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GIS-based quantitative geomorphological and drainage morphometric evaluation and analysis in Atalanti river basin, Central Greece

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Abstract
In this paper, an attempt is made to study both the topographic and morphometric aspects of streams and landscape characteristics of Atalanti river basin (248.5 km^2) in Central Greece to understand the structure, process, soil physical properties, erosion and evolution of the landform as well as its hydrological characteristics based on the morphological aspects. Morphometric analysis is vital in any hydrological study and is considered mandatory in drainage basin's development and management as various hydrological processes in the catchment are strongly related to the landform characteristics (e.g., discharge rate, rainfall intensity, flash flood potential, sediment yield etc.). The quantitative evaluation and analysis of numerous morphometric parameters of the drainage area was determined based on the linear (Stream order, stream length, stream length ratio, bifurcation ratio etc.), areal (Drainage density, stream frequency, form factor, elongation ratio, circularity ratio etc.) and relief (Slope, aspect etc.) aspects. The aforesaid geomorphological characteristics were derived from DEM (with 25 m spatial resolution) using GIS processing on the basis of toposheets 1:50.000 scale. The drainage basin is divided into two main sub-basins, namely, Alargino, and Karagkiozis and all the aspects were studied for each sub-basin separately. Morphometric analysis of the drainage basin revealed that the Alargino and Karagkiozis sub-basins are designated as 4th order (Strahler's classification) all exhibiting dendritic to sub-dendritic drainage pattern following the natural terrain gradient. Poor drainage density and stream frequency confirmed the permeability of the sub-surface material, thick vegetative cover and homogeneous lithological characteristics in both larger sub-basins especially in lowlands (Low basin relief). However, in highlands both drainage density and stream frequency become higher due to the formations' impermeability and the structurally controlled area. The elongation ratio of the sub-basins was found to be low indicating that the terrains are elongated in shape. The results also showed that the Horton's laws with reference to quantitative geomorphology were applicable to the sub-basins of the Atalanti river basin. The study revealed that the area of the Atalanti basin presents low slope relief directed towards East to the gulf of Atalanti and subsequently low response to surface runoff. All the relief characteristics indicated that the studied basin is rejuvenated or at the young stage of geomorphological development. It is therefore concluded that GIS techniques provided useful results and competent tools for river basin's morphometric analysis, management as well as hydrological behavior and design.

Keywords: drainage pattern, landform evolution, terrain gradient, structural control, hydrological response

1. Introduction

The morphometric analysis of a basin reveals important information regarding both hydrological and geomorphological processes and land surface development (Chow 1964, Clarke 1996, Sharma 1981, Singh 1998, Strahler 1956, 1957) [40, 9, 33, 34, 38, 39]. The basin geomorphological characteristics have been used in various studies and when measured and expressed in quantified form can be studied for the influence on sediment yield, infiltration, catchment characterization, changing river flows, modelling surface processes, flood discharge, flash flood hazard assessment, flood risk management, soil loss, erosive susceptibility processes, water conservation activities etc. providing a quantitative aspect of the drainage system and an important indicator about the landform development process (Agarwal 1998; Biswas *et al*. 1999; Biswas 2016; Khan *et al*. 2001; Malik *et al*. 2011; Miller 1953; Paretta *et al*. 2011; Rai *et al*. 2014; Sarma *et al*. 2013; Singh 1997) [1, 4, 5, 15, 18, 20, 23, 27, 29, 35]. GIS techniques provide an excellent as well as useful and accurate tool and were used for assessing numerous terrain and morphometric parameters to determine, interpreting and analyze the spatial information related to river basins. Drainage network analysis based on morphometric parameters is useful for watershed planning since it gives an idea about the basin characteristics in slope, topography, soil condition, runoff characteristics etc. also the definition of certain variables of drainage basins in numerical terms (Chorley 1969, 1972) [6, 7]. In the current study Atalanti river basin was divided into two sub-basins, namely, Alarginos and Karagkiozis to which flowing pattern and drainage characteristics were quantitatively and separately analyzed. The drainage basin morphometric analysis was subdivided into three classes i.e. linear (one dimension-1d), shape both geometrically and topologically (2d) and parameters dealing with the relief aspect (3d) of sub-basins. Besides, detailed basin's geomorphometric analysis makes us adequately understand the effect of drainage morphometry on landforms characteristics (Dingman 1970; Gardiner 1978; Horton 1932; Schumm 1956, 1963, 1986; Waugh 1996) [11, 12, 13, 38, 31, 32, 42]. In the present essay an effort was made to derive drainage network from DEM analysis and evaluate the morphometric parameters with the help of ArcHydro tool. The DEM file was used to generate the basin's hydrological aspect and response such as flow direction, flow accumulation, ordering of stream network, basin's ground slope, terrain gradient etc. Therefore, combining both morphological parameters and hydrological characteristics may provide useful procedure to simulate and forecast the hydrological behavior (e.g. peak flow and flooding) and thereby planning for basins' design, particularly the ungauged ones since various hydrological phenomena can be correlated with drainage basin's physiographic characteristics. Finally, basins' morphometric characteristics have been used in numerous papers to predict and depict flood peaks and erosion rate estimation (Diakakis 2011) [10].

2. Regional Setting

2.1 Study Area

The River Basin District extent of Eastern – Central Greece with longitudes between $21^0 49´$ - $24^0 37$ and latitudes between $37^0 55´$-$39^0 19´$ is approximately 12.2×10^3 km^2 surrounded by the mountain ranges of Orthris, Timphristos, Gkiona – Parnassos and Parnitha from the North, Northwest, Southwest and Southeast, respectively while towards East the area is washed by the sea (Psomiadis 2010; Psomiadis *et al*. 2013) [25, 26]. The maximum elevation equals to 2,431 m, while the mean elevation reaches 417.5 m (a.s.l.). The hilly and valley areas cover approximately 38.8% και 37.1% respectively, mainly concerning the coastal areas at the East considering the geomorphological relief flat to hilly – semi mountainous. In particular, Atalanti river basin (Fig.1) is located at Eastern Central Greece at Lokrida province of Fthiotida Prefecture with area of 248.5 km^2 and perimeter of 105 km, mild-gentle slopes in valleys (0-10^0) with flat terrain which become gradually steeper towards the outskirts in rocky formations (>35^0). Furthermore, the basin's altitude ranges between sea level and 1073 m (a.s.l.) with mean elevation of 275.3 m (a.s.l.) having also a diverged drainage (streams, rivers) with several kilometers of length which discharges into the sea (Tsioumas *et al*. 2011) [41]. The drainage network in the valley is relatively dense due to semi-permeable formations while in the mountainous areas the active tectonics forms a sparse network with 1st or 2nd order streams, by Strahler, with steep slopes and deep river bed. The dendritic to sub-dendritic drainage is composed of intermittent small streams flowing mostly in a WSW-ENE direction which becomes E-W mainly controlled by geotectonic structure. Finally, the wider area's climate belongs to the Csa type (by Köppen) which represents the average Mediterranean climate with mild wet winters and mild hot and dry summers. The mean annual precipitation ranges between 500-600 mm with observed higher rainfall values in the mountains and lower ones in the valley and air temperature between 16.7-17.9 °C.

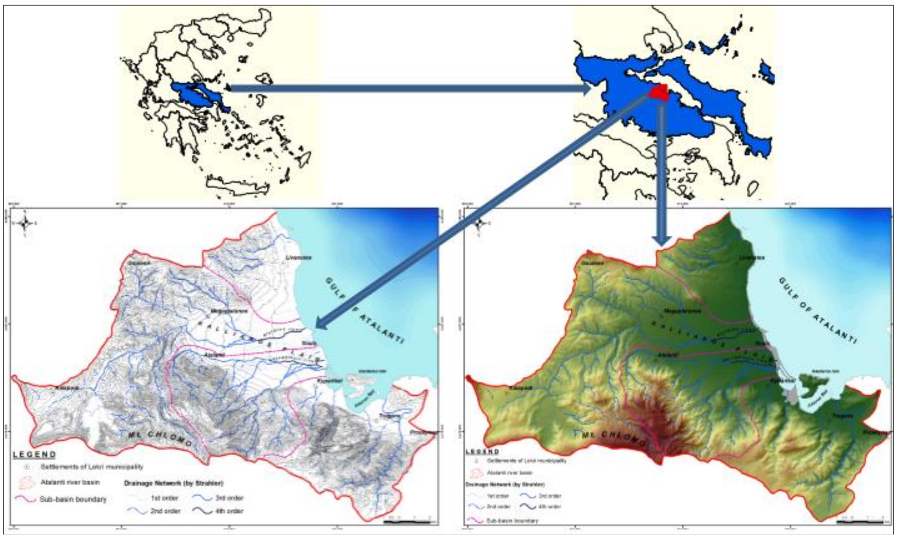

Fig 1: Geographical location of the study area as well as topographical and digital elevation model (DEM) of Atalanti river basin with contributing drainage network of the two main sub-basins

2.2 Geotectonic Setting

The wider area of interest is composed of several rock types including Paleozoic shales, sandstones and conglomerates, Triassic and Jurassic dolomites, limestones and ophiolitic rocks, Createaceous limestones and flysch comprising the bedrock along the eastern, northern and southern outcrops of the alluvial plain (Maratos *et al*. 1965) [19]. Also, post-alpine unconsolidated-semi-consolidated sandy formations of Tertiary/Quaternary age such as Neogene sediments consisting of marls, calcareous marls, marly limestones, clays, sandy loams, sandy marls, lignitic beds, conglomerates with sandstones intercalations, lacustrine deposits and Quaternary formations (Alluvial sediments) such as coastal sandy and clay-sandy sediments, debris cones are mainly located in the coastal region and loose sediments of silts, sands and pebbles are deposited at the lower parts of the basin with materials derived from weathering of all previous formations, which come across at highlands (Fig.2, left). These sediments constitute the most recent formations covering the lowland part whereas in the coastal zone sand dunes and coastal sediments prevail. Tectonically speaking, the large-scale faulting zones in Atalanti basin with West-North West and North-North East directions are the main features of the regime that took place during Miocene (Fig. 2, right). Finally, the Atalanti normal faulting zone of 30 km length with NW-SE direction has reactivated many other faults giving significant earthquakes of which two of them took place on April 1894 A.D. with magnitudes of 6.4 and 6.9 (Palivos 2001) [22].

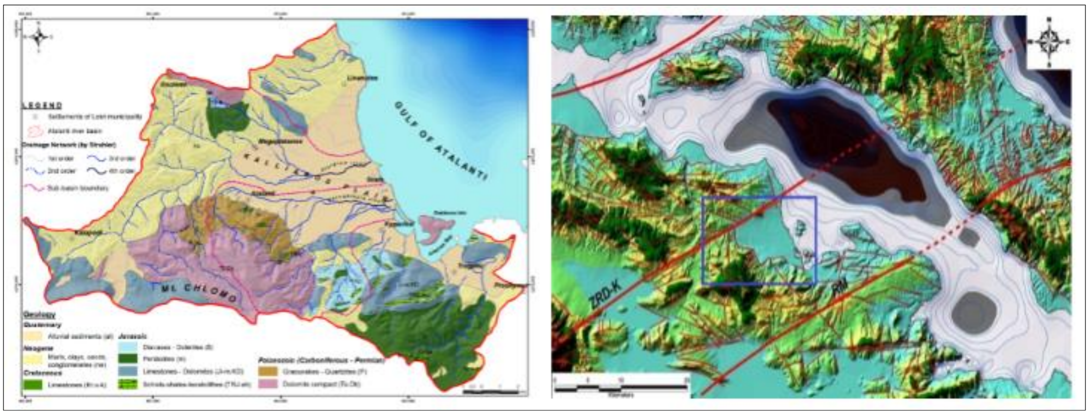

Fig 2: Geological map (Maratos *et al*. 1965) of Atalanti river basin (left) and geotectonic map (Lappas 2018) of the wider area of interest (right) including tectonic lineaments and isodepth curves (the study area lies within the blue rectangle)

3. Materials and Methods

3.1 Dataset Collection

The map which depicts the drainage pattern of the entire river basin was prepared based on topographic maps of 1:50,000 scales, obtained from the Hellenic Military Geographical Service after geometrical rectification, geo-reference and digitation processing. These maps were also used for preparation and delineation of the study area basin boundary and especially the base and drainage maps as well as the digital elevation model for creating, managing and generating different layer and maps as reference for geometric corrections, area and perimeter calculations. Terrain pre-processing was also used in the processing and creating the watershed basin of the study area. Digitization work was carried out to cover entire analysis of drainage morphometry. All the derived maps were in National Grid coordinating system, namely, GGRS 87 for the calculations of drainage morphometric characteristics through GIS. Then the data obtained were superimposed on geological and structural maps of the study area for the interpretation purposes.

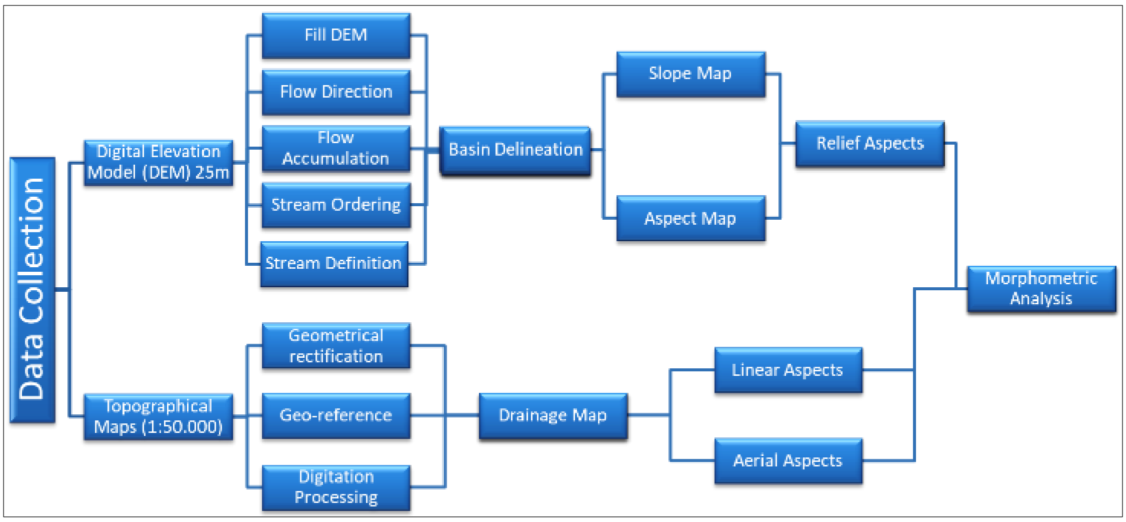

Fig 3: Flow chart for the drainage basin morphometry

3.2 Methodology Analysis

Morphometric analysis of the river catchment requires delineation of the drainage networks and watersheds. A quantitative study of the drainage basin was undertaken to understand the relations among various morphometric parameters. This study was based on the processing of the digital elevation model with spatial resolution of 25 m for computing relief parameters as illustrated in the flow chart (Fig.3) in a sequential step order. Different thematic maps such as contour, slope, aspect and drainage ones were prepared by GIS as considered a reliable tool for topographic analysis. The DEM was the origin for extracting several topographic and morphometric parameters and was also processed by several automated operations such as delineation of the river basin boundary, drainage network, flow direction, flow accumulation, stream definition, stream ordering etc. (Fig.4). The morphometric parameters were used to describe the evolution and behavior of surface drainage network which involves the measurement of various stream properties that are important for the hydrological studies and were classified into basin geometry, linear, aerial and relief aspects (Ali *et al*. 2017; Bera *et al*. 2018; Nag *et al*. 2003; Patel *et al*. 2016; Sangma *et al*. 2017) [2, 3, 21, 24, 28]. In the present study, quantitative morphometric analysis for numerous parameters was computed either in GIS environment with the help of ArcHydro (Maidment 2002) [17] and spatial analyst tools or using standard established mathematical equations, the computation of which is described and summarized in Table 1. All measurements were directly computed from the vector data that were extracted from the topographic maps. The choice of morphometric variables that were examined in this study was based on the results obtained from previous studies, which were found to fully integrate the geomorphological investigation and evolution of a drainage network morphometry on landform characteristics quantifying various hydrological aspects i.e. flow discharge, runoff volumes, flash flood hazard, sediment yield, soil erosion, landslide risk zone etc. Based on drainage characteristics and relief variability (landscape morphology assessed for elevation, slope and dissection degree), the basin was subdivided into two main sub-basins, namely, Alarginos and Karagjiozis. Sub-basins individually characterization behaviour aimed at the critical study of these parameters to arrive at conclusions on watershed response and behaviour. Moreover, the basin's drainage network was analyzed by Horton's laws (1945) [14] and the stream ordering was made using the method proposed by Strahler (1964) [40].

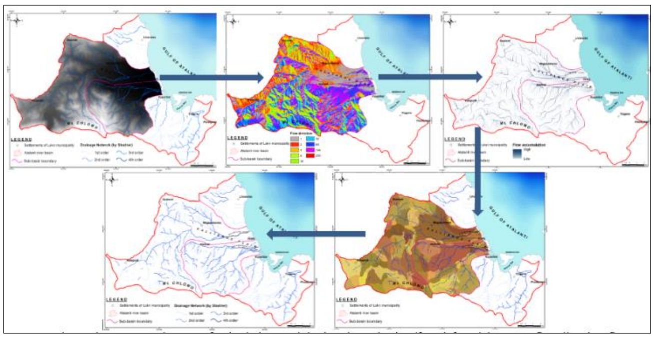

Fig 4: Certain terrain pre-processing maps for the drainage sub-basins' determination (from left to right; DEM, flow direction, flow accumulation, sub-catchments delineation, stream ordering)

Table 1: Morphometric parameters with mathematical equations

	Morphometric Parameter	Equation	Results	
			Alargino sub-basin	**Karagkiozis sub-basin**
A Drainage Network				
1	Stream Order (S_u)	Hierarchical Rank	1 to 4	1 to 4
2	1st Order Stream (S_{uf})	$S_{uf} = N_1$	262	192
3	Stream Number (N_u)	$N_u = N_1+N_2+\ldots+N_n$	466	368
4	Stream Length (L_u) km	$L_u = L_1+L_2+\ldots+L_n$	197.8	137.0
5	Stream Length Ratio (L_{ur})	see Table 2	1.47-6.06	1.52-6.71
6	Mean Stream Length Ratio (L_{urm})	see Table 2	3.65	3.30
7	Bifurcation Ratio (R_b)	see Table 2	1.51-29.0	1.43-41.0
8	Mean Bifurcation Ratio (R_{bm})	see Table 2	12.17	15.23
9	Rho Coefficient (ρ)	$\rho = L_{urm}/R_b$	0.30	0.22
B Basin Geometry				
1	Length from B's Center to Mouth of B's (L_{cm}) km	GIS Analysis/DEM	11.31	6.71
2	Width of B at the Center of Mass (W_{cm}) km	GIS Analysis/DEM	12.53	8.93
3	Basin Length (L_b) km	$L_b = 1.312\times A^{0.568}$	18.85	12.80
4	Mean Basin Width (W_b) km	$W_b = A/L_b$	5.79	4.31
5	Basin Area (A) km^2	GIS Analysis/DEM	109.05	55.18
6	Basin Perimeter (P) km	GIS Analysis/DEM	66.62	38.39
7	Relative Perimeter (P_r) km	$P_r = A/P$	1.64	1.44
8	Length Area Relation (L_{ar})	$L_{ar} = 1.4\times A^{0.6}$	23.37	15.53
9	Lemniscate Ratio (k)	$k = L_b^2/A$	3.26	2.97
10	Form Factor Ratio (F_f)	$F_f = A/L_b^2$	0.31	0.34
11	Shape Factor Ratio (S_f)	$S_f = L_b^2/A$	3.26	2.97
12	Elongation Ratio (R_e)	$R_e= 2/L_b\times(A/\pi)^{1/2}$	0.62	0.65
13	Texture Ratio (R_t)	$R_t = N_1/P$	3.93	5.00
14	Circularity Ratio (R_c)	$R_c = 4\pi\times(A/P^2)$	0.31	0.47
15	Drainage Texture (D_t) km^{-1}	$D_t = N_u/P$	3.93	9.59
16	Compactness Coefficient (C_c)	$C_c= 0.2841\times P/A^{1/2}$	1.81	1.47
C Drainage Texture Analysis				
1	Drainage Density (D_d) km/km^2	$D_d = L_u/A$	1.81	2.48
2	Stream Frequency (F_s) km^{-2}	$F_s = N_u/A$	4.27	6.67
3	Constant of Channel Maintenance (C) km^2/km	$C = 1/D_d$	0.55	0.40
4	Drainage Intensity (D_i)	$D_i = F_s/D_d$	2.36	2.69
5	Infiltration Number (I_f)	$I_f = F_s\times D_d$	7.73	16.54
6	Length of Overland Flow (L_g) km	$L_g = 1/(2\times D_d)$	0.28	0.20
D Relief Characters				

1	Height of Basin Mouth (z) m	GIS Analysis/DEM	0	0
2	Maximum Height of the Basin (Z) m	GIS Analysis/DEM	1025	1073
3	Basin Relief (H) m	$H = Z–z$	1025	1073
4	Absolute Relief (R_a) m	GIS Analysis/DEM	1025	1073
5	Relief Ratio (R_h)	$R_h = H/L_b$	0.054	0.084
6	Relative Relief (R_r)	$R_r = Z/P$	0.015	0.028
7	Gradient Ratio (R_g)	$R_g= (Z–z)/L_b$	0.054	0.084
8	Ruggedness Number (R_n)	$R_n= (D_d×H)/1000$	1.86	2.66
9	Total Contour Length (C_{tl}) km	GIS Analysis/DEM	189.82	137.56
10	Contour Interval (C_{in}) m	GIS Analysis/DEM	20	20
11	Average Slope (S) %	$S = [Z×(C_{tl}/H)]/(10×A)$	17.41	24.93
12	Hypsometric Integral (HI)	$HI = (H_{mean}-z)/H$	0.31	0.29
13	Erosional Integral (EI)	Hypsometric Curve	0.69	0.71

4. Results and Discussion

The quantitative morphometric analysis of drainage system refers to spatial relationship among streams which may be influenced by slope, soils, rock resistance, structure and geology. Geomorphologically speaking, the utmost effort is to describe the evolution and behaviour of surface drainage network involving the measurement of various stream properties that are important for the hydrological studies, also including the linear, areal and relief aspects of the watersheds and contributing ground slopes which are highly important to the landform making processes. The morphometric analysis of the study area was carried out on the DEM with 30 m spatial resolution and 44 morphometric parameters (Table 1) were evaluated for identifying various characteristics of the watershed.

4.1 Basic Geomorphology

Slope: the slope map (Fig.5) of the Atalanti basin was classified into five division's varing from 0 up to 54.97^0 with a mean slope of 10.52° and standard deviation of 8.76°. Approximately 55.9% of the study area has a slope of 0-10^0 (low lands where permeable loose formations prevail), 27.7% has moderate slope (10-20^0), 13.3% slightly high slope (20-30^0) while only 3.1% represents high slope areas (high lands) in the Southern basin's outskirts where limestones-dolomites and ophiolites are the dominant rocks creating steep cliffs.

Aspect (slope direction): Aspect determines the direction of terrain to which slope faces. The aspect map (Fig.5) was divided into ten classes which were Flat (4.1%), North (6.6%), North East (18.2%), East (16%), South East (16.4%), South (9.2%), South West (6.7%), West (6.2%), North West (10.9%) and North (5.6%). The slope faces are mainly directed towards North East, followed by South East and South direction (Fig.5).

Shaded relief: The Shaded relief map (Fig.5) is raster surface that provides a DEM's orthogonal view in a grey colourful scale to visually interprete and analyze the valley, semi-hilly, hilly and mountainous areas identifying certain geomorphological features, tectonic structures and rock types. Shaded relief is controlled by the elevation of the area, direction of light and the inclination of the light source. The fine texture in the shaded relief map indicates smooth topography in the center part of the basin (alluvial plain) while the geomorphic units located in the North, North West and South are highly dissected.

Topographical Zones: The mountainous areas account only for 2.2% (>800 m) of the total area mainly at the Southern end of the basin (Mt. Chlomo). The semi-mountainous topographical zone accounts for 4.5% (600-800 m) while the flat areas account for 39.5% (0-200 m) mostly concerning the coastal areas. Also, the hilly and semi-hilly areas occupy almost 54% (200-600 m) of the basin. Therefore, the basin's relief can be considered flat to hilly at 93.3% (Fig.5).

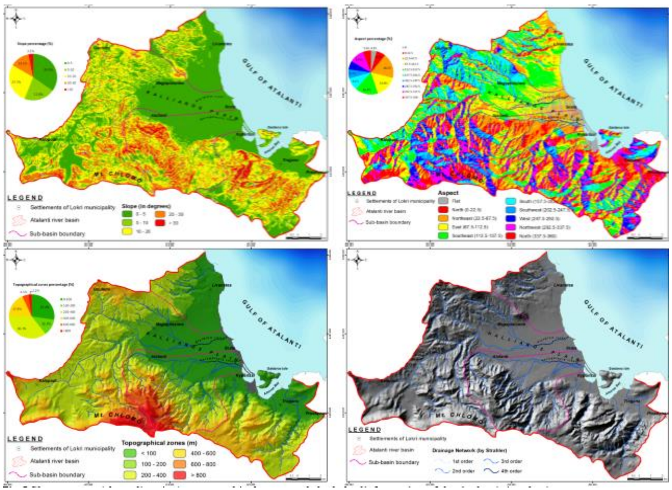

Fig 5: Slope, aspect (slope direction), topographical zones and shaded relief mapping of the Atalanti river basin

4.2 Morphometric Analysis

Linear aspects (Drainage Network)

Stream Order (S_u), Number (N_u) and Length (L_u)

The system for ordering stream was adopted in accordance with Strahler classification (1957). Total number of streams for both sub-basins of 4th order each, namely, Alarginos and Karagkiozis is 466 and 368 respectively, with the first order streams represent 56.2% and 52.2% respectively. Additionally, in Fig. 6 through rose diagrams, the streams' direction for each sub-basin is also shown. Also, the total stream length for Alarginos sub-basin is 197.8 km and 137.0 km for Karagkiozis one (Table 2). It is noted that the mean stream length of any given order is greater than that of the lower order and less than that of its next higher order in the basin. Numerous streams of smaller length are developed where the bedrocks and formation are less permeable, that is, in the hilly and mountainous areas. Below, Fig.7 (semi-logarithmic plot) shows the relationship between stream number and stream order as well as stream order and cumulative stream length satisfactorily applying the 1st and 2nd Horton's laws since inverse linear relationship is revealed (inversely proportional). Any deviation in the points from the straight line may be due to rock structural control of the streams. This indicates that maximum stream order frequency is observed in first order stream and gradually decreases as the order increases and stream lengths also decrease with increasing stream order.

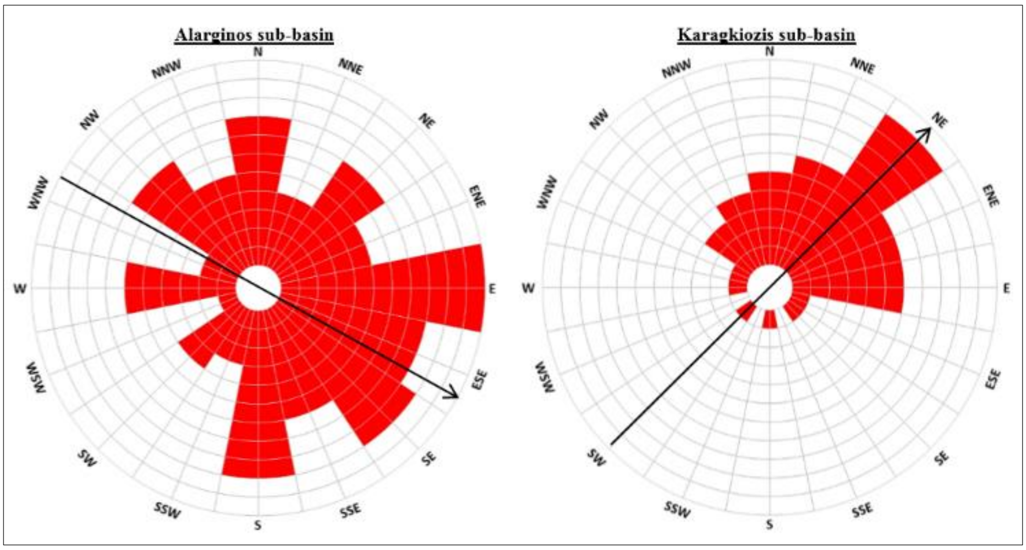

Fig 6: Rose diagrams for the sub-watersheds of the Atalanti river basin depicting the main stream directions (the black arrow determines the mean stream direction)

Stream Length Ratio (L_{ur})
Concerning the stream length ratio, the value ranges from 1.47 to 6.06 for Alarginos and from 1.52 to 6.76 for Karagkiozis indicating an increasing trend from lower to higher order except a value between third and fourth streams in Karagkiozis sub-basin which indicates the influence of both slope and topographical variations due to neo-tectonic deformations (Table 2).

Table 2: Application of the 1st and 2nd Horton's laws at the sub-basins of the study area

A/A	Sub-basin	N_1	N_2	N_3	N_4	L_1	L_2	L_3	L_4	R_b	L_{ur}	D_d	F_s	R_h
1	Alarginos	262	174	29	1	103.5	70.3	20.6	3.4	12.17	3.65	1.81	4.27	0.054
2	Karagkiozis	192	134	41	1	64.9	42.8	25.5	3.8	15.23	3.30	2.48	6.67	0.084

Bifurcation Ratio (R_b): It is a dimensionless parameter showing the drainage network's degree of ramification having significant control over the surface runoff. For the two sub-watersheds, bifurcation ratios range between 1.51 to 29 with the mean bifurcation ratio (R_{bm}) being 12.17 for Alarginos and 1.43 to 41 with the mean bifurcation ratio being 15.23 for Karagkiozis implying high structural complexity and strong influence of geological and lithological development as well as drainage pattern distortion as a consequence of structural disturbances. Also, bifurcation ratio over 10 indicates that the drainage basin is developed over erodible rocks.

Rho Coefficient (ρ): The Rho coefficient of the Alarginos catchment equals to 0.30 and of the Karagkiozis one to 0.22; the higher value shows higher water storage during flood periods and thus attenuation of the erosion effect. The lower value indicates low water storage during flood periods and high erosion effect.

Areal aspects (Basin Geometry, Drainage Texture Analysis)
Certain aerial parameters such as the Length from B's Center to Mouth of B's (L_{cm}), the Width of B at the Center of Mass (W_{cm}), the Basin Length (L_b), the Basin Area (A) and the Basin Perimeter (P) were derived through GIS processing and their values are summarized in Table 1.

Form Factor (F_f): Has a direct relation to the stream flow and shape of the watershed. The smaller the form factor the more elongated. Flood flows in elongated basins are easier to manage than the watersheds developed towards rectangular to circular shape. The values range from 0.31 to 0.34 which indicate that both sub-basins have elongated shape (triangular or longitudinal shape) suggesting low stream flow discharge hydrograph of longer duration.

Lemniscate Ratio (k) – Shape Factor (S_f): The values for the two watersheds in the study area range between 2.97 and 3.26 representing elongated sub-basins with nearly pear-shaped.

Circularity Ratio (R_c): The values obtained for the sub-basins range from 0.31-0.47 which indicate that the drainage basin is more or less elongated and is characterized by medium to low relief, low runoff discharge with permeable homogenous geological formations. It is a significant ratio which indicates the dendritic to sub-dendritic stage of the basin. This is mainly due to the diversity of slope and the basin's relief pattern.

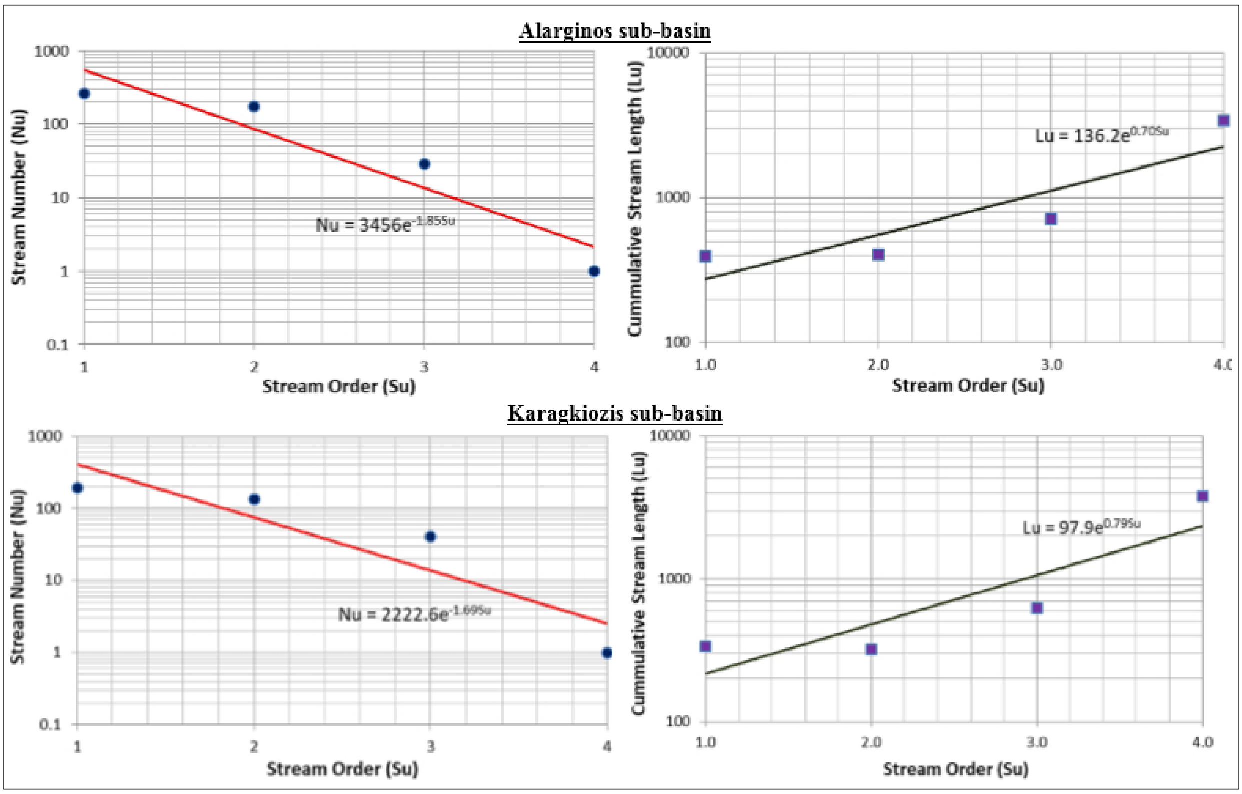

Fig 7: Graphical presentation of the 1st and 2nd Horton's laws at the two sub-watersheds of the Atalanti river basin

Elongation Rario (R_e): In elongated basins the surface water flows over a longer period than in circular ones indicating low erosion and sediment yield as well as limited flooding risk. Both sub-basins have elongation ratio between 0.5-0.7 meaning that are close to elongated shape.

Texture Ratio (R_t): Depends on the underlying lithology, infiltration capacity and relief aspects of the terrain. The texture ratio of Alarginos sub-basin is 3.93 and 5.00 for Karagkiozis one which were categorized as to the presence of moderate to low reliefs. These low values indicate coarse texture due to the presence of resistant and hard rocks especially in the southern areas, also indicating good permeability of subsurface material and infiltration capacity and lower surface runoff rate.

Compactness Coefficient (C_c): Refers to homogeneity between the shape of basin perimeter and basin area, independent of size of watershed and dependent only on the slope. It ranges between 1.47 (Karagkiozis) and 1.81 (Alargino). In general, compactness ratio values are seemed to be low refering to the basin's development in its geomorphic stage. Compactness ratio increases with increasing curvature of water divide.

Drainage density (D_d): The parameter equals to 1.81 and 2.48 km/km^2 for Alarginos and Karagkiozis sub-basins respectively (moderate value) which indicates medium soil permeability, moderate relief, dense vegetation cover and medium capacity to surface runoff. A low drainage density also indicates that the most rainfall infiltrates the ground recharging groundwater aquifers and few channels are required to carry the runoff (Fig.8). Also, the values indicate a positive correlation with the stream frequency and drainage texture (Fig.9). Generally speaking, a low drainage density means a poorly drained basin with a slow hydrological response and less prone to flooding.

Stream Frequency (F_s): The stream frequency is 4.27/km^2 and 6.67/km^2 for Alarginos and Karagkiozis sub-basins respectively explaining the semi-permeable formations and low to moderate relief. The calculated drainage density values of the studied sub-basins are high which may indicate the limited contribution to flash flood potentiality owing to low runoff rate (Fig.8). Lesser the drainage density and stream frequency in a basin, slower the runoff and therefore, flooding is less likely in basins with a low to moderate drainage density and stream frequency as well.

Constant of Channel Maintenance (C): The values for the sub-basins were found to be 0.55 (Alarginos) and 0.40 km^2/km (Karagkiozis) indicating semi-permeable soils, adequate vegetation cover and plain terrain at the lowlands. The absolute values are seemingly identical and low as a result of coarse texture and intensive dissection of drainage areas.

Drainage Intensity (D_i): The lithology, the infiltration capacity and relief aspect influence the drainage texture. Both sub-watersheds of Atalanti river basin have a mean value between 2-4 indicating coarse texture category, less dissection and erosion.

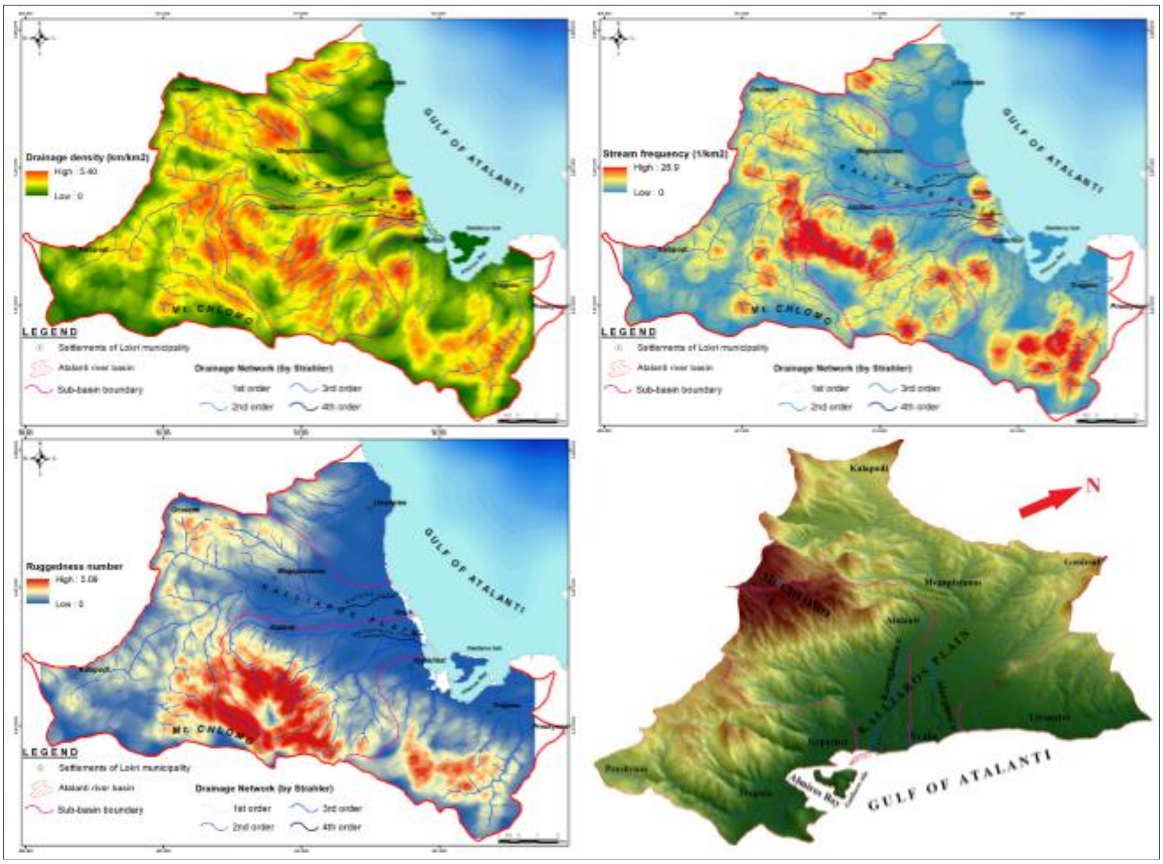

Fig 8: Drainage density, stream frequency and ruggedness number mapping as well as 3D display of the Atalanti river basin

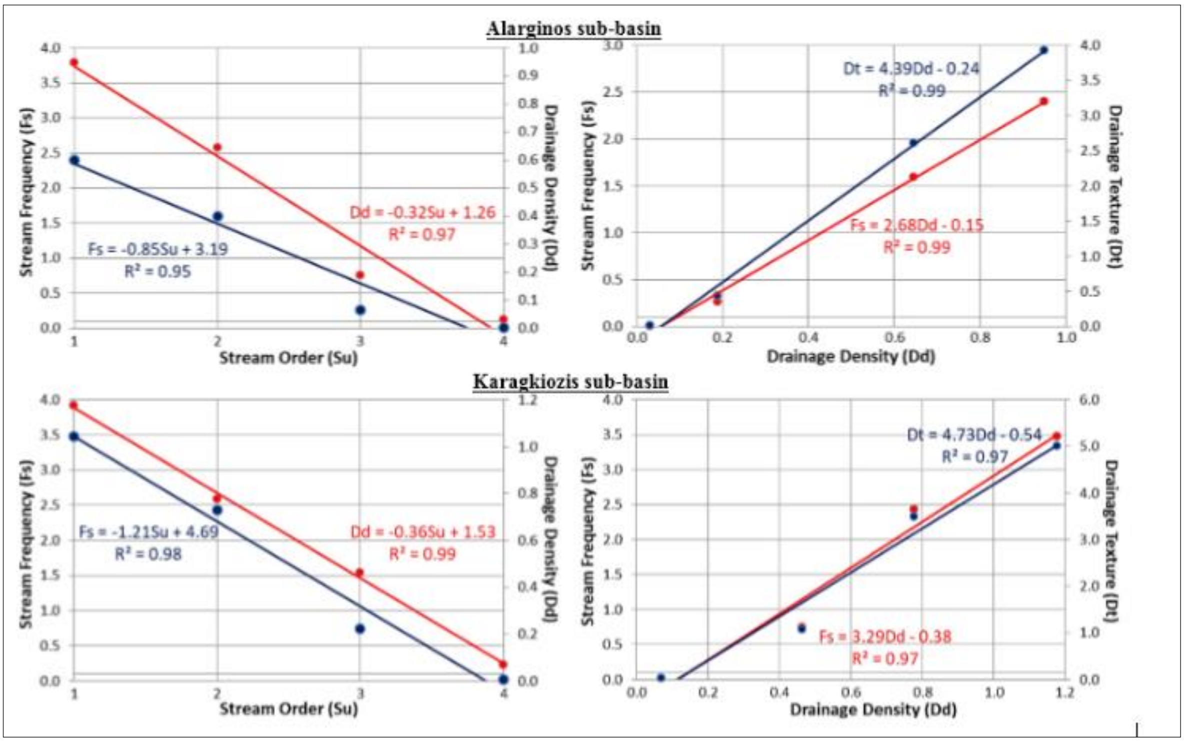

Fig 9: Linear correlation between Stream Frequency (F_s) – Drainage Density (D_d) vs Stream Order (S_u) and Stream Frequency – Drainage Texture (D_t) vs Drainage Density (D_d) of the two sub-basins (Alarginos and Karagkiozis)

Infiltration Number (I_f): The high mean values for both sub-basins (from 7.73 to 16.54) mean the moderate runoff and soil permeability.

Length of Overland Flow (L_g): Controls the quantity of erosion. The length of overland flow for both sub-watersheds is low (between 0.20 and 0.28 km) indicating the development of lower order channels, moderate ground slopes and longer flow paths with moderate infiltration associated with moderate runoff. The low L_g values indicate that the rainwater has to travel relatively shorter distance before getting concentrated into stream channels. On an average, most of the drainage basins in its youth or rejuvenated stages have minimum length of overland flow.

Relief aspects

Linear and areal features were considered as the two dimensional aspects lying on a plan. The third dimension introduces the concept of relief. Relief characteristics of drainage network relate to the three dimensional features of the basin involving surface and altitude of vertical landforms' dimension wherein different morphometric methods are used to analyse ground aspects. Various relief characteristics such as the Height of Basin Mouth (z), the Maximum Height of the Basin (Z), the Basin Relief (H), the Absolute Relief (R_a), the Total Contour Length (C_{tl}) and the Contour Interval (C_{in}) were derived through GIS processing and their values are summarized in Table 1.

Relative Relief (R_r): The value of the relative relief for the two sub-watersheds is shown in Table 1. Alarginos sub-watershed equals to 0.015, while Karagkiozis sub-watershed equals to 0.028.

Gradient Ratio (R_g): A gradient ratio is an indicator of channel slope enabling assessment of the runoff volume. The low values of 0.054 and 0.084 for Alarginos and Karagkiozis sub-basins reflect the hilly to flat nature of the terrain especially in the middle towards east of the whole basin.

Ruggedness Number (R_n): Measures the structural complexity of the terrain in association with the relief and drainage density. The value of Alarginos sub-basin is 1.86 and 2.66 for Karagkiozis one. These values are relatively medium to high as a consequence of moderate drainage density and relief, especially over 200 m. They occur when both variables (basin relief and density) are large and when the slopes are not only steep but long as well (Fig.8).

Hypsometric and Erosional Integral (HI & EI): Hypsometric curves show the correlation between watershed's area and relief. The hypsometric and erosional integrals calculated from the percentage hypsometric curve, give accurate knowledge of the basin's geomorphological stage (Singh *et al*. 2008; Strahler 1952) [36, 37]. The hypsometric integral (Fig.10) of Alarginos and Karagkiozis sub-watersheds are 31% and 29% while the erosional one is 69% and 71% respectively, which indicates the old to rejuvenated stage of the Atalanti basin due to the neotectonic activity.

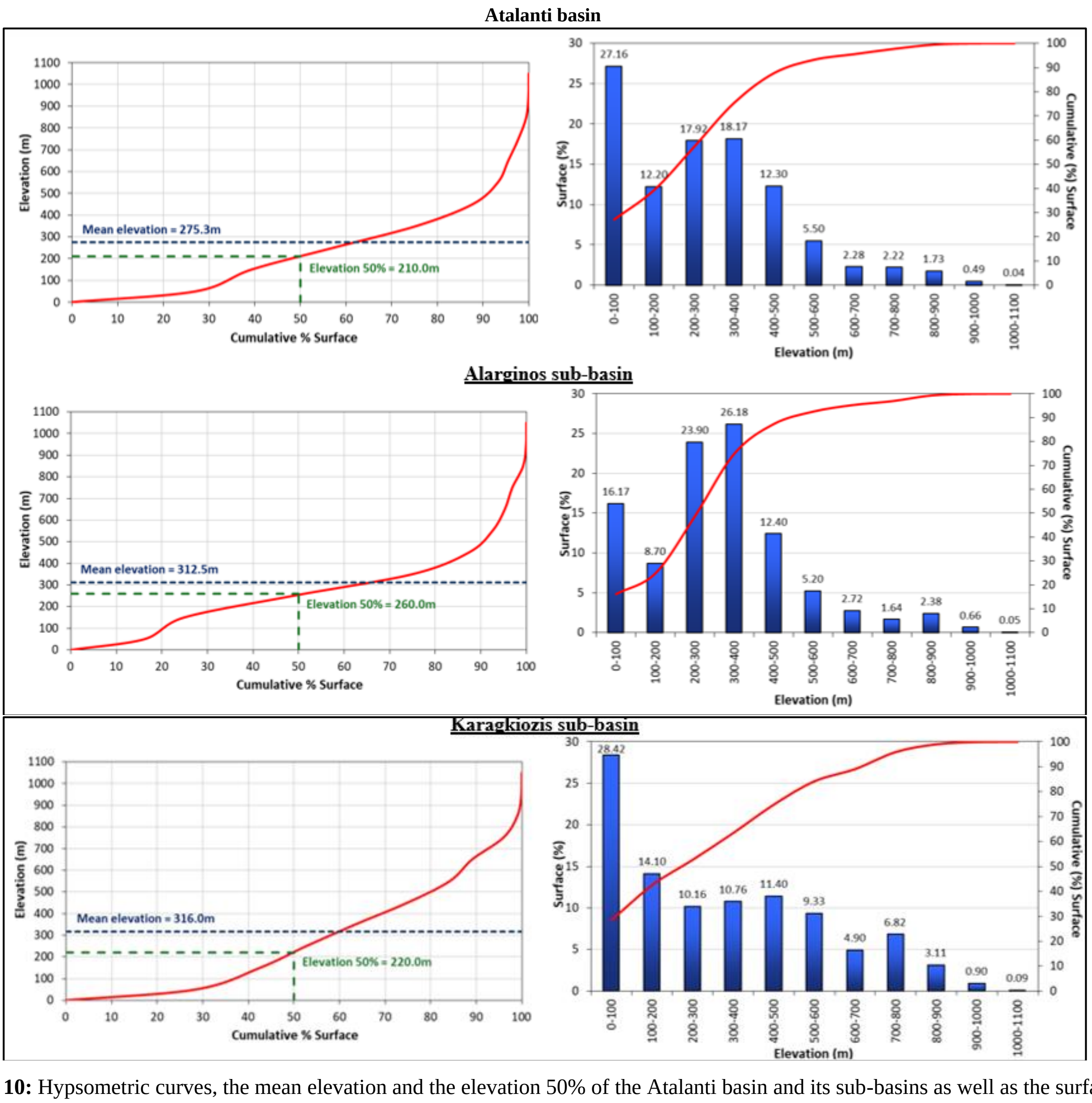

Fig 10: Hypsometric curves, the mean elevation and the elevation 50% of the Atalanti basin and its sub-basins as well as the surface percentage occupied per 100m

Relief Ratio (R_h): It is an indicator of the overall steepness of a drainage basin and the intensity of erosional processes operating on the basin slope. The Relief ratio of the Alarginos sub-basin was found to be 0.054 and 0.084 for Karagkiozis one. These low values indicate resistant basement rocks, steep to moderate slopes in the river basin and hence limited susceptibility to erosion processes.

Average Slope (S): It has direct influence on the erodibility of the watershed (the more the percentage of slope the more the erosion). The values vary from 17 to 25% to both sub-basins hence less erosion processes. The main stream flows through the mountains and plateau, the general slope of the basin decreases towards north-northwest. Physiographically, the slope varies with very slopes (30°-45°) in the mountainous areas, moderate to steep slopes (10°-30°) in the hilly areas and gentle to moderate slope (2°-10°) in the plains. A detailed understanding of slope distribution helps in planning for various aspects like, settlement, agriculture, planning of engineering structure, etc. It helps to understand and identify the areas prone to soil erosion and runoff which could lead to severe flash floods when steep slopes prevail.

Longitudinal and cross-section profiles of the rivers: The profiles (Fig.11) are the plotting of height (H) against the distance downstream (L). The profiles of a river are based upon the lithology of the sub-strata structure, stream flow discharge, amount and texture of the stream load, flow resistance, velocity, width and depth of the channel and regional slope as well. The cross-section profiles vary from the narrow, steep-sided trenches to gentle open form, ultimately depends on the resistance offered by the valley slopes and the erosive capacity of the water. Most of the cross-section profiles are 'V' shaped in nature and it represents down cutting rather than lateral erosion.

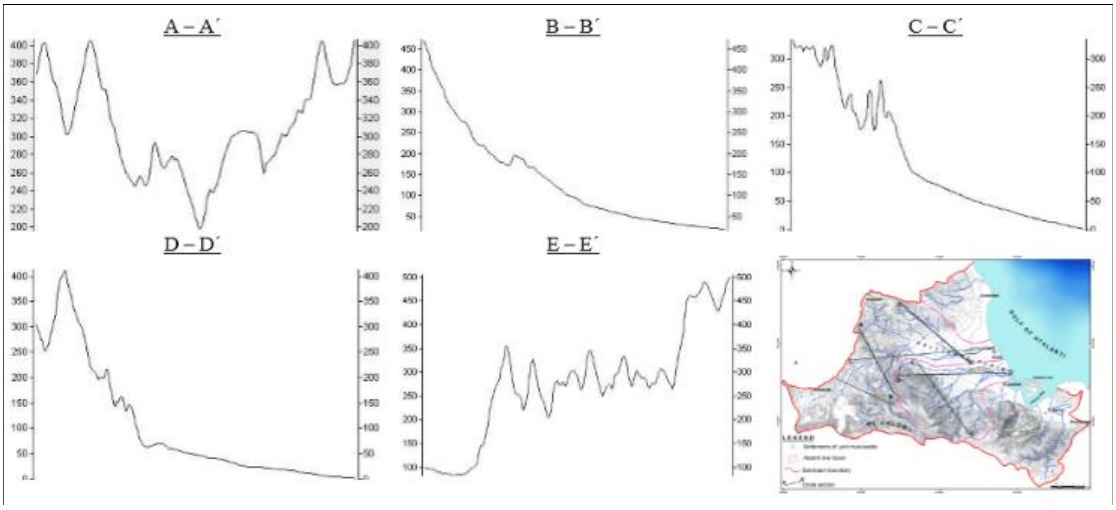

Fig 11: Schematical cross-sectional topographical profiles showing the geomorphological relief of the two sub-watersheds of Atalanti river basin

5. Conclusions

In the present research, GIS-based geomorphological approach facilitated the Atalanti river basin's quantitative analysis of various morphometric parameters and focused on the relationship between the drainage morphometry and properties of terrain characteristics through linear, areal and relief aspects with the help of digital elevation modelling (DEM). This procedure was found to be of immense utility in river basin evaluation in a rapid, convenient and accurate way interpreting the analysis results of the physical-geographical environment. Besides, it is obvious that the morphometric analysis of a drainage system is considered essential to any watershed related study. Drainage density and stream frequency are the most useful criteria for the morphometric interpretation of drainage sub-basins which certainly control the surface runoff, sediments yield and other hydrological parameters. The drainage texture of the watershed is coarse and its drainage density showed areas of moderate permeable subsoil material, thick vegetation cover, low relatively relief and effect by structural disorders. Topographical analysis showed that 93.5% of the basin areas is below 600m. About 83.6% of the area has a slope ranging from 0^0 to 20^0 while the aspect map of the watershed indicated that the terrain gradient is from North East to South East (50.6%). The stream analysis (dendritic to sub-dendritic drainage pattern) showed that the two main sub-basins are of 4^{th} order and a strong relationship was found between stream order and stream numbers as well as between stream order and stream length (1^{st} and 2^{nd} Horton's laws). The elongation ratio also showed that basin is close to elongated shape. Relief aspects of sub-basins showed low slope and long flow paths which gives reduced runoff and high infiltration rate. In addition, the ruggedness number implies more or less the same conclusions of limited soil erosion susceptibility and flood vulnerability. Moreover, the higher value of rho coefficient was found in both sub-basins which showed higher water storage during flood periods and thus attenuation of the erosion effect. The hypsometric analysis indicates the sub-basins' rejuvenated stage due probably to the influence of the recent ongoing neotectonic activity. This study can be useful for integrated water management such as watershed prioritization and natural hazard management. Hence, it can be inferred that DEM processing in a GIS environment ascertains to be an effective and powerful tool for the evaluation of drainage network morphometry as well as watershed management plans with respect to basin's hydrologic response and behaviour.

Conflict of Interests

The authors declare no conflict of interests.

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6. References

1. Agarwal S. Study of drainage pattern through aerial data in Naugarh area of Varanasi district, U.P, Journal of Indian Society of Remote Sensing. 1998; 26:169-175.
2. Ali K, Bajracharya M, Sitaula K, Raut N, Koirala L. Morphometric analysis of Gilgit river basin in a mountainous region of Gilgit-Baltistan Province, Northern Pakistan. Journal of Geoscience and Environment Protection. 2017; 5:70-88.
3. Bera A, Mukhopadhyay B, Das D. Morphometric Analysis of Adula River Basin in Maharashtra, India using GIS and Remote Sensing techniques Geo-spatial Data in Natural Resources, 2018, pp.13-35.
4. Biswas S, Sudhakar S, Desai R. Prioritization of sub-watersheds based on morphometric analysis of drainage basin-A remote sensing and GIS approach. Journal of the Indian Society of Remote Sensing. 1999; 27:155-166.
5. Biswas S. Analysis of GIS based morphometric parameters and hydrological changes in Parbati river basin, Himachal Pradesh, India. Journal of Geography and Natural Disasters. 2016; 6:175-182.
6. Chorley J. Introduction to physical hydrology. Methuen and Co. Ltd., Suffolk, 1969 p.211.
7. Chorley J. Spatial Analysis in Geomorphology. Methuen and Co. Ltd., London, 1972.
8. Chow T. Handbook of Applied Hydrology. McGraw-Hill, New York, 1964.
9. Clarke J. Morphometry from Maps. Essays in geomorphology. Elsevier publication. Co., New York, 1996, pp.235-274.
10. Diakakis M. A method for flood hazard mapping based on basin morphometry: application in two catchments in Greece. Natural Hazards. 2011; 56(3):803-814.
11. Dingman L. Physical Hydrology. NY, McMillan Pub, 1970.
12. Gardiner V. Drainage basin morphometry. Tech. Bull. (British Geom group). 1978; 14:48.
13. Horton E. Drainage basin characteristic. Trans Amer. Geophys. U. 1932; 13:350-361.
14. Horton E. Erosional development of stream and their drainage basin: Hydrological approach to quantitative morphology. Bull. Geol. Soc. Amer. 1945; 56:275-370.
15. Khan A, Gupta P, Moharana C. Watershed Prioritization Using Remote Sensing and Geographical Information System: A Case Study from Guhiya. India Jour. Arid Environment, 2001, pp.465-475.
16. Lappas I. Applied hydrogeological research in coastal aquifers. Case study of the coastal part of Atalanti region, Prefecture of Fthiotida. PhD Thesis Dissertation, School of Mining and Metallurgical Engineering, National and Technical University of Athens, 2018, p487.
17. Maidment R. Arc Hydro: GIS for water resources. ESRI, Inc, 2002.
18. Malik M, Bahat S, Kuchay A. Watershed Based Drainage Morphometric Analysis of Lidder Catchment in Kashmir Valley Using Geographical Information System. Recent Research in Science and Technology. 2011; 3(4):118-126.
19. Maratos G, Rigopoulos K, Athanasiou A. Geological maps of Atalanti and Livanates sheets, scale 1:50.000, Institute of Subsurface Geological Research, 1965.
20. Miller C. A quantitative geomorphic study of drainage basin characteristics on the Clinch Mountain area, Virgina and Tennessee, Columbia University, Department of Geology, Technical Report. 1953; 3:389-402.
21. Nag K, Chakraborty S. Influence of rock types and structures in the development of drainage network in hard hock area. J. Indian Soc. Remote Sensing. 2003; 31(1):25-35.
22. Palivos N. Geomorphological study of Atalanti area of Fthiotida prefecture. PhD Thesis Dissertation, School of Sciences, Department of Geology, Athens, 2001.
23. Paretta K, Paretta U. Quantitative morphometric analysis of a watershed of Yamuna basin, India using ASTER (DEM) data and GIS. International journal of Geomatics and Geosciences, 2011; 2(1):248-269.
24. Patel S, Sengupta D, Tiwari K, Dwivedi B. Morphometric aspects of a small river system of Mirzapur District, Uttar Pradesh, India: A case study of Barhi river system. International Journal of Multidisciplinary Research and Development. 2016; 3(3):250-255.
25. Psomiadis E. Geomorphologic and environmental changes research in the Sperchios river basin utilizing new technologies (Remote Sensing & GIS). PhD Thesis Dissertation, Agricultural University of Athens, Lab. of Mineralogy & Geology, 2010, p394.
26. Psomiadis E, Migiros G, Antoniou V. Geomorphological quantitative analysis of Sperchios river basin area (central Greece) utilizing geographical information systems. Bulletin of the Geological Society of Greece, vol. XLVII, Proceedings of the 13th International Congress, Chania, 2013.
27. Rai P, Mohan K, Mishra M, Ahmad A, Mishra V. GIS-based approach in drainage morphometric analysis of Kanhar River Basin, India. Applied Water Science. 2014; 7:217-232.
28. Sangma F, Balamurugan G. Morphometric analysis of Kakoi river watershed for study of neotectonic activity using geospatial technology. International Journal of Geosciences. 2017; 8:1384-1403.
29. Sarma P, Sarmah K, Chetri P, Sarkar A. Geospatial study on morphometric characterization of Umtrew River basin of Meghalaya. India. International Journal of Water Resources and Environmental Engineering. 2013; 5:489-498.
30. Schumm A. Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geol. Soc. Am. Bull. 1956; 67:597-646.
31. Schumm A. Sinuosity of Alluvial Rivers on the Great Plains. Bulletin of the Geological Society of America. 1963; 74:1089-1100.
32. Schumm A. Alluvial river response to active tectonics. In: R.E. Wallace (Eds), Active Tectonics. Natl. Acad. Press, Washington, D.C., 1986, pp.80-94.
33. Sharma S. Perspectives in geomorphology. Naurang Rai, Cocept publishing company, New Delhi, 1981, pp.109-140.

34. Singh S. Physical Geography. Prayag Pustak Bhawan, Allahabad, India, 1998.
35. Singh S, Singh C. Morphometric analysis of Kanhar river basin. National Geographical Journal of India, 1997; 43(1):31-43.
36. Singh O, Sarangi A, Milap C, Sharma M. Hypsometric integral estimation methods and its relevance on erosion status of North-Western Lesser Himalayan watersheds. Water Resources Management. 2008; 22:1545-1560.
37. Strahler N. Hypsometric (Area-Altitude) Analysis of Erosional Topography. Bull. Geol. Soc. of Am. 1952; 63(11):1117-1142.
38. Strahler A. Quantitative Slope Analysis. Bulletin of the Geological Society of America. 1956; 67:571-596.
39. Strahler A. Quantitative analysis of watershed geomorphology. American Geophysical Union Transactions. 1957; 38(6):913-920.
40. Strahler A. Quantitative geomorphology of drainage basins and channel networks. Handbook of applied Hydrology. V.T. Chow (ed.), New York, Mc Graw-Hill. 1964; 4-II:439-476.
41. Tsioumas V, Zorapas V, Pavlidou E, Lappas I, Voudouris K. Groundwater contamination by nitrates and seawater intrusion in Atalanti basin (Fthiotida, Greece). Proceedings of the 9th International Congress of Greek Hydrogeological Society, 2011.
42. Waugh D. Geomorphology: An Integrated Approach. Thomson Nelson Publishing Company, London, 1996.