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MORPHOMETRIC AND HYDROGRAPHIC CHARACTERISTICS OF TORRENTS OF NW PELOPONNESE, GREECE

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Abstract

The study area includes the catchments of Selemnos, Xylokeras and Volinaios torrents, with 456 streams of 277.848 km total length. The pattern is generally dendritic. A quantitative analysis of the drainage systems of the study area was interpreted and then correlated to the fault systems that appear in the area. The main direction of the streams and the tectonic features is WSW-ENE. The drainage density and stream frequency is highly variable as a result of many factors, most important of which is lithology with high infiltration capacity. The number and the length of most streams show divergence of the 1st and 2nd law of Horton since they have dissimilar values from those theoretically expected.

Key words: *Hydrology, drainage network, geomorphology.*

Περίληψη

Η περιοχή έρευνας αποτελείται από τις υδρολογικές λεκάνες των χειμάρρων Σέλεμνου, Ξυλοκέρα και Βολιναίου όπου διακρίνονται 456 κλάδοι συνολικού μήκους 277.848 χλμ. Το υδρογραφικό δίκτυο είναι κυρίως δενδριτικό. Στην παρούσα εργασία έγινε ποσοτική ανάλυση των υδρογραφικών δικτύων της περιοχής καθώς και σύγκρισή τους με το σύστημα των τεκτονικών ασυνεχειών. Η κύρια διεύθυνση των ρευμάτων και των τεκτονικών ασυνεχειών είναι ΔΝΔ-ΑΒΑ. Οι τιμές της υδρογραφικής πυκνότητας και συχνότητας παρουσιάζουν υψηλές μεταβολές ως αποτέλεσμα πολλών παραγόντων, κυριότερος των οποίων είναι η λιθολογία η οποία παρουσιάζει υψηλή υδροπερατότητα. Το μήκος και ο αριθμός των περισσότερων κλάδων παρουσιάζουν απόκλιση από τον πρώτο και το δεύτερο νόμο του Horton αφού εμφανίζουν τιμές διαφορετικές από τις θεωρητικά αναμενόμενες.

Λέξεις κλειδιά: *Υδρολογία, δίκτυο απορροής, γεωμορφολογία.*

1. Introduction

The study area is located in NW Peloponnese and covers 68.626 km^2. It consists of three drainage basins, those of the Selemnos, Xylokeras and Volinaios. The elevation varies between 0 and 1621 m, the mean elevation is 480 m and the mean gradient is 42 %.

The aim of this study is the quantitative description of the basin morphometry by the characterization of linear and areal features, gradient of channel network and contributing ground slopes of the drainage basin. Detail analysis of drainage parameters is of great help in understanding the influence of drainage morphometry on landforms and their characteristics.

The analysis showed a correlation between the calculated parameters (drainage density, stream frequency and slope) and the lithology of the area. The combination of the specific lithology and the active tectonics have resulted that the development of the drainage network is strongly dependant on the tectonic activity in the area.

2. Geology

In the study area the geological formations of the Pindos zone are present (Fig. 1). The northern part of the area consists of limestones with thin layers of cherts (Upper Cretaceous) and radiolarites (Jurassic-Lower Cretaceous). In some places flysch of Upper Cretaceous-Eocene is present. This flysch is mainly beds of sandstones, alternating with thin-platy pelagic limestones. In the central part marine, brackish and lacustrine deposits are developed (Pliocene-Pleistocene). Particularly, these deposits are alternating layers of marls, clays, coarse-grained sands, fine-grained sandstones, conglomerates of low and often high cohesion. The coastal zone is composed by recent Holocene deposits, such as clays, sands, pebbles and cobbles.

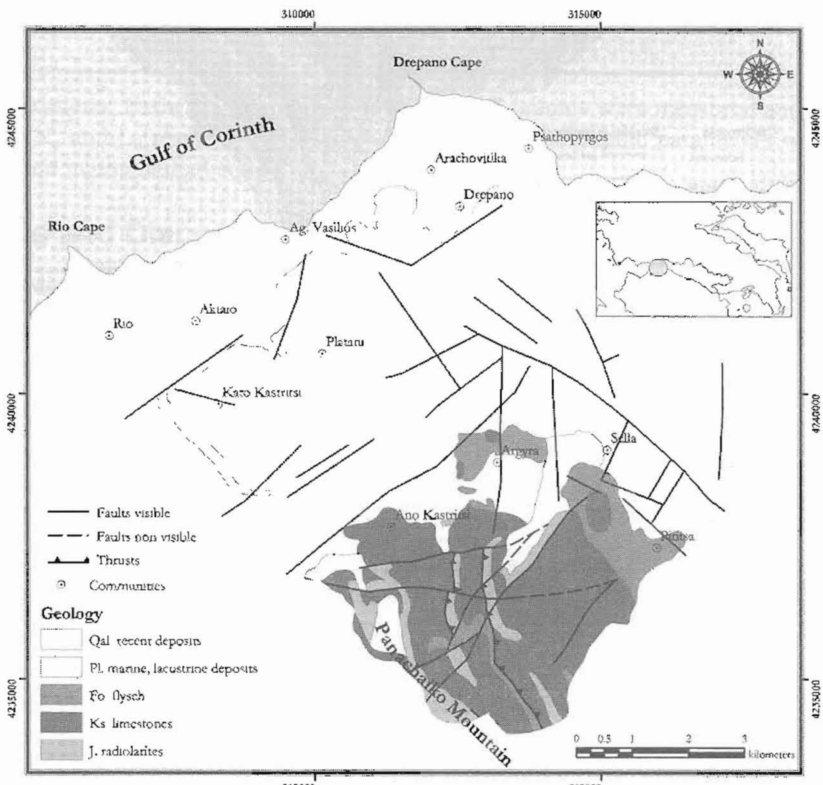

Figure 1 – Geological map of study area (IGSR 1971, IGME 1984, Doutsos *et al.* 1988)

3. Materials and Methods

For the geomorphological analysis of the study area, the drainage pattern was digitized, based on the topographic maps (scale 1:50,000) (HMGS, 1987) (Fig. 2). A Digital Elevation Model (DEM) was generated based on the contour values to generate height maps. A Geographical Information System (GIS) was used as a tool to handle and manage data for application of the model. Based on the drainage order, the drainage channels were classified into different orders (Strahler 1964). The

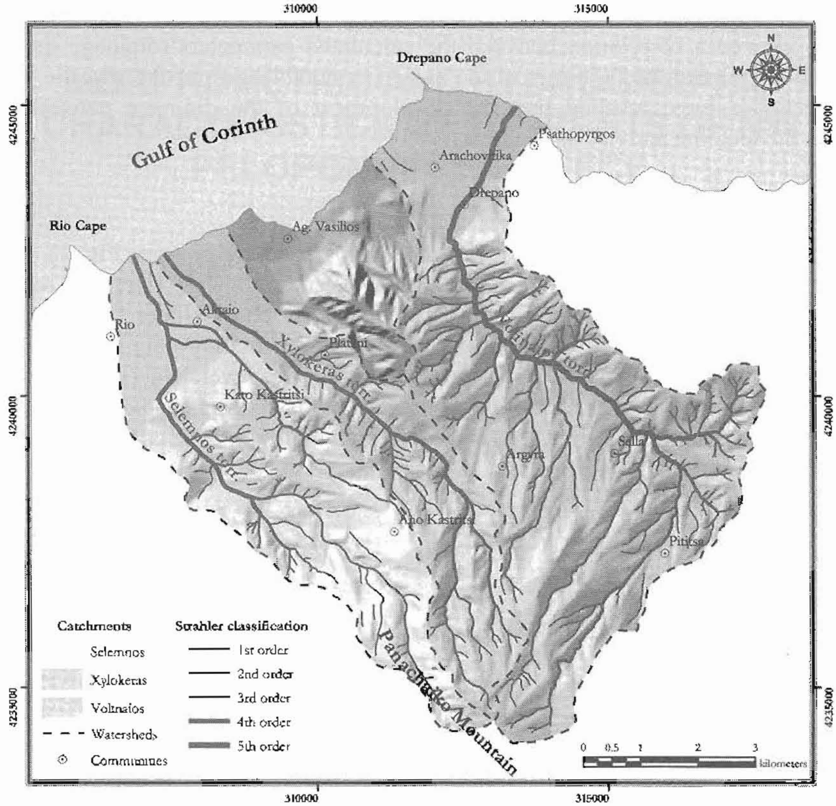

Figure 2 – Drainage network of the study area

Table 1 – Morphometric and hydrographic parameters and their mathematical expressions

No.	Parameter	Formula	Description
1	Form factor	$F = \frac{A}{L^2_{\max}}$	F was computed as the ratio between the basin area and square of the basin length (Horton 1932)
2	Circularity ratio	$R_C = \frac{4\pi \cdot A}{\Pi^2}$	R_C was computed as the ratio between the basin area and square of the basin perimeter (Tauer and Humborg 1992)
3	Elongation ratio	$R_L = \frac{2\sqrt{A/\pi}}{L_{\max}}$	R_L was computed as the ratio between the basin area and the basin length (Tauer and Humborg 1992)
4	Basin relief	$H = h_{\max} - h_{\min}$	H was defined as the maximum vertical distance between the lowest and the highest points of the basin
5	Relief ratio	$R_h = \frac{H}{L_{\max}}$	R_h was calculated as the ratio between the maximum hypsometrical difference of the basin and the basin length (Schumm 1956)

No.	Parameter	Formula	Description
6	Bifurcation ratio	$R_b = \frac{N_u}{N_{u+1}}$	R_b was computed as the ratio between the number of streams of any given order to the order of streams in the next higher order (Horton 1945)
7	Length ratio	$R_L = \frac{\sum \overline{L}_u}{\sum \overline{L}_{u+1}}$	R_L was computed as the ratio between the mean cumulative length of any given order to the order of streams in the next higher order (Horton 1945)
8	Drainage density	$R_D = \frac{\sum L}{A}$	R_D was measured as the length of stream channel per unit area of drainage basin
9	Stream frequency	$R_N = \frac{\sum N}{A}$	R_N was computed as the ratio between the total number of streams and area of the basin
10	Stream relief	$S_C = \frac{H}{L_{u_{main}}}$	S_C was calculated as a ratio between the relief ratio and the main stream length

basin area, perimeter, basin length, number and length of streams were measured and expressed as A, Π, Lmax, N_u and L_u respectively. Morphometric and hydrographic parameters were evaluated with established mathematical equations (Table 1).

4. Results and Discussion

4.1. Evaluation of morphometric parameters

The area-elevation curves were developed for describing the distribution of catchments areas with elevation (Figs 3, 4).

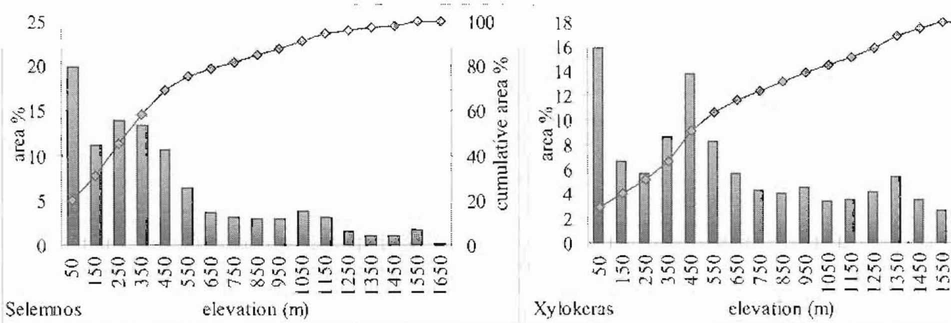

Figure 3 – Area-elevation curves of Selemnos and Xylokeras basins

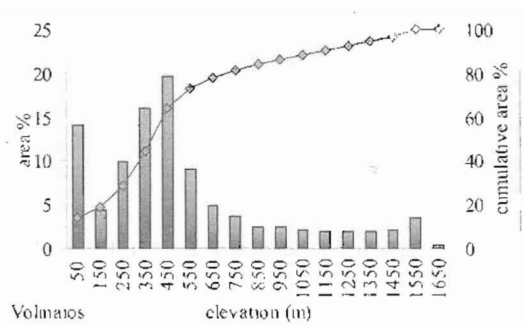

Figure 4 – Area-elevation curve of Volinaios basin

Analysis of *form factor (F)* reveals that basins having low F have less side flow for shorter duration and high main flow for longer duration and vice versa. This condition prevails in all three basins (Table 2). *Circularity ratio (R_C)* values approaching 1 indicate that the basin shapes are circular and as a result, there is scope for uniform infiltration and it takes a long time to reach excess water at basin outlet, which further depend on the existing geology, slope and land cover. The low values of R_C in the three basins support the above concept. Analysis of *elongation ratio (R_L)* indicates that the areas with higher R_L values have high infiltration capacity and low runoff. All three basins have low R_L which means that are susceptible to high erosion and sedimentation load. *Basin relief (H)* aspects of the basins play an important role in drainage development, surface and subsurface water flow, permeability, landforms development and erosion properties of the terrain. The analysis reveals that these basins have relief more than 1600 m which indicates the importance of water flow, low infiltration and high runoff conditions. Low values of the *relief ratio (R_h)* mean low gradient of the basins.

Table 2 – Morphometric parameters

Basin	N_1	N_2	N_3	N_4	N_5	L_1	L_2	L_3	L_4	L_5
Selemnos	67	18	5	1	-	17.766	13.235	6.150	5.484	-
Xylokeras	64	14	4	1	-	14.861	9.173	4.435	7.013	-
Volinaios	205	59	14	3	1	48.310	30.175	14.941	2.335	103.969

Basin	A (km^2)	Π (km)	L_{max} (km)	F	R_C	R_L	H (m)	R_h
Selemnos	17.584	23.674	10.087	0.173	0.394	0.469	1607	0.159
Xylokeras	11.896	23.986	9.755	0.125	0.26	0.399	1607	0.165
Volinaios	32.259	34.051	11.346	0.251	0.349	0.565	1621	0.143

4.2. Drainage morphometry

After the ordering of the drainage networks, the 1st and 2nd laws of Horton (1945) have been applied for the number (N) and the mean length of streams ($\overline{L}$). The results are shown in Figure 5.

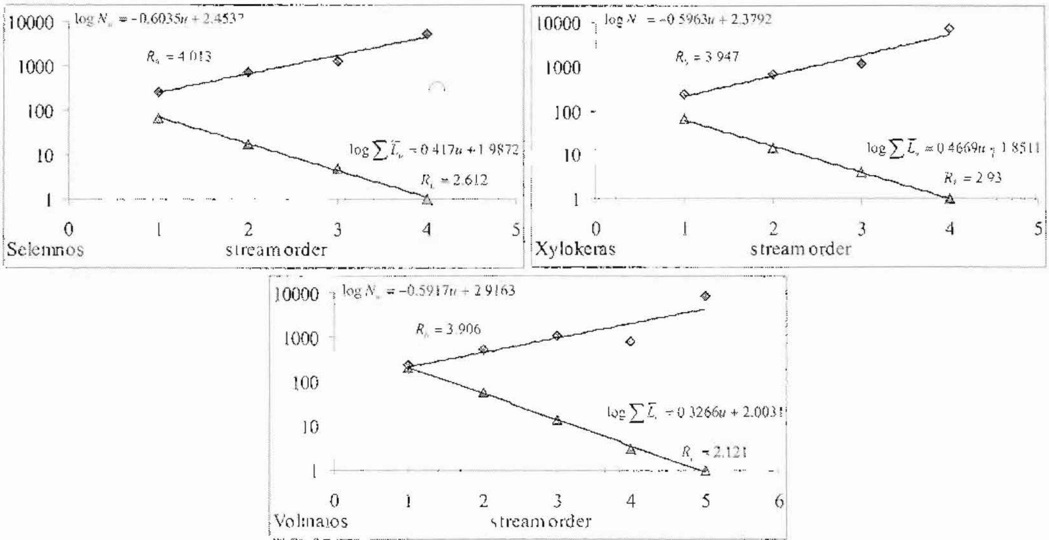

Figure 5 – Diagram showing the 1st and 2nd law of Horton

According to these laws, the theoretically expected number and mean length of streams respectively have been calculated (Fig. 6). Positive deviation values show the presence of more streams and a length longer than the ideal, while negative values show less number and smaller length than expected.

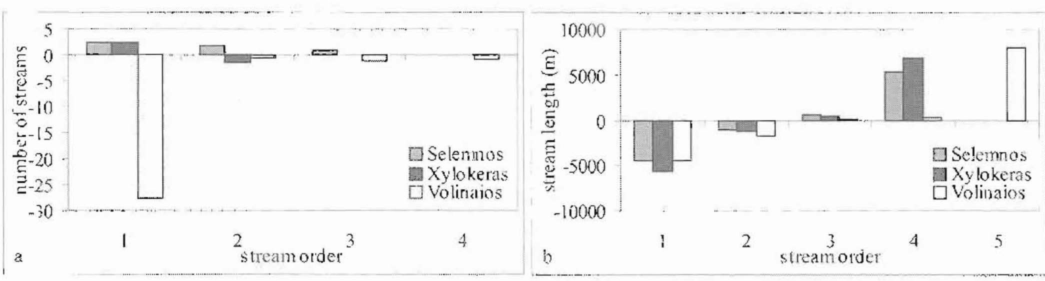

Figure 6 – Diagram showing the deviation of the number (a) and length (b) of streams

Lower values of *bifurcation ratio* (R_b) are attributed to the characteristics of less structural disturbances which, in turn, have not distorted the drainage pattern (Strahler 1964). The higher R_b values in the three basins (Table 3) therefore indicate high structural complexity and low permeability of the subsurface strata. Drainage basins with high *drainage density* (R_D), like the study basins, are characterized by a finely divided network of streams with short lengths and steep slopes. In contrast, a basin with low drainage density is less strongly textured. Analysis of *stream frequency* (R_N) reveals that high values correspond to geological formations with high infiltration capacity. The study basins are characterized by high R_N. *Stream relief* (S_C) controls downstream velocity; so low values of S_C in the study area imply low velocities.

Table 3 – Hydrographic parameters

Basin	R_b	R_L	R_D (km^{-2})	R_N (km^{-1})	S_C (%)
Selemnos	4.013	2.612	2.425	5.175	12.67
Xylokeras	3.947	2.93	2.983	6.977	13.8

Basin	R_b	R_L	R_D (km^{-2})	R_N (km^{-1})	S_C (%)
Volinaios	3.906	2.121	3.223	8.742	11.08

The influence of the tectonic activity (Doutsos *et al.* 1988) on the development of the drainage network was investigated. The directions of the streams per order of the drainage networks were measured and the corresponding rose diagrams were drawn (Fig. 7). The dominant orientation of all streams is ENE-WSW and coincides with the dominant faulting system. This shows the direct influence of the tectonic activity to the development of the drainage networks.

Table 4 – Streams and faults orientations

Basin	1st order	2nd order	3rd order	4th order	faults
NNE-SSW	19.35 %	27.47 %	17.39 %	20 %	13.51 %
NE-SW	22.02 %	21.98 %	21.74 %	20 %	35.14 %
ENE-WSW	18.75 %	24.17 %	26.09 %	0	10.81 %
WNW-ESE	12.80 %	14.29 %	8.69 %	20 %	16.22 %
NW-SE	14.88 %	9.89 %	17.39 %	20 %	13.51 %
NNW-SSE	12.20 %	2.20 %	8.70 %	20 %	10.81 %

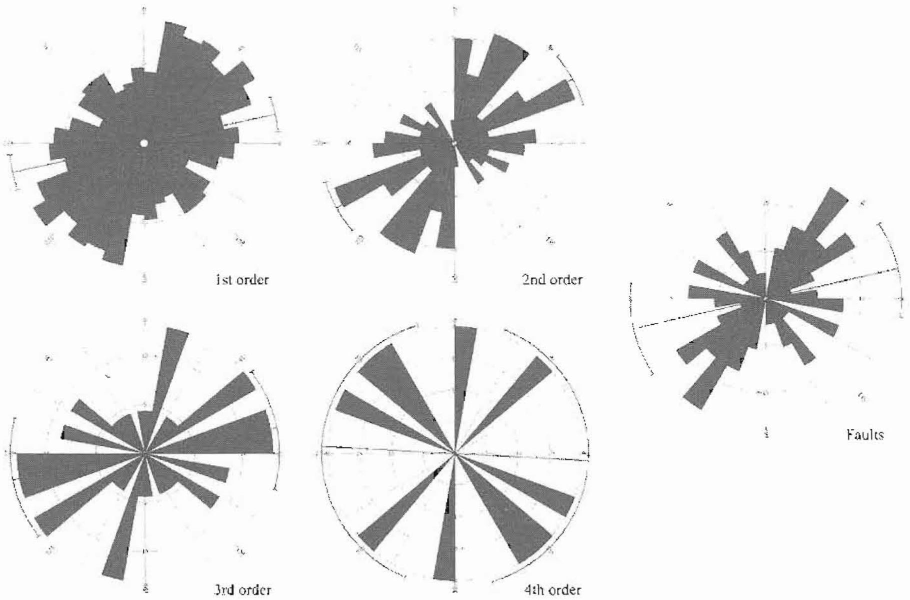

Figure 7 – Rose diagrams showing all streams of the drainage uetworks, as well as the faults of the study area

5. Conclusions

The geomorphological image of the area cousists of three torrents. According to the Strahler (1964) classification, 1 of 5th order, 5 of 4th, 23 of 3rd, 91 of 2nd and 336 of 1st order streams are distinguished. The relief in general is smooth and the pattern of the networks is dendritic. The drainage networks are mostly controlled by the tectonic activity with WSW-ENE direction.

Elongation ratios indicate high erosion and sedimentation load.

Bifurcation ratio and drainage density values as well as stream frequency, which varies from 5.175-8.742, show a well developed drainage network and that the infiltration capacity of the geological formations is relatively high.

The number of streams of different orders is generally less than the theoretically expected, except the 1st, 2nd and 3rd orders of Selemnos torrent which is higher. The length of streams of orders one and two is longer than expected, while in all other orders is shorter, showing negative divergences.

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