in the case of a square basin and to 10-15 in the case of very elongated basins (Horton, 1945). The value for Baki basin is 1.20.
The ratio of main channel length (Cl) to the length of the watershed perimeter (P) is the fitness ratio (Rf), which is a measure of topographic fitness (Pareta, 2011). The value for Baki watershed is 0.19.
Watershed Eccentricity (τ) is a dimensionless parameter used for the measurement of basin length to the center of mass and at right angles to the center line. Black (1972) found a correlation wherein basins with higher eccentricity values also had higher peaks of streams discharge. To calculate this parameter it is necessary to obtain the values of the straight length from the watershed mouth to the centre of mass of the watershed (Lcm), which in case of the studied basin is 5, 35 m, and of the width of the watershed (Wcm) at the centre of mass and perpendicular to Lcm, which is 5, 81 m (Pareta,2011). The result of watershed eccentricity of Baki watershed is 1.

C. Drainage texture

In order to define the number of streams per unit area, Horton (1945) introduced a parameter called the stream frequency (Fs). The value of this parameter shows that in Baki watershed are 2.89 streams per unit area.
Drainage density (Dd) represents the average length of streams within the basin per unit of area (Horton, 1945). As a result, a smaller value means a higher density of network. A high density may indicate the existence of a well developed channel system. Also, this can show a situation where the surface runoff moves rapidly from slopes to channels, thin/deforested vegetation cover, basin surface (soil and lithology) has generally low infiltration rate. The value of drainage density for Baki basin is 2.58, which means that Baki basin is well drained by a developed drainage network.
Schumm (1956) used the inverse of drainage density or the constant of channel maintenance (C) as a property of landforms. Theis paramenter indicates the number of square kilometers of basin surface required to develop and sustain a channel 1 kilometer long. The constant of channel maintenance indicates the relative size of landform units in a drainage basin and has a specific genetic connotation (Strahler, 1957). The value for Baki watershed is 0.39.
Faniran (1968) introduces the drainage intensity (Di), as the ratio of the stream frequency (Fs) to the drainage density (Dd). The value of drainage intensity for Baki watershed is 7.48 which represent a high value (Pareta, 2011). This means that drainage density and stream frequency have an important effect on the extent to which the surface has been lowered by agents of denudation.
Drainage texture (T) is an expression of the relative spacing of drainage lines in a fluvial dissected terrain. According to Smith (1950), drainage texture is classified into four categories: coarse ($T \leq 4$), moderate ($T = 4 - 10$), fine (T value is above 10), and ultra-fine or badlands topography (T value is >15) (Faniran, 2015). The drainage texture for Baki catchment is moderate, the value resulted being 6.62.
It is defined as the total number of stream segments of all orders per perimeter of that area
The length of overland flow (Lg) refers to the distance that the water is crossing on a hill side, on the maximum slope path, before is carried out by the watercourse. This parameter is an important variable on which runoff and flood processes depend on (Horton, 1945). The length of overland flow is equal with the basin area divided by double channels length. The value of length of overland flow for Baki basin is 0.19.

D. Relief Analysis

Relief refers to the measurement of the change in vertical elevation in a drainage basin. The action and intensity of external agents depend on the global position and altitude, which determines climatic conditions and hence the rates of flow of matter and energy. Baki watershed was developed in a region with high altitude, which ranges between 996-2005 m and covers 161 km². The higher altitudes are in the southern part of the basin while the lower relief values are on the left part of Baki basin.
For relief analysis, the vertical distances traversed by channels and drainage basins have been calculated using the Digital Elevation Model (Figure 3). These parameters determine both runoff processes and drainage-basin evolution.
The maximum altitude (Z) is the vertical distance from sea level to the highest point in the basin area. The maximum altitude for Baki's watershed is 2005 m.
The minimum altitude (z) is measured from sea level to the lowest point of the basin. The lowest point of a basin is watershed mouth, which corresponds to the minimum altitude point. For Baki's watershed the minimum altitude is 996 m.

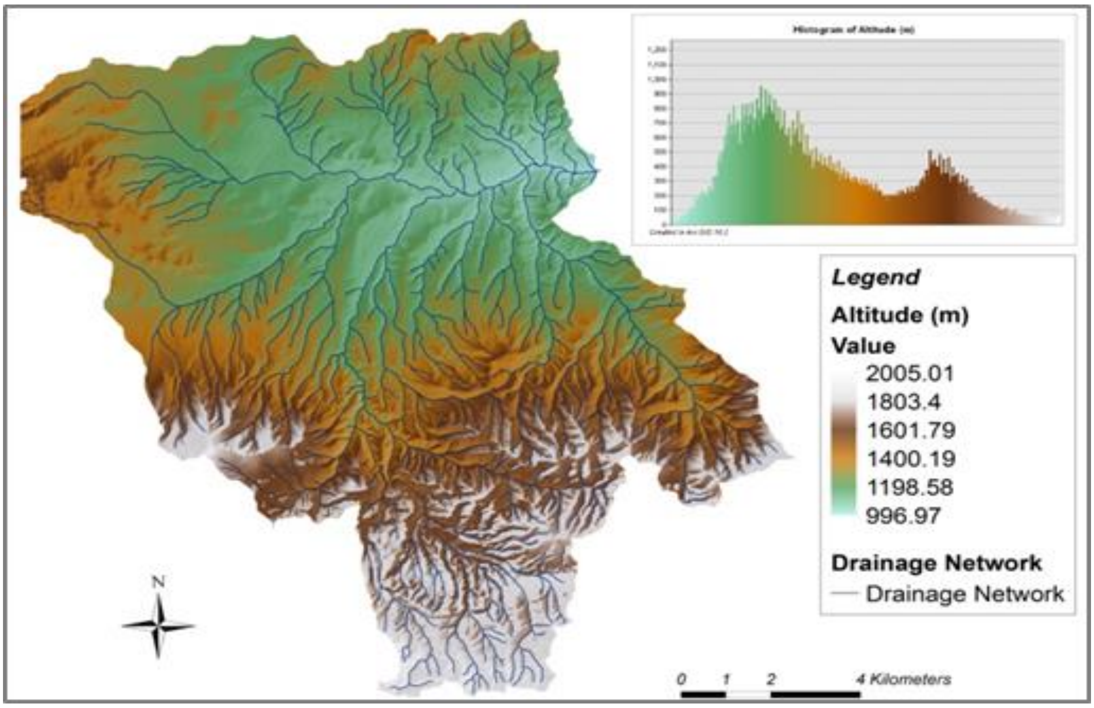


Figure 3. Digital Elevation Model of Baki basin;

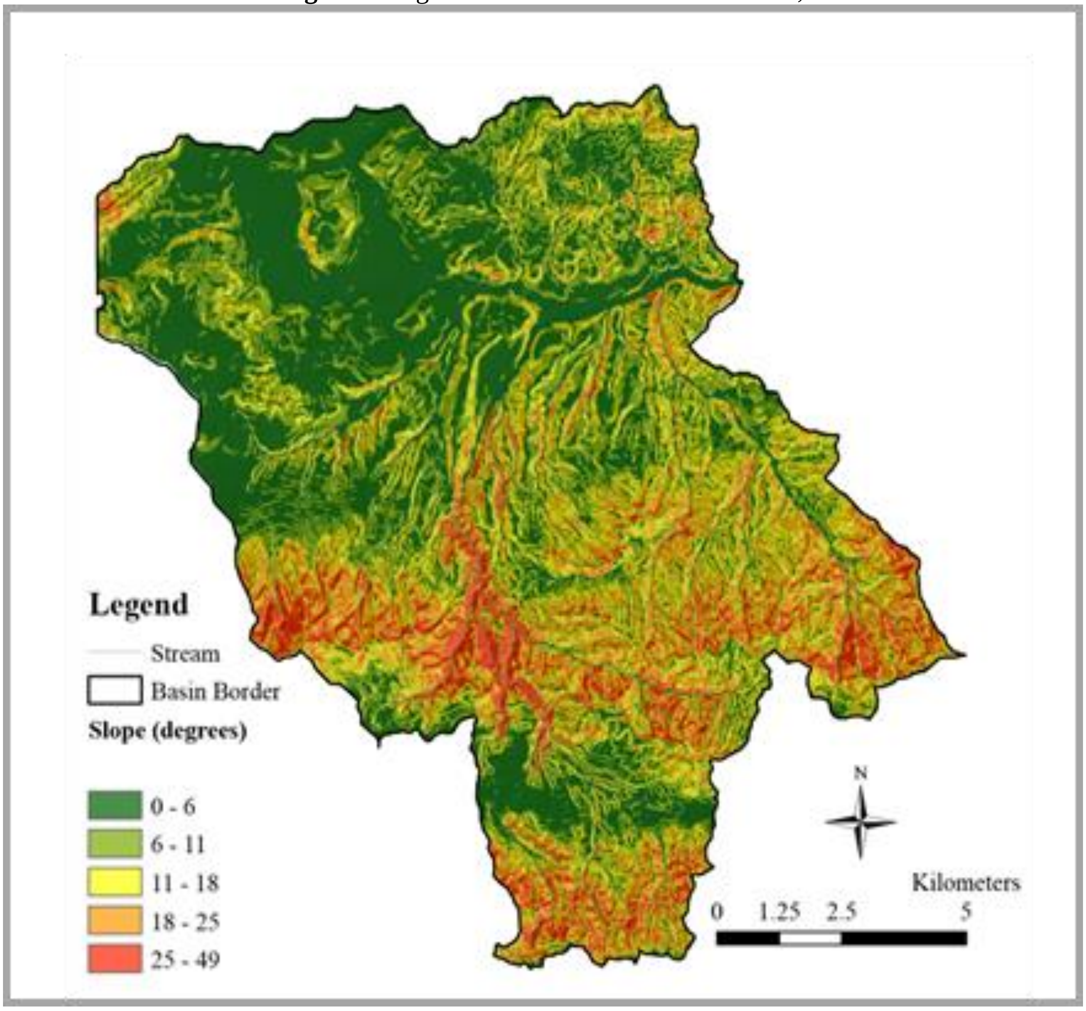


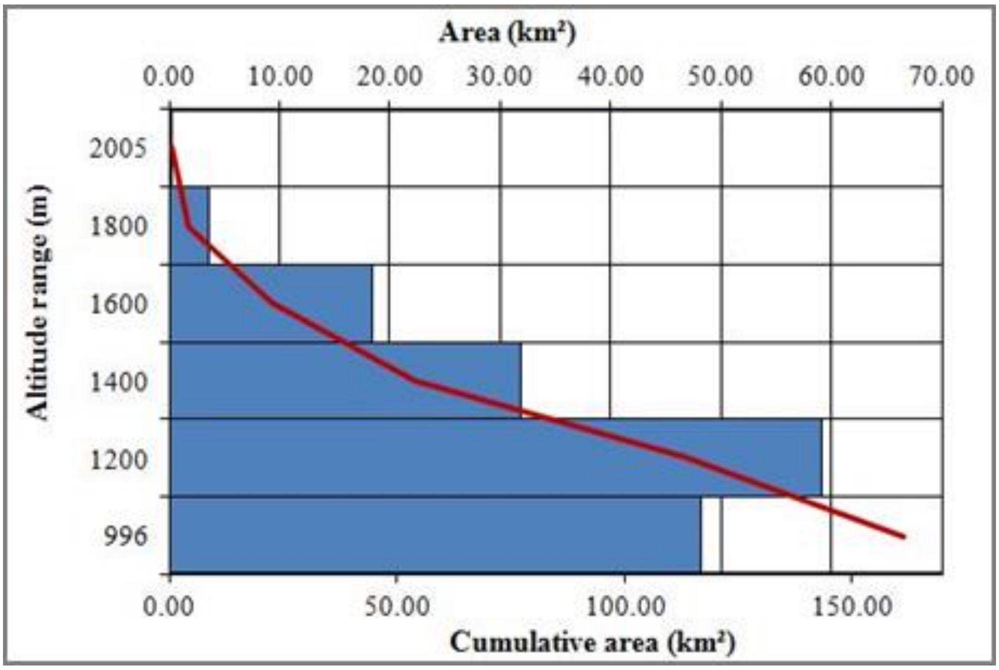
Figure 4. Slope distribution in Baki watershed.

The basin height (H) also termed as the total or maximum basin relief (Schumm, 1956) is given by the difference between the maximum and minimum basin altitudes. Baki's basin height is 1109 m.
Absolute Relief (Ra) represents the difference in elevation between a given location and sea level. Baki watershed is 2005 m high.
Hypsometry is a measure of the relationship between elevation and area in a basin, watershed or catchment (Langbein, 1947; Strahler, 1952). Basin hypsometry is strongly tied to flood response and the maturity of the erosion of a basin. The Hypsometric Index (a value) and Hypsometric Curve (a curve) are products of hypsometric analysis.

Table 4. Hypsometric Absolute and Relative values (H = 1009.00, A = 16);

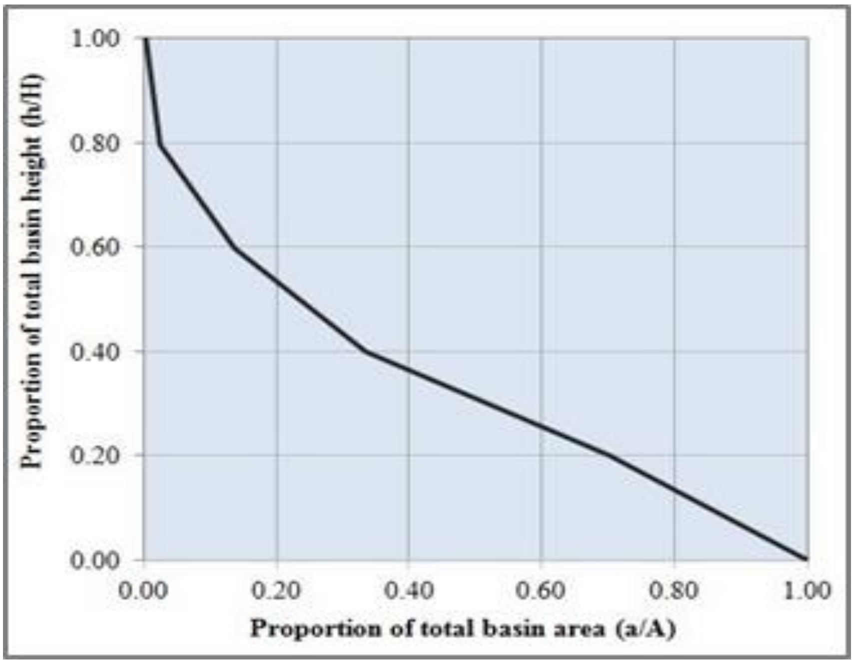
Nr.	Altitude Range	Height (m)	Area (kms)	h/H	a/A
1	2005	1009	0.24	1.00	0.001
2	1800-2005	804	3.87	0.80	0.024
3	1600-2005	604	22.20	0.60	0.138
4	1400-2005	404	54.07	0.40	0.335
5	1200-2005	204	113.14	0.20	0.701
6	996-2005	0	161.37	0.00	1.000

The altitude range from Digital Elevation Model has been reclassified using ArcGIS 10.2 in 6 classes, calculating for each class the height from the lowest point and spread area (Table 4). The values have been normalized by diving maximum height in the basin to height for each class and total area to the each class area. Absolute units of each class, area and height of partial surfaces, are the components for the first graph. The partial areas (km²) were used to construct the histogram, which represents the form of a frequency-distribution. The class interval of 200 m for the Baki basin (Graph 1) has the largest areas at moderate altitudes, between 1200 and 1400 m, the mean altitude of the basin (1341 m) falling in this interval. The frequency-distribution representation of the areas can be used to construct a hypsometric curve of cumulative absolute frequencies.



Graph 1. .Hypsometric curve and histogram in absolute units.

Strahler (1957) holds the fact that, for a quantitative analysis, plotting of hypsometric curves in absolute units is not always advisable, because areas of various sizes cannot be compared, the slope of the curve obtained differing greatly in relation to scale. To remove this inconvenience, a dimensionless parameter is necessary. The percentage hypsometric curve of Baki basin has been created using relative cumulative values of partial areas and heights (Graph 2). The values of partial areas, on the horizontal axis (x), were obtained by dividing area values to the highest value (161.37 km²). The values of heights, on the vertical axis (y), were calculated by dividing each value to the maximum height (1009 m). The graph represents the hypsometric curve. Convex hypsometric curves characterize young slightly eroded regions. S-shaped curves characterize moderately eroded regions. Concave curves point to old, highly eroded regions. The hypsometric curve of Baki basin shows that the basin has moderate eroded stage of evolution.
The Hypsometric Index (HI), sometimes called the Elevation/Relief Ratio, can be calculated for any basin dividing the diference between the mean elevation value and minimum elevation value to basin height. Willgoose & Hancock (1998) consider values >0.5 dominated by diffusive processes. HI values <0.5 are considered dominated by fluvial erosion (channel processes play a larger role). Straight hypsometric curves, where HI=0.50, suggest a relatively stable, but still developing landscape. The value for HI of Baki basin is 0.50.

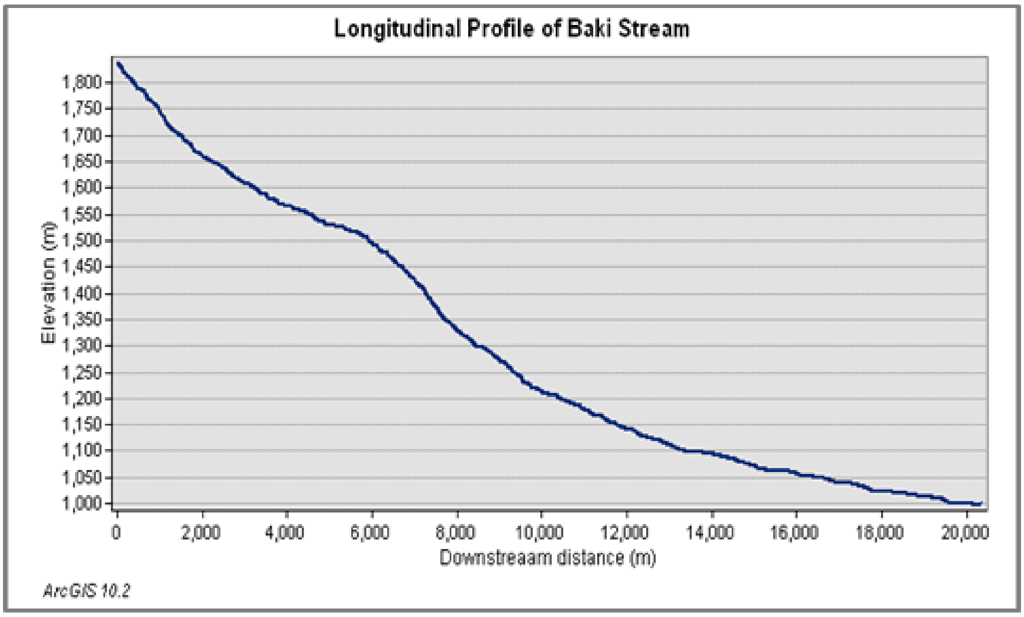


Graph 2. Hypsometric Curve of Baki basin;

The longitudinal profile represents an important way to characterize average stream slopes and to determine the stage of evolution (Graph 3). The form of the profile, is the result of several factors like the concentration of the discharge collected by a drainage network into single channels, which determines the transport capacity of the main stream, the decreasing slope of valley sides from the source to the mouth in most drainage basins, Longitudinal Profile of Baki stream shows that the stage of evolution is moderate. There are no major river rapids. It can be observed that Baki stream profile has convex form between 1600 and 1300 m. This portion of the stream transverses a mountainous region and values of slope are high.

E. Slope Analysis
Slope is defined as the tangent of the angle of inclination of a line or plane defined by a land surface and represents the best parameter to indicate how gravity determines and controls the water flows and materials mobility. The slope elements are controlled by the climatic and morphologic processes in the area underlying the rocks of varying resistance (Zăvoianu, 1985). An understanding of slope distribution is essential, as a slope map provides data for planning, settlement, agriculture, reforestation, deforestation, planning of engineering structures, etc.
The slope map for Baki watershed has been created using ArcGIS 10.2 Surface – Slope tool (Figure 4). The Baki Basin Mean Slope was extracted from slope raster histogram, the value is 11.58 degrees.

The Basin Minimum Slope 0 and Maximum Slope is 49°. The histogram has been divided into 5 classes from the lowest values to the highest. The first class ranges between 0°01'-6°, has maximum frequency and occupies more than 50 km² from the Baki basin surface. It's typical for the right side of the basin where the altitudes are low and the surface is almost flat. The slope values are rising especially on the left part of the Baki valley. Higher slope values like 18°-25° and 25°-49° takes up the most of the surface where mountains, high fragmented hills, deep valleys are characteristic. This means that the watercourses have a powerful erosional effect for lithology and soil, creating well dissected hills and valleys.
Stream's slope values have been generated by ArcGIS 10.2. The drainage network was interpolated with the DEM using 3D Analyst Tools – Functional Surface – Interpolate Shape. For the new vector file created, a few parameters were automatically calculated, like the minimum and maximum altitude, minimum, maximum and mean slope using 3D Analyst Tools – 3D Features – Add Z Information. Having the data, the calculation of slope ratio was possible dividing the average mean slopes of stream segments of successively higher orders and calculated the mean slope ratio. The mean slope of drainage network is 7.57 degrees. The mean slope ratio is 1.62. Weighted mean slope ratio is 1.63. The main channel mean slope is 4.13 degrees.



Graph 3. Logitudinal Profile of Baki Stream

F. Drainage Basin Characteristics
The details of the morphometric analysis and comparison of drainage basin characteristics of Baki watershed are present in Table 5.

Table 5: Morphometric Analysis of Baki Watershed - Comparative Characteristics

Nr.	Mophometric Parameter	Formula	Reference	Result
1	Stream Order (Su)	Hierarchical Classification	Horton (1945)	1 – 5
2	1st Order Stream (Nu1)	Table 1.	Horton (1945)	355
3	Stream Number (Nu)	Table 1.	Horton (1945)	467

4	Bifurcation Ratio (Rb)	Table 1.	Horton (1945)	4.13 – 4
5	Mean Bifurcation Ratio (Rbm)	Table 1.	Horton (1945)	4.37
6	Weighted Mean Bifurcation Ratio (Rbwm)	Table 1.	Strahler (1957)	4.17
7	Stream Length (Lu) (km)	Table 2.	Horton (1945)	416
8	Stream Length Ratio (Lur)	Table 2.	Horton (1945)	1.55 – 2.45
9	Mean Stream Length Ratio (Lurm)	Table 2.	Horton (1945)	2.05
10	Weighted Mean Stream Length Ratio (Luwm)	Table 2.	Horton (1945)	2.21
11	Rho Coefficient (ρ)	P= Lur/Rb	Horton (1945)	0.47
12	Main Channel Length (Cl) (km)	ArcGIS Analysis		20
13	Valley Length (Vl) (km)	ArcGIS Analysis		13.1
14	Minimum Arial Distance (Adm) (km)	ArcGIS Analysis		12.82
15	Coefficient of hydraulic sinuosity (Hs)	Hs=Cl/Vl	Mueller (1968)	1.53
16	Coefficient of river sinuosity (Ks)	Ks= Cl/Adm	Mueller (1968)	1.56
17	Coefficient of topographical sinuosity (Ts)	Ts= Vl/Adm	Mueller (1968)	1.02
18	Topographic Sinuosity Index (Tsi) (%)	TSI=100(Ts-1)/(Ks-1)	Mueller (1968)	3.90
19	Hydraulic Sinuosity Index (%)	HSI=100(Ks-Ts)/(Ks-1)	Mueller (1968)	96.10
20	Basin Aria (A) (kms)	ArcGIS Analysis		161.37
21	Area Ratio (Ar)	Table 3.	Horton (1945)	1.70 – 3.06
22	Mean Aria Ratio (Arm)	Table 3.	Horton (1945)	2.26
23	Weighted Mean Area Ratio (Arwm)	Table 3.	Horton (1945)	2.68
24	Length of Overland Flow (Lg)	Lg= A/2*Lu	Strahler (1957)	0.19
25	Length Area Relation (Lar)	Lar= $1.4*A^{0.6}$	Zăvoianu (1985)	29.57
26	Stream frequency (Fs)	Fs=Nu/A	Horton (1945)	2.89

27	Drainage Density (Dd) (km/kms)	Dd= Lu/A	Horton (1945)	2.58
28	Constant of Channel Maintenance (C) (kms/km)	C= 1/Dd	Schumm (1956)	0.39
29	Drainage Intensity (Di)	Di=Fs*Dd	Faniran (1968)	7.48
30	Drainage Texture	T= Nu/P	Smith (1950)	6,62
31	Basin Perimeter (P) (km)	ArcGIS Analysis		70.56
32	Relative Perimeter (Pr)	Pr= A/P	Chebotarev, 1953	2.29
33	Basin Length (Lb) (km)	ArcGIS Analysis		13.10
34	Mean Basin Width (Mwb)	Wb= A/Lb	Zăvoianu (1985)	12.32
35	Basin Width (Wb)	ArcGIS Analysis		19.10
36	Length from basin center to mouth of the basin (Lcm) (km)	ArcGIS Analysis		5.81
37	Width from basin center of mass to the limit of the basin (Wcm) (km)	ArcGIS Analysis		5.35
38	Watershed Eccentricity (τ)	$T= (Lcm^2-Wcm^2)^{0.5}/Wcm$	Black (1972)	1.00
39	Form Factor (Ff)	$F= A/ Lb^2$	Horton (1945)	0.94
40	Elogation Ratio (Re)	$Re= 2/Lb*(A/\pi)^{0.5}$	Schumm (1960)	1.09
41	Elipticity Index (Ie)	$Ie= \pi*Lb^2/4A$	Horton (1945)	1.20
42	Circularity Ratio (Rc)	$Rc= 12.57*(A/P^2)$	Miller (1953)	0.41
43	Compactness Coefficient (Cc)	$Cc= 0.2841*P/A^{0.5}$	Luchisheva (1950)	1.57
44	Fitness Ratio (Rf)	Rf= Cl/P	Pareta (2011)	0.19
45	Maximum Altitude (Z) (m)	ArcGIS Analysis		2005
46	Minimum Altitude (z) (m)	ArcGIS Analysis		996
47	Basin Height (H) (m)	H= Z-z	Zăvoianu (1985)	1009
48	Absolute Relief (Ra) (m)	ArcGIS Analysis		2005
49	Relative Height (h/H)	Table 4.		100 – 1
50	Relative Area (a/A)	Table 4.		1 – 100
51	Hipsometric Index (HI)	Hypsometric Curve	Langbein (1947)	0.5
52	Slope Analysis (Sa)	ArcGIS Analysis		0.01-49°
53	Basin Mean Slope	ArcGIS Analysis		11.58°
54	Basin Minimum Slope	ArcGIS Analysis		0

55	Basin Maximum Slope	ArcGIS Analysis		49°
56	Main Channel Maximum Slope	ArcGIS Analysis		29.58°
57	Main Channel Mean Slope	ArcGIS Analysis		4.03°
58	Stream Slope Ratio	ArcGIS Analysis		1.72 – 1.96
59	Mean Stream Slope Ratio	ArcGIS Analysis		1.62
60	Weighted Mean Slope Ratio	ArcGIS Analysis		1.63

5. Conclusions

Morphometric laws can be verified from the analysis of the morphometric patterns for the Baki basin in the Eastern Anatolian Plateau. The Baki basin is an area of 161.37 km located on a hilly and highly fragmented surface, which includes all the effects of the Baki stream in the 41646 km long 461 river segment located on the Eastern Anatolian Plateau. The Baki river is a low fold stream of the 5-th order, 20,41 km long, with a moderate evolutionary phase and no large river runoff in the waterway. The rectangular basin length of the Baki basin is twice the length of the basin. Drainage tissue shows the amount of landscape dissection well-drained by an advanced drainage network. The surface of the basin is hilly and highly fragmented with large slope values that can reach up to 49 ° on the right side of the hill. Due to the impermeability of the large part of the field, the density of the rivers is high. The high density of the stream allows the falling rainfall to pass to the surface flow. Thus, the surface flow reaches the main stream in a short time and creates high peaks. Excessive surface flow caused the stream to be more fragmented. In addition, as a result of the strong abrasion, the stream bed reached the base level early and the stream bed lengthened. . Because the leaking water is delayed to the current. Therefore, it can be concluded that GIS techniques and linear, straight and vertical measurements, characterized by a very high accuracy mapping, are a method that assists in morphometric analysis and generates data for the calculation of 60 parameters.

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