GEOMORPHOMETRIC ANALYSIS OF ALBANIA RIVER BASINS

Hasan ÖZDEMİR

Geography Department, Physical Geography Division,
Istanbul University, Turkey.
ozdemirh@istanbul.edu.tr

Abstract

Geomorphometry is the science of topographic quantification; its operational focus is the extraction of land-surface parameters and objects from digital elevation models (DEMs). In this reason, DEMs are main data sources in geomorphometric analysis of interested areas and they give an opportunity analysing of them quantitatively. In this study, morphological and hydrological characteristics of eight main river basins in Albania namely Drin, Mat, Ishmi, Erzen, Shkumbin, Seman, Vjosa, Bistrica were analysed using ASTER GDEM, which is an easy-to-use, highly accurate DEM covering all the land on earth and available to all users regardless of size or location of their target areas, and GIS. For this purpose, ASTER GDEM of Albania were pre-processed by fill and sink operations in GIS before the analysing. After that slope, hypsometric curve and integral, stream power index, ruggedness number, form factor, drainage networks and related morphometric characteristics such as bifurcation ratio, drainage density, length of overland flow, and time of concentration were analysed and results were evaluated between the basins in point of flood risk. The results show that geomorphometric analysis of the basins gives great opportunity on understanding geomorphic evolution and flood risk of the basins.

Keywords: *Geomorphometry, Albania River, Flood, GIS.*

Introduction

Geomorphometry, which is an interdisciplinary field that has evolved from mathematics, the Earth sciences and -most recently- computer science, is the science of quantitative land-surface analysis (Pike, 1995, 2000a; Rasemann et al. 2004; Pike et al. 2009). It supports Earth and environmental science (including oceanography and planetary exploration), civil engineering, military operations and video entertainment. Geomorphometry focuses on the extraction of land-surface parameters and objects from digital elevation models (DEMs). The usual input to geomorphometric analysis is a squared-grid representation of the land-surface namely digital elevation models (DEMs) or digital surface models (DSMs).

In general, there are three sources of DEM data: Ground survey techniques, existing topographic maps and remote sensing (Webster et al, 2006; Nelson et al., 2009). Every method has advantage and disadvantage in the DEM producing. However, remote sensing methods can rapidly cover large areas with changing resolution and accuracy. DEMs can be derived from four types of sources in remote sensing: stereo photos and images (e.g. Wolf and Dewitt, 2000; Lane et al. 2000; Smith, 2005), LiDAR (e.g. X. Li et al., 2001; Norheim et al., 2002; Smith, 2005; Webster et al., 2006; Xiaoye, 2008; Rayburg et al. 2009) and RADAR (e.g. Hensley et al., 2001; Northeim et al., 2002; Rabus et al., 2003; Rodriguez et al. 2005). The ASTER *(Advanced Spaceborne Thermal Emission and Reflection Radiometer)* NASA's Terra spacecraft collects in-track stereo using nadir- and aft-looking near infrared cameras. Since 2000, these stereo pairs have been used to produce single-scene (60 x 60 km) digital elevation models having vertical (root-mean-squared-error) accuracies generally between 10 m and 25 m. On June 29, 2009, NASA and the Ministry of Economy, Trade and Industry (METI) of Japan released a GDEM *(Global Digital Elevation Model)* to users worldwide at no charge as a contribution to the Global Earth Observing System of Systems (GEOSS). ASTER GDEM was compiled from over 1.2 million scene-based DEMs covering land surfaces between 83°N and 83°S latitudes. It is a 1 arc-second (30m) elevation grid distributed as 1°-by-1° tiles (ASTER GDEM Validation Team, 2009; 2011).

Some geomorphometric analyses such as flash flood risk estimation, evaluation of drainage morphometries, terrain evaluations have been carried out using different DEM data sources like SRTM, topographic contours, ASTER DEM and GDEM (e.g. Ozdemir and Bird, 2009; Prasannakumar et al, 2011; Ahmed et al., 2010; Malik et al., 2011; Rawat et al., 2012). All these applications and analyses have been applied more generally to a single basin and its sub-basins. The aim of this study is application of some geomorphometric parameters to a country scale (Albania) river basins and evaluation of them in point of flood.

Study Area

Albania, located between the 39°35' – 42°40'N and 19°20' – 21°05'E geographic coordinates, is a small mountainous country that faces the southern Adriatic Sea and Ionian seas, with a total coastline length of about 380 km. Albania has a total area of 28.748 km^2 and it shares a 172 km border with Montenegro to the northwest, a 115 km border with Kosova to the northeast, a 151 km border with Macedonia to the north and east, and a 282 km border with Greece to the south and southeast (Fig. 1).

There are four main geographic regions in Albania: the Northern Mountain Range *(Krahina Malore Veriore)*, the Southern Mountain Range, the Western Lowlands

(Ultesira Bregdetare), and the Central Mountain Range *(Krahina Malore Qendrore).* In the north and central mountain range are highly rugged and predominantly limestone, sandstone and serpentine rocks are covered respectively. The Southern Mountain Ranges are more accessible than the eastern highland or the Prokletije. The transition to the lowlands is less abrupt, and the arable valley floors are wider. The Western Lowland is generally alluvial plain, receives precipitation seasonally, and poorly drained and alternately arid or flooded.

With its coastline facing the Adriatic and Ionian seas, its highlands backed upon the elevated Balkan landmass and the entire country lying at latitude subject to a variety of weather patterns during the winter and summer seasons, Albania has a high number of climatic regions relative to its landmass. The coastal lowlands have typically Mediterranean weather with precipitation rates between 930 and 2200mm, mean annual temperatures of 15-16.5^{o}C and most of the annual rainfall concentrated in the period October-March (Ciavola, 1999); the highlands have a Mediterranean continental climate. In both the lowlands and the interior, the weather varies markedly from north to south.

The river basins of Albania and their hydrological regimes are varied morphologically as well as geologically. Most of the rivers origin in the second inland chains of mountains and they flow westerly through the first chains forming the canyon valleys. Considerable slopes as well as large amounts of bed-load causes the typical braided channels found downstream (Balek, 1966). The hydrographic basins of the rivers of Albania have a total area of 43,305 km^2, but only 28,748 km^2 are situated within the state territory of Albania. The remaining area, which mainly belongs to the catchments of the Rivers Drini, Seman and Vjosa, is situated in Greece, Macedonia, Montenegro and Kosova. Albania is crossed by several rivers, in a general East-West direction: Drin, Mat, Ishmi, Erzen, Shkumbin, Seman, Vjosa and Bistrica are the most important ones (Fig. 1). These rivers discharge to the Adriatic Sea 1308 $m^3 s^{-1}$ annually, corresponding to a specific discharge of 30 $m^3 s^{-1} km^{-2}$, nearly the same as Switzerland. During large floods, they can be treated as one river because the flood flows through the Albanian western plain frequently form a single river mouth. In general, floods have a pluvial origin. They form during the period November- March when 80-85% of the annual flow occurs (Bogdani and Selenica, 1999).

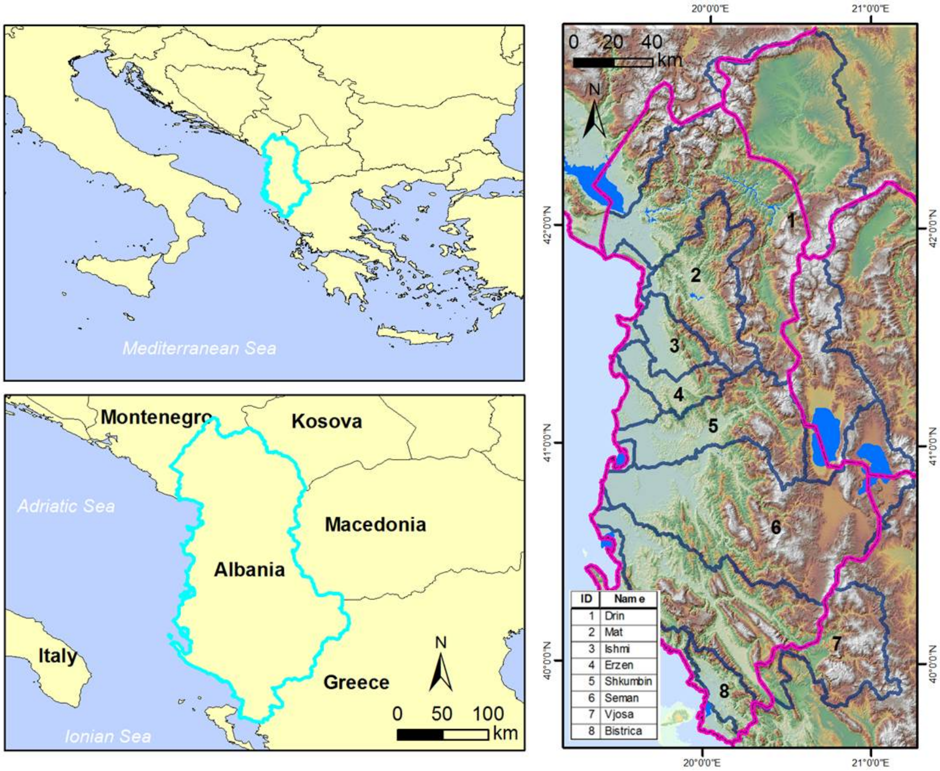

Figure 1. Location map of Albania and the main river basins.

Data and Method

The main data source is ASTER GDEM with 30m spatial resolution product which can be downloaded freely from ASTER GDEM project page (http://www.gdem.aster.ersdac.or.jp). Data pre-processing is started by cropping the interest area which is larger from Albania country border to be able to extract river basins (Fig. 1a). Then, Geographic coordinates is converted to WGS 1984 UTM Zone 34N metric coordinates. After cropping the ASTER GDEM of the study area, data pre-processing has been completed by removing the errors such as sinks and peaks in order to eliminate discontinuities in the drainage network (Fig. 2b). Flow direction was calculated for each pixel using the filled DEM, i.e. the direction in which water will flow out of the pixel to one of the eight surrounding pixels. This concept is called the eight-direction (D8) pour point model (Fairfield and Leymarie, 1991). There are several variants of the model, but the simplest, and the one used in ArcGIS, allows water from a given cell to flow into only one adjacent cell, along the direction of steepest descent. The resulting flow direction is encoded from 1 to 128 in different directions (Fig. 2c).

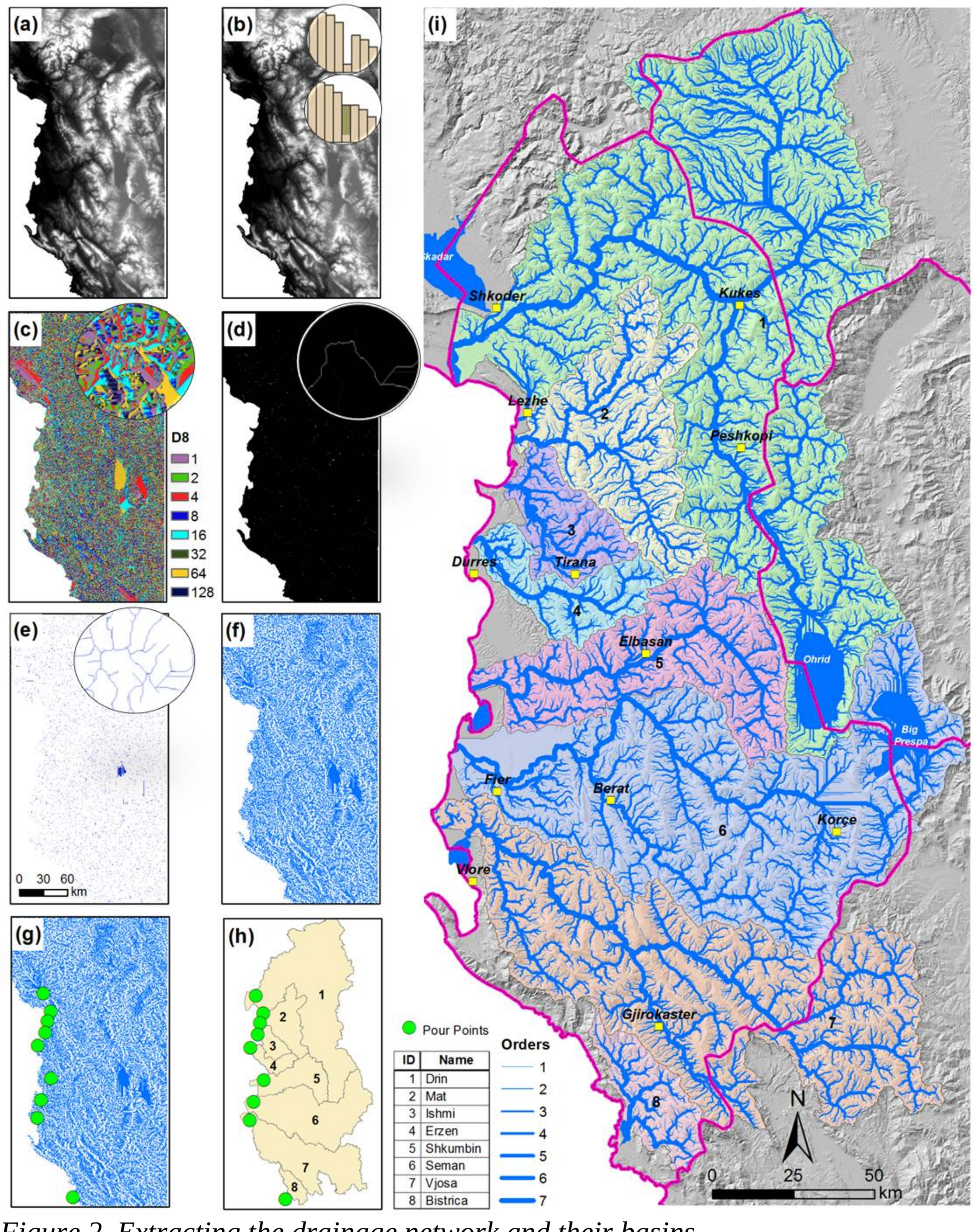

Figure 2. Extracting the drainage network and their basins

Flow accumulation was calculated from the flow direction grid. Each pixel was assigned a value equal to the number of pixels drained through a given pixel in the flow accumulation (Fig. 2d). The drainage network was extracted by considering the pixels greater than a threshold of 700 using the raster calculator (Fig. 2e-f). In addition, using pour points on the main rivers of Albania and their flow accumulation raster, boundary of the basins were extracted from the DEM (Fig. 2i). Some of the geomorphometric parameters of the basins (Table 1) such as the slope

(S), hypsometric curve and integral *(H_c - H_i)*, stream power index (*SPI*), ruggedness number *(R_n)*, form factor (R_f), drainage networks and related morphometric characteristics such as bifurcation ratio *(R_b)*, drainage density *(D_d)*, length of overland flow *(l_o)*, and time of concentration *(T_c)* were applied to Albania's river basins and the results were evaluated between the basins in point of flood potential and risk.

Table 1: Some geomorphometric parameters and their mathematical expressions*

Geomorphometric Parameters	**Formula**	**Abbreviations**
Slope (in degree) *(S)*	$S = \tan^{-1}\{(H-h)/L)\}$	*H: Elevation L: Distance*
Hypsometric Curve and Integral *(H_c-H_i)*	$H_c = h/H$ and a/A $H_i = (h_{mean}-h_{min})/(h_{max}-h_{min})$	*a: Specific area* *A: Total Area*
Stream Power Index *(SPI)*	$SPI = A \; x \; tan(\beta)$	*A: Specific catchment area* *β: Local slope angle*
Ruggedness Number *(R_n)*	$R_n = B_h \; x \; D_d$	B_h: h_{max}-h_{min} *(h: elevation)*
Form Factor *(R_f)*	$R_f = A/L^2$	*A: Basin area* *L: Basin length*
Bifurcation Ratio *(R_b)*	$R_b = N_u/N_{u+1}$	N_u: *Total no of stream segment of order 'u'*
Drainage Density *(D_d)*	$D_d = \sum L/A$	*L: Stream length* *A: Basin area*
Length of Overland Flow *(l_o)*	$l_o = 1/2D_d$	D_d: *Drainage density*
Time of Concentration *(T_c)*	$T_c = 0.0195 \; x \; L^{0.77}/S^{0.385}$	*L: Stream length* *S: Basin slope*

*Keller and Pinter (2002); Moore et al., (1991); Melton (1957); Strahler (1957); Horton (1932); Schumm (1956); Horton (1945); Kirpich (1940); Pike and Wilson, (1971); Mayer (1990).

Results and Discussions

Slope (S): *S* measures the rate of change of elevation in the direction of steepest descent. Slope is the means by which gravity induces flow of water and other materials, so it is of great significance in hydrology and geomorphology. It affects the velocity of both surface and subsurface flow and hence soils water content, erosion potential and many other important processes (Gallant and Wilson, 2000). In addition, steep slopes generally have high surface run-off values and low infiltration rates. Sediment production thus tends to be high expect when largely barren slopes are concerned (Verstappen, 1983). Based on ASTER GDEM, the slope properties of Albania river basins are given in Fig. 3a. Slope is classified in 4 classes which are 0-2^{o} (low); 2-15^{o} (moderate); 15-30^{o} (high) and 30^{o}< (very high). Ishmi, Erzen, Mat and Bistrica river basins have the highest low slope (0-2, 32%), moderate slope (2-15, 53%), high slope (15-30, 42%) and very high slope percent (30<, 13%) respectively between the basins (Fig. 3a). However, Ishmi river basin has the highest slope value (78.45^{o}) in the basins. When we consider the over 15^{o} slope in the basin, Mat river basin has the highest percent of slope (53%) between the basins (Fig. 3a).

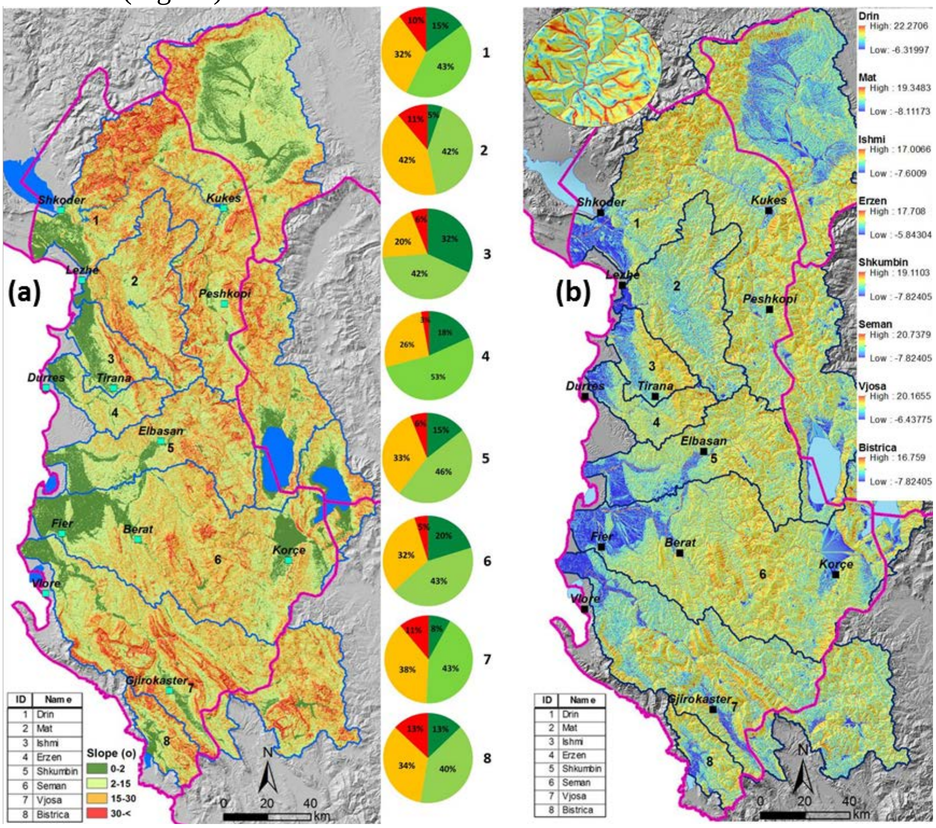

Figure 3. (a) Slope of Albania river basins, (b) SPI of Albania river basins.

Hypsometric Curve and Integral (H_c and H_i): The hypsometric curve describes the distribution of elevations across an area of land, ranging in scale from one drainage basin to the entire planet. Hypsometric curves *(H_c)* are obtained by plotting the proportion of the total height *(h/H)* against the proportion of the total area *(a/A)* of the basin, where *H* is the total relative height, *A* is the total area of the basin and *a* is the area of the basin above a given line of elevation *h* (Strahler, 1952). The hypsometric integral *(H_i)* can be calculated from the area under the curve (Table 1), and it expresses, in percentage, the volume of the original basin that remains unweathered. High values of H_i indicate that most of the topography is high relative to mean, such as a smooth upland surface cut deeply incised stream. Intermediate to low values of the integral are associated with more evenly dissected drainage basins (Keller and Pinter, 2002). H_c and H_i of the river basins based on ASTER GDEM are given in Fig.3. According to the results, all the basins are highly dissected and there is no youthful topography (convex upward curves) in the country. In the meantime, Ishmi river basin is the most weathered basin, and Drin and Seman river basins are the most unweathered basins in Albania. Erosional processes and river energy are still higher in the Drin, Seman and Mat river basins.

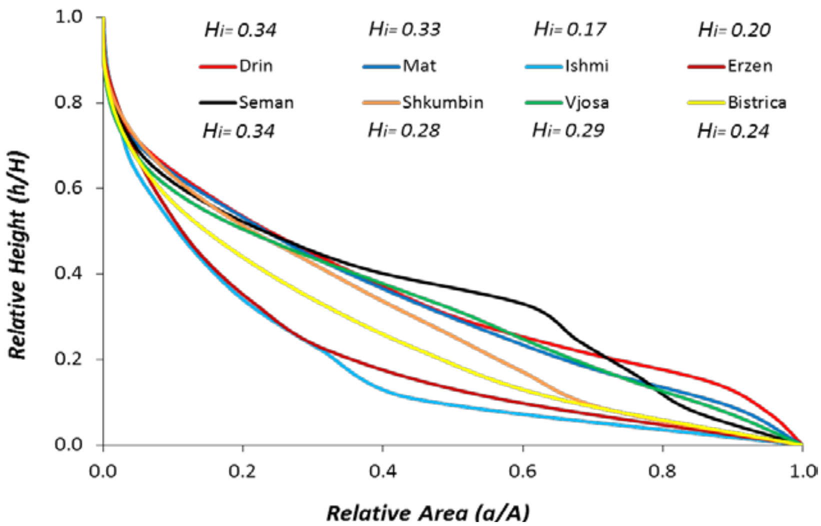

Figure 4. Hypsometric curves and integrals of the basins

Stream Power Index (SPI): SPI is the time rate of energy expenditure and has been used extensively in studies of erosion, sediment transport, and geomorphology as a measure of the erosive power of flowing water (Moore et al. 1991). As specific catchment area and slope steepness increase, the amount of water contributed by upslope areas and the velocity of water flow increase, hence stream power and potential erosion increase (Gruber and Peckman, 2009). SPI results are given in Fig. 3b. The data is stretched using natural logarithmic display. According to the results, Drin River has the highest stream power value and followed by Seman and Vjosa respectively (Fig. 3b). Bistrica River has the lowest stream power value. Blue areas in the results show that stream power is very less and deposition and flooding can be seen in these areas.

Ruggedness Number (R_n): R_n is expressed as the product of basin relief and drainage density (Strahler, 1952). It indicates the structural complexity of terrain. R_n is particularly useful because it summarizes the interaction of relief and dissection such that highly dissected basins of low relief are as rugged as moderately dissected basins of high relief. In addition, these data were used to develop an index of flash flood potential (Beard, 1975). Patton and Baker (1976) found that basins with high flash flood potential had greater ruggedness numbers than low-potential watersheds. Ruggedness numbers of the Drin river basin has the highest value and followed by the Vjosa and Seman river basins respectively (Table 2; Fig. 5). Bistrica river basin has the lowest value of the R_n. This means Drin, Vjosa and Seman river basin are highly susceptible to erosion and therefore susceptible to increased peak discharge.

Form Factor (R_f): R_f is expressed as the ratio of the basin area to the squared of the basin length (Horton, 1945). Larger values of R_f indicating higher flow peaks but of shorter duration and low value R_f implying a more elongate plan view of watersheds and suggesting consequent flatter peak flows of longer duration. The range of the R_f value is between 0.16 – 1.83 (Table 2; Fig. 5). Bistrica river basin has the highest value of R_f and followed by Mat river basins whilst the Drin river basins has the lowest. Characteristic of river flow in Bistrica and Mat basins is flashy with sharp hydrograph peak, but in Drin or low R_f basins is more sustained with having lower hydrograph peak.

Bifurcation Ratio (R_b): R_b is defined as the ratio of the number of streams of a given order to the number in the next higher order. High values of R_b indicate high overland flow and discharge due to hilly nature of terrain plus steeper disposition of slopes, while low R_b values reflect high infiltration rate. Low bifurcation ratios and nearly equal path lengths of water flow would have sharp hydrograph peaks whereas elongate basins with bifurcation ratios and greatly unequal flow path lengths would have lower hydrograph peaks but more sustained flow (Strahler, 1964). Based on the R_b analysis results, Mat and Bistrica basins have the lowest R_b values whereas Shkumbin and Drin have the highest R_b values (Table 2; Fig. 5).

Drainage Density (D_d): Drainage density (D_d) is the ratio between the total stream lengths of all orders to the area of the basin (Horton, 1945). It shows the landscape dissection, runoff potential, infiltration capacity of the land, climatic conditions and vegetation cover of the basin (Verstappen, 1983; Patton, 1988; Reddy et al., 2004). On the one hand, the D_d is a result of interacting factors controlling the surface runoff; on the other hand, it is itself influencing the output of water and sediment from the drainage basin. In general, resistant surface materials and those with high infiltration capacities exhibit widely spaced streams, consequently yielding low D_d. As resistance or surface permeability decreases, runoff is usually accentuated by the development of a greater number of more closely spaced channels, and thus D_d tends to be higher. Drainage networks of the basins were extracted from ASTER

GDEM using 700 flow accumulation raster values. D_d was analysed using this extracted drainage networks. According to the result, D_d values are changing in between 0.75 and 0.86 (Table 2; Fig. 5). Mat river basin has the lowest D_d value and followed by Bistrica river basin. In contrast, Drin river basin has the highest value.

Length of Overland Flow (l_o): This factor relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree. Drainage density is an approximate measure of the length of overland flow. For basins of comparable relief, the hydrologic response of a stream network should be directly related to drainage density because with increasing drainage density the path length of overland flow decreases while hillslope angle increases (Schumm, 1956). According to l_o results, Drin river basin have the lowest value while Mat and Bistrica river basins have the highest values (Table 2; Fig. 5). This means, erosion and dissection are much higher in Drin river basin. In contrast, erosion and dissection are lower in Mat and Bistrica river basins.

Time of Concentration (T_c): T_c is the ratio between length of the main river and distance weighted channel slope. The time of concentration (T_c) is the time taken by water to travel from the most distant point of a basin to its outlet. The concept of T_c is useful for describing the time response of a watershed to a driving impulse, namely that of watershed runoff. T_c represents the time at which all areas of the watershed that will contribute runoff to the watershed outlet are just contributing runoff to the outlet. T_c of the basins was calculated using Kirpich formula (1940). T_c analysis results show that water contributing time in Albania river basins changes in between 2.82 and 36.37 hours. Drin river basin has the highest concentration time (36.37 hrs.) and followed by Seman river basin (32.35 hrs.). In contrast, Bistrica river basin has the lowest concentration time (2.82 hrs.) and followed by Ishmi river basin (8.42 hrs.) (Table 2: Fig. 5).

Table 2: Some geomorphometric analysis results of the basins.

No	Basin Name	*Area (km²)*	*Tot. Drainage Length (km)*	B_h	R_n	R_f	R_b	D_d	l_o	T_c
1	Drin	13624.57	11760.71	2716.85	2.35	0.16	5.74	0.86	0.58	36.37
2	Mat	2572.80	1935.91	2228.62	1.68	1.03	3.86	0.75	0.66	10.15
3	Ishmi	931.7	777.11	1812.1	1.5	0.4	4.3	0.8	0.6	8.42

				0	1	5	1	3	0	
4	Erzen	974.72	775.03	1811.21	1.44	0.23	4.29	0.80	0.63	9.34
5	Shkumbin	2872.05	2242.01	2307.72	1.80	0.22	5.86	0.78	0.64	18.41
6	Seman	7773.51	6517.86	2441.59	2.05	0.20	4.76	0.84	0.60	32.35
7	Vjosa	6753.39	5461.32	2588.41	2.09	0.19	4.43	0.81	0.62	24.31
8	Bistrica	757.69	573.09	1788.25	1.35	1.83	3.94	0.76	0.66	2.82

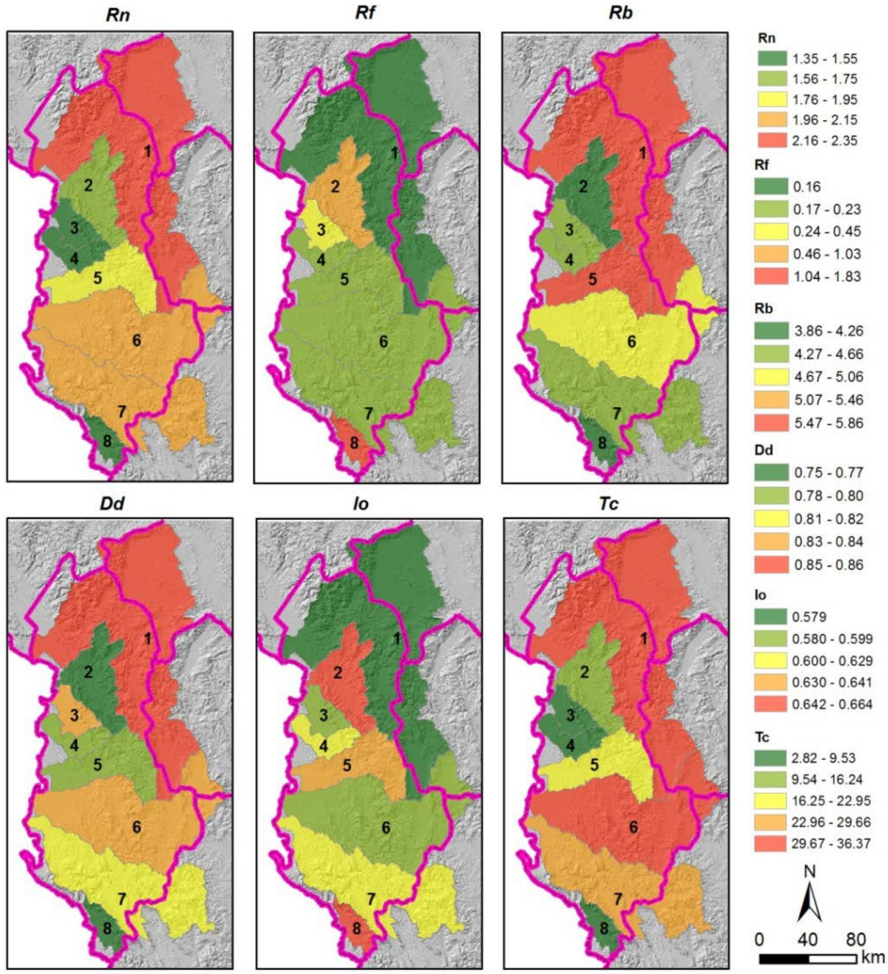

Figure 5. Classifying some geomorphometric analysis results of the basins

Conclusions

In this study, geomorphometric analysis of Albania river basins was done using ASTER GDEM data, which is available on the internet freely, and GIS. All the analyses are based on ASTER GDEM and extracted features. Eight main river courses such as Drin, Mat, Ishmi, Erzen, Shkumbin, Seman, Vjosa and Bistrica with their drainage networks and basins characteristics were extracted from the DEM. All the rivers flow generally east-west directions (from mountainous regions to plains). Generally, the basins are inside the Albania except Drin, Seman and Vjosa rivers which have trans-boundary basin between Montenegro, Kosova, Macedonia and Greece.

Some of the geomorphometric parameters such as slope, hypsometric curve and integral, stream power index, ruggedness number, form factor, bifurcation ratio, drainage density, length of overland flow and time of concentration were applied to the ASTER GDEM and extracted features. Every parameter's result can be evaluated between the basins in point of flood or flash flood potentials. However, when we consider all the results some of the basins such as Drin, Seman, Mat and Vjosa are more important than the others. These basins have great potential for the flood and flash floods, so they should be studied more precisely.

To understand the basin geomorphic characteristics, specifically in country level, ASTER GDEMs and GIS can be used efficiently. However, all these analyses give general assumption and evaluation of the basins. Hence, this kind of studies must be supported by field works and specific studies.

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