PAN
JOURNAL OF WATER AND LAND DEVELOPMENT
e-ISSN 2083-4535
ITP-PIB
Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2023.145359
2023, No. 58 (VII–IX): 31–41

Morphometric analysis of Klina River basin using geospatial technology and open access datasets

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RECEIVED 16.01.2023 ACCEPTED 24.03.2023 AVAILABLE ONLINE 13.09.2023

Abstract: According to the Water Framework Directive 2000/60 EC, the river basin is the basic unit for integrated water management at the basin level. In this sense, the knowledge of the morphometric parameters of the river takes on special importance. Morphometric analysis helps in understanding the geo-hydrological characteristics of a river basin. Various authors point out that the morphometric analyses of a drainage watershed demonstrate the dynamic equilibrium that has been achieved due to the interaction between matter and energy. The analysis of morphometric parameters also facilitates and helps to understand the hydrological relations of the basin. This paper deals with the morphometric analysis of sub-basins in the Klina River basin which is located in the northeastern part of the Dukagjini depression. To determine the morphometric parameters in the Klina River basin, the digital relief model from the Advanced Land Observation Satellite (ALOS) platform with a resolution of 20 × 20 m and the ArcMap 10.5 software were used. The results reveal that the total number of streams is 753 of which 602 are 1st order streams, 119 – 2nd order, 23 – 3rd order, 6 – 4th order, 2 – 5th order, and 1 – 6th order streams. The mean bifurcation ratio is 3.81, drainage density is 1.52 km·km^{-2}. The data and information presented in this study will be helpful and interesting in the plan of the management of Klina River basin which covers an area of 477 km^2 within which is estimated to live about 100,000 inhabitants.

Keywords: digital elevation model, morphometric analysis, stream, water resources, watershed

INTRODUCTION

A watershed represents a portion of the land surface from which water flows into a river system or a specific river. According to the Water Framework Directive 2000/60 EC (Directive, 2000), the watershed is the elementary and most suitable unit for integrated management of water resources. Also Directive (2000) emphasises that water management at the basin level enables the integration of issues such as: upper river flow, quantity and quality of surface and underground water, land use, etc. It is bounded by the watershed or the line that separates it from neighbouring watersheds. The purpose of this paper is to demonstrate the use of geospatial technology and open-access datasets to define and analyse morphological parameters including the use of ArcGIS software. Work with the data and information presented in it, present a special importance at the national level, thus becoming the first work that presents the morphometric parameters for the Klina River basin. At the same time, this work brings new knowledge to the scientific community, which is interested in getting to know the river basins of Kosovo more closely. The hydrographic network of the study area consists of a system of permanent and temporary surface water flows. The development of this network is the result of physical-geographic factors, while the character of the hydrographic network of the study area depends on topography, surface, relief, atmospheric precipitation, geological structures, tectonics, climatic conditions, coverage, type of vegetation, etc. A watershed represents a portion of the land surface from which water flows into a river system or a specific river. A watershed is bounded by a watershed or the line that separates it from neighbouring watersheds. The watershed of the Klina River basin separates the waters from the Ibër, Istog and Mirushë river basins, while it discharges the water into the Drini i Bardhë River.

Gajbhiye, Sharma and Tignath (2015), and Meshram and Sharma (2017) in their papers point out that a watershed is an area of land, respectively a watershed is a natural hydrological unit that generates surface runoff from rainfall, which flows through canals, streams, rivers, lakes or oceans. In the printed and electronic literature, a large number of authors in their works emphasise the importance of the analysis of the morphometric parameters of a watershed. Thus, Strahler (1957), Strahler (1964), Agarwal (1998), Nag (1998), Reddy, Maji and Gajbhiye (2004), Paul and Bayode (2012), Adhikari (2020), Çadraku (2022) treat morphometric analysis as a quantitative description, feature measurement, measurement and mathematical analysis of land surface configuration. Morphometric analysis of watersheds provides a detailed explanation of the interconnection between process act over the Earth's surface, a quantitative assessment of different watershed parameters. Therefore, based on these data and information, it results that the analysis of the morphometric parameters of the watershed enables us to understand the relationships between the different physical, geographic, hydrological, etc. aspects of the drainage pattern of the basin, as well as to make a comparative assessment of different drainage basins developed in different geological and climatic regimes.

MATERIALS AND METHODS

The Klina River basin area lies between the coordinates 42°40'00" and 42°50'00" N, and 20°30'00" and 20°50'00" E (Fig. 1). The altitude of the watershed varies from 375 m to 1751 m (Mount Radopole Neck), covering a total geographical area of 477 km^2 and with a perimeter of 161 km (Earth Observation Research Center and Japan Aerospace Exploration Agency, 2022). The main river of the basin is the Klina River which forms its flow in the district of Kuqicë village. According to the "Report: The state of water in Kosovo 2020" (MESPI and KEPA, no date), the basin area is 458.7 km^2, perimeter – 126 km, its average annual inflows are 2.8 $m^3·s^{-1}$, flow coefficient – 0.22, flow module is 4.92 $dm^3·s^{-1}·km^{-2}$. According to the Hydrometeorological Institute of Kosovo (Instituti Hidrometeorologjik i Kosovës, 2022), meteorological data, monthly average 2001–2019 for the Peja station for the period 2002–2019, the minimum rainfall was 571.70 mm, maximum – 1081.90 mm, and average – 880.98 mm, while the average annual temperature is 10°C. Its upper part represents a typical mountain river with a relatively fast flow, while the middle and lower flow represent elements of a combined mountain-plain in certain segments of it. The largest water inflows are in the spring season, while the lowest ones are in the summer season. Paleozoic, Mesozoic, Neogene and Quaternary rock formations take part in the geological construction of the study area, which is mainly represented by different types of shales, limestone, marl, marble, conglomerate, sandstone, clay, gravel, sand, partly peridotite, serpentinite, andesite, etc. (The Independent Commission for Mines and Minerals, 2006; Çadraku, 2014). The basin is characterised by forest and shrub coverage (60.20%), pastures, meadows and vegetation area (25.60%), and others (14.15%). According to the erosion map

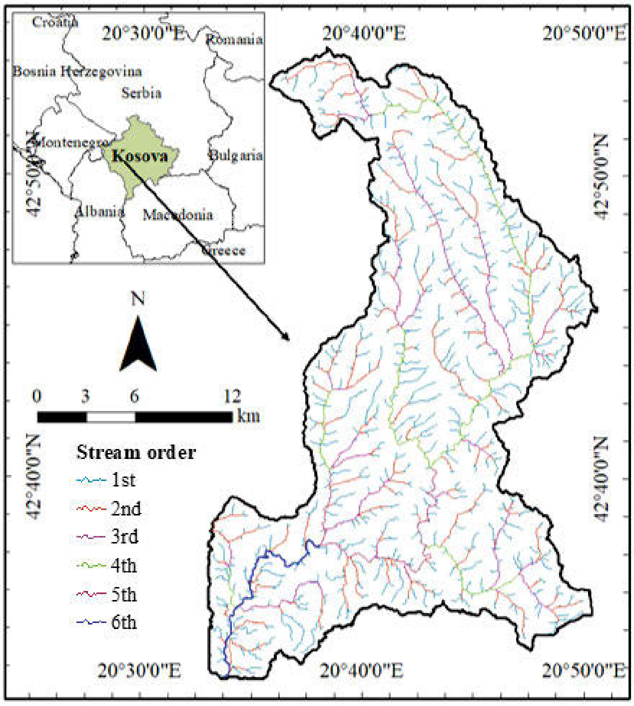


Fig. 1. Position of the study area, Klina River basin; source: own elaboration

(Institut za vodoprivredu "Jaroslav Černi", 1981) of the territory of Kosovo, the Klina River basin area fell into category III.

For the realisation of this work, a work methodology based on observations, statistics and analysis was followed. The survey method relies on up-to-date surveys without asking questions. The characteristics of which were: systematic planning for the purpose of research, evidence-systematic recording of events, and reliability of data verification. Statistics and analysis were supported by the collection of data and information which were selected, processed, analysed and interpreted for the purpose of the work. In determining the morphometric characteristics of the Klina River basin, cartographic material was used, topographic maps (1:25 000) which present clarity, accuracy and objectivity of the study area. Also, for morphometric analysis, aerial photography, digital elevation model (DEM) from the Advanced Land Observation Satellite (ALOS) (Earth Observation Research Center and Japan Aerospace Exploration Agency, 2022), a platform with 20 × 20 m special resolution was used, which enabled the identification of geographic and morphometric phenomena, such as ravines, fractures, etc. Based on the DEM model, using the ArcMap 10.1 software, respectively the spatial analyst tools hydrology, it was possible to determine the watershed, the hydrographic network and the definition of other morphometric parameters which are presented in this work in the results and discussion chapter.

RESULTS AND DISCUSSION

Topography dictates the distribution of water from one basin to another. So, the topographic watershed represents a line that joins the points with the highest altitude between the two basins. Topography affects the speed and direction of surface runoff. The range of elevation (Fig. 2a) in the study area varies from 375 m to 1751 m (Mount Radopole Neck).

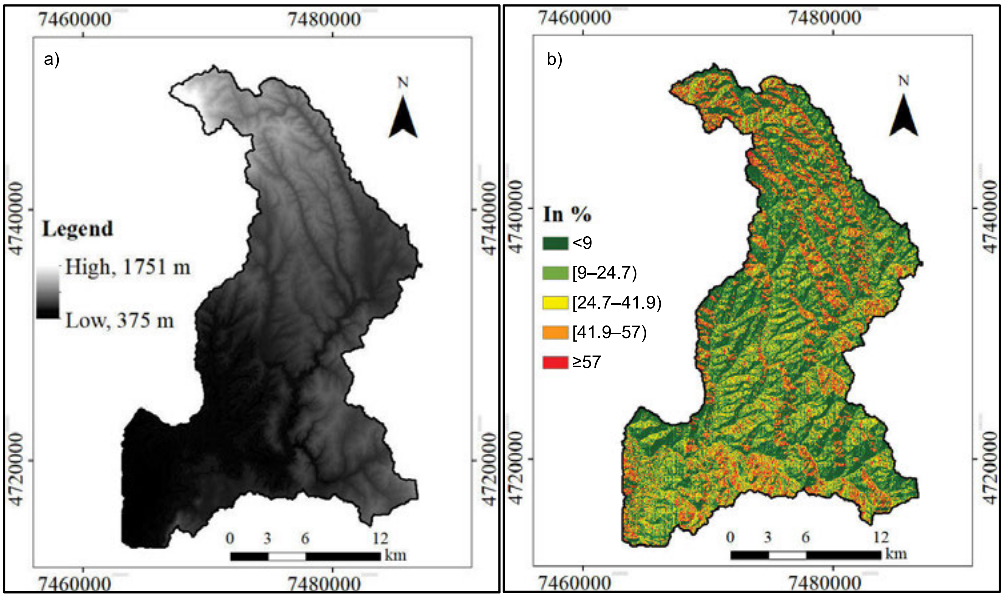


Fig. 2. Map of: a) relative relief (m), b) slope; source: own study

Slope in the study area varies from <9% to ≥57% (Fig. 2b). Higher slope results in rapid runoff and increased erosion rate with less groundwater recharge potential. In general, the variations of slope in the study area are controlled by the local lithological settings.

Geology of the study area is characterised by quite diverse geological structures. It is represented by sand, gravel, clay, lignite, conglomerate, breccia, sandstone, limestone, shale, andesite, etc.

The watershed boundary represents the line that separates neighbouring watersheds, passing through the highest points between them. Topographic maps are used to delineate the border of the basin, which can be of different scales, while the space located within the watershed represents the surface of the watershed. To determine the parameters such as surface, perimeter, length, etc., in this study area, the digital elevation model (DEM) with a resolution of 20 × 20 m was used through ArcMap 10.5 v. software. The results are presented in Table 1. The study area turned out to have an area of 477 km^2 and a perimeter of 161 km. Using the spatial analyst tool hydrology menu, the set of maps shown in Figures 2, 3 and 4 was created.

Slope is the main factor in how water flows. Jenson and Domingue (1988) showed a method for extracting flow from a digital elevation model (DEM). The paper used the pour point model to show how and in which direction water travels. The eight adjacent cells in the spill point model have a value that expresses how the water falls. So the numbers 1, 2, 4, 8, 16, 32, 64 and 128 (flow direction coding) (Fig. 3a) represent the execution of the water flow direction algorithm.

The flow direction map is used to help model the surface flow. Flow direction calculates the direction the water will flow using the slope from neighbouring cells (Fig. 3a). The flow accumulation calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster. The results of flow accumulation can be used to create a stream network (Fig. 3b).

The area of the basin is an important element that argues qualitatively and quantitatively many geographical and hydrological phenomena. The measurement of the surfaces from both sides of a river indicates its orientation, the tendency of the development of the reduction and enlargement of the surfaces through river erosions, etc. It is usually expressed in square kilometres and less often in hectares. The results for the surface area measured in the Klina River basin and its sub-basins are

Table 1. Morphometric parameters for sub-basins

ID	Area		P	L_b	H_{max}	H_{min}	H
	km^2	%	km		m		
W1	64.75	13.57	40.54	14.30	750	430	320
W2	22.82	4.78	35.47	14.03	1020	580	440
W3	57.68	12.09	38.19	10.92	920	460	460
W4	10.77	2.26	17.65	7.00	760	550	210
W5	10.80	2.26	18.07	6.06	760	600	160
W6	7.09	1.49	12.08	3.49	790	480	310
W7	16.17	3.39	21.87	5.97	600	350	250
W8	14.12	2.96	21.74	6.83	500	370	130
W9	51.99	10.9	47.92	18.18	1130	500	630
W10	34.70	7.27	42.15	16.72	1030	590	440
W11	3.55	0.74	9.16	2.44	700	580	120
W12	5.68	1.19	12.27	3.53	630	460	170
W13	3.17	0.66	8.59	3.24	600	440	160
W14	5.97	1.25	13.94	4.30	590	430	160
W15	5.05	1.06	11.16	3.67	630	360	270
W16	3.34	0.70	9.60	3.15	350	700	350
Wo	159.35	33.41	195.74	39.12	362	1217	855

Explanations: W1–W16 = sub-basins' ID numbers, Wo = other basins, P = perimeter, L_b = length of sub-basin, H_{max} = maximum basin relief, H_{min} = maximum basin relief, H = difference between.
Source: own study.

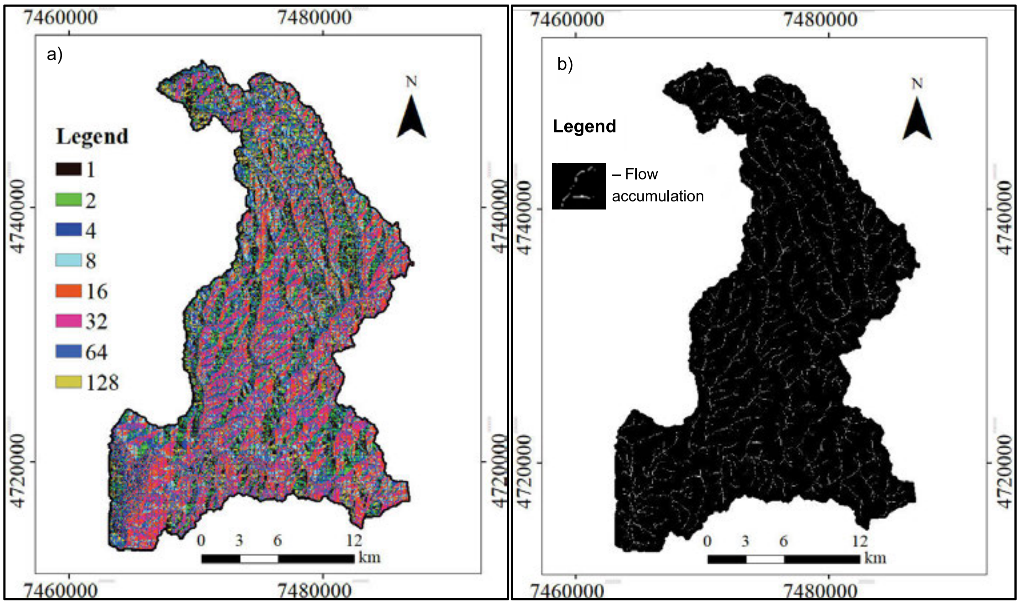


Fig. 3. Flow map of: a) direction, b) accumulation; 1, 2, 4, 8, 16, 32, 64, 128 = flow direction coding; source: own study

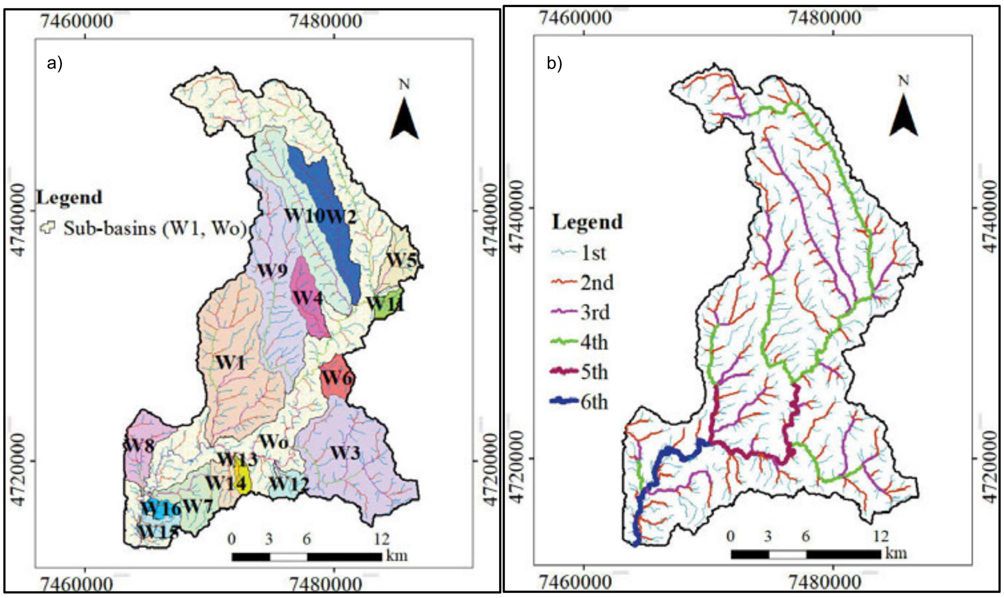


Fig. 4. Map of: a) sub-basins, b) stream order; source: own study

shown in Table 1. The area of the Klina River basin was compared with the division model for this purpose given by Rees (1986), which divides the basins according to the size of the surface into: 1) small watersheds <250 km^2, 2) medium watershed between 250 and 2500 km^2, 3) large watersheds >2500 km^2. Thus, based on this division, the Klina River basin with an area of 477 km^2 belongs to the range between 250 and 2500 km^2, respectively medium.

Basins in the study area are divided into 16 sub-basins (mini-basins) which cover an area of 317.65 km^2 (Fig. 4a). Their surface area ranges from 3.17 km^2 to 64.75 km^2. The largest area was shown in the sub-basin W1 (64.75 km^2 or 13.57%), while the smallest area – in sub-basin W13 (3.17 km^2 or 0.66%) (Tab. 1).

Now applying formulas (Talani, 2000) (Eqs. 1, 2):

$$A_s = \sum_{1}^{16}(A_1, \ldots, A_{16}) \tag{1}$$

$$A_{\text{total}} = A_s + A_o \tag{2}$$

where: A_s = sum of sub-basin areas (A_s = 317.65 km^2), A_1+…+A_{16} = sum of sub-basins, A_o = sum of areas of other territories (A_o = 159.35 km^2).

Now the total area (A_{total}) is calculated as the sum of area of the sub-basins and the area of other territories (A_{total} = 477.00 km^2).

The perimeter is a curved or broken line that limits a geometric figure, in this case, the surface of the watershed (basin study area). The perimeter of the sub-basin in the study area ranges from 8.59 km to 47.92 km (Tab. 1). This parameter is useful to differentiate the shape of the basin when comparing basins of the same area; that is, if is elongated or rounded.

A river network is formed by tributaries, including temporary river branches. In the technical literature, there are several systems for weighting rivers. Stream ordering is the main step in the quantitative interpretations of the drainage network (Sajadi *et al.*, 2020). In this study area, the method given by Strahler (1957) was used. The order of the watershed is equal to the order of the main river. River order is highly dependent on the scale of the map used. The study area is a 6th order drainage basin. The stream order of the study area is shown in Table 2 and Figure 4b.

Stream number (N_u) which is the morphometric system according to Horton (1945) provides information about the hierarchical structure of water streams. According to this system, the lowest order of water flow is the first order. The total number of water streams of the first, second and highest order (N_1, N_2, N_3, ...) gives an overview of the degree of branching (bifurcation) of the hydrographic network. In the study area, the total number of stream segments present is 753 of which 602 or 79.95% are 1st order streams, 2nd order – 15.80%, 3rd order – 3.05%, 4th order – 0.80%, 5th order – 0.27% and 6th order – 0.13%. The largest number of 1st order stream (75) was in W1 sub-basin (watershed) while the smallest (4) was in the W13 and W16 sub-basins, etc. (Tab. 2).

$$N_u = N_1 + N_2 + \ldots + N_n \quad (3)$$

where: N_u = stream number; N_1, N_2, ..., N_n = total number of water streams of the first, second and highest order.

Table 2. The number of stream and the stream order in the sub-basin of Klina River watershed

ID	Stream order						Total number of streams of all orders	In %
	1st	2nd	3rd	4th	5th	6th		
W1	75	20	4	2	1	0	102	13.55
W2	25	4	1	0	0	0	30	3.98
W3	74	14	3	1	0	0	92	12.22
W4	11	1	0	0	0	0	12	1.59
W5	14	3	1	0	0	0	18	2.39
W6	11	4	1	0	0	0	16	2.12
W7	18	4	1	0	0	0	23	3.05
W8	19	4	2	1	0	0	26	3.45
W9	54	11	2	1	0	0	68	9.03
W10	48	9	1	0	0	0	58	7.70
W11	7	2	1	0	0	0	10	1.33
W12	9	2	1	0	0	0	12	1.59
W13	4	1	0	0	0	0	5	0.66
W14	8	1	0	0	0	0	9	1.20
W15	7	1	0	0	0	0	8	1.06
W16	4	1	0	0	0	0	5	0.66
Wo	214	37	5	1	1	1	259	34.40
Total	602	119	23	6	2	1	753	100.00

Explanations: W1–W16, Wo as in Tab. 1.
Source: own study.

Stream length (L_u) is a very important linear parameter because it shows the characteristics of the surface flow in a given basin. Hajam, Hamid and Bhat (2013) point out that stream length is demonstrative of sequential improvements of the stream sections including interlude structural tectonic influence. The total length of individual stream segments of each order is calculated using Equation (4) (Horton, 1945). In this study area, the length of the stream is 723.75 km, the results are shown in Table 3.

Table 3. Stream characteristics in the Klina River basin

Stream order	Number of streams	Stream length	Mean stream length	Cumulative stream length	Stream length ratio
		km			
1st	602	363.54	0.6	0.6	–
2nd	119	165.24	1.39	1.99	0.3
3rd	23	87.65	3.81	5.8	0.34
4th	6	67.18	11.2	17	0.34
5th	2	23.41	11.71	28.7	0.59
6th	1	16.55	16.55	45.25	0.63
Total	753	723.57	–	–	avg.: 0.44

Source: own study.

$$L_u = L_1 + L_2 + \ \ldots \ + L_n \quad (4)$$

where: L_u = stream length, L_1, L_2, ..., L_n = stream segment of each order.

Mean stream length ($\bar{L}_u$) was calculated based on Equation (5) (Horton, 1945), and the results are presented in Table 3.

$$\bar{L}_u = \frac{\sum L_u}{N_u} \quad (5)$$

where: $\bar{L}_u$ = mean stream length, $\sum L_u$ = total stream length, N_u = total number of stream.

The stream length ratio (R_L) was calculated based on Equation (6) (Horton, 1945). The variations in stream length ratio in the study area were due to variances in slope and topography. The values for this parameter are presented in Table 3.

$$R_L = \frac{\bar{L}_u}{\bar{L}_{u-1}} \quad (6)$$

where: R_L = stream length ratio, $\bar{L}_u$ = mean stream length, L_{u-1} = the total stream length of its next lower order.

Schumm (1956) defined the bifurcation ratio (*BR*) as the ratio of the number of stream segments of a given order (N_u) to the number of divisions of the next higher order (N_{u+1}). Using the number of river branches of different orders, the bifurcation ratio is determined, which is a constant value for a river system. The bifurcation ratio provides information on the shape of the basin and therefore also on the shape of the complete hydrograph. In the study area bifurcation ratio ranges from 2 to 5.17. Mean bifurcation ratio (*MBR*) is 3.81.

$$BR = \frac{N_u}{N_{u+1}} \quad (7)$$

where: N_{u+1} = number of segments of the next higher order.

Table 4 shows the results for stream order, bifurcation ratio and mean bifurcation ratio for each sub-basin of the Klina River basin (watershed).

Table 4. Characteristics for each sub-basin: stream order, bifurcation ratio (BR) and mean bifurcation ratio (MBR)

Charac-teristics	Stream order					
	1st	2nd	3rd	4th	5th	6th
W1	75	20	4	2	1	0
BR	–	3.75	5	2	2	–
MBR	3.19	–	–	–	–	–
W2	25	4	1	0	0	0
BR	–	6.25	4	–	–	–
MBR	5.13	–	–	–	–	–
W3	74	14	3	1	0	0
BR	–	5.29	4.67	3	–	–
MBR	4.32	–	–	–	–	–
W4	11	1	0	0	0	0
BR	–	11.00	–	–	–	–
MBR	–	–	–	–	–	–
W5	14	3	1	0	0	0
BR	–	4.67	3	–	–	–
MBR	3.83	–	–	–	–	–
W6	11	4	1	0	0	0
BR	–	2.75	4	–	–	–
MBR	3.38	–	–	–	–	–
W7	18	4	1	0	0	0
BR	–	4.5	4	–	–	–
MBR	4.25	–	–	–	–	–
W8	19	4	2	1	0	0
BR	–	4.75	2	2	–	–
MBR	2.92	–	–	–	–	–
W9	54	11	2	1	0	0
BR	–	4.91	5.50	2	–	–
MBR	4.14	–	–	–	–	–
W10	48	9	1	0	0	0
BR	–	5.33	9	–	–	–
MBR	7.17	–	–	–	–	–
W11	7	2	1	0	0	0
BR	–	3.50	2	–	–	–
MBR	2.75	–	–	–	–	–
W12	9	2	1	0	0	0
BR	–	4.50	2	–	–	–
MBR	3.25	–	–	–	–	–
W13	4	1	0	0	0	0
BR	–	4	–	–	–	–
MBR	–	–	–	–	–	–
W14	8	1	0	0	0	0
BR	–	8	–	–	–	–
MBR	–	–	–	–	–	–
W15	7	1	0	0	0	0
BR	–	7	–	–	–	–
MBR	–	–	–	–	–	–
W16	4	1	0	0	0	0
BR	–	4	–	–	–	–
MBR	–	–	–	–	–	–
Wo	214	37	5	1	1	1
BR	–	5.78	7.40	5	1	1
MBR	4.04	–	–	–	–	–

cont. Tab. 4

Explanations: W1–W16, Wo as in Tab. 1.
Source: own study.

The densities of the river networks of a territory represent the intensity and dynamics of the development of the hydrographic network in the different areas, giving us areas with a developed river network. According to Horton (1945) and Strahler (1964) drainage density (D_d) is the ratio of stream length per unit area in km·km^{-2}, while according to Selenica (2000), the drainage density of a basin is the total length of all river branches per unit area and indicates the drainage intensity of the basin. According to IBAL (2009) there is a classification for drainage density (approximate values): 0.1–1.8 km·km^{-2} (low), 1.9–3.6 km·km^{-2} (moderate), 3.7–5.6 km·km^{-2} (high). The drainage density is governed by the factors like rock type, runoff intensity, soil type, infiltration capacity and percentage of rocky area. The overall density in the Klina River basin is determined by Equation (8) (Horton, 1945), while the results are presented in Table 5 and Figure 5. According to this parameter, the study area is ranked in the limits of 0.1–1.8 km·km^{-2}, with a slight tendency from the limit of 1.9–3.6 km·km^{-2} (Fig. 5a), for example, W11, W16.

$$D_d = \frac{L_u}{A} \quad (8)$$

where: D_d = drainage density, L_u = stream length, A = basin area.

An example of the division of water sub-basins in the Klina River basin is shown in Figure 6.

Gravelius compactness coefficient (K_G) – according to Gravelius (1914), the compactness coefficient for a watershed is the ratio of the perimeter of the watershed to the circumference of a circular area, which equals the area of the watershed. Equation (9) (Gravelius, 1914) was used to calculate the Gravelius coefficient.

$$K_G = \frac{P}{2\sqrt{\pi A}} \approx 0.28\frac{P}{\sqrt{A}} \quad (9)$$

where: K_G = Gravelius compactness coefficient, P = perimeter, A = area.

This coefficient in the study area showed values from 1.27 to 4.34 with an average value of 1.74. According to this coefficient, sub-basins are divided into ovoid shape, amoeboid, stretched, and very stretched with an amoeboid tendency (very elongated), which indicates a slower or greater acceleration or delay if flooding will occur in this basin. Tables 5, 6 and Figure 5b reflect the values of this coefficient for all sub-basins.

Drainage texture (T) – there are several textures on which this parameter depends. The most important are topographical factors – relief, climatic factors – precipitation, geological – lithological composition, pedological – soil type, soil coverage, etc. Based on the change in drainage, Smith (1950) classifies this parameter into five groups: ≤2 – very coarse, (2–4] – coarse, (4–6] – moderate, (6–8] – fine, and >8 – very fine, while Equation (10) given according to Horton (1945) was used for calculation. This parameter in the Klina River basin ranges from 0.52 to 4.68 km^{-1} with an average value of 1.34 km^{-1} (Tabs. 5, 7). The results of the drainage texture parameters obtained in the Klina River basin were compared with the end classification given according to Smith (1950) and it turned out that this study area ranks as very coarse with a slight tendency from coarse (Tab. 7, Fig. 5c).

Table 5. Morphometric parameters in the Klina River basin

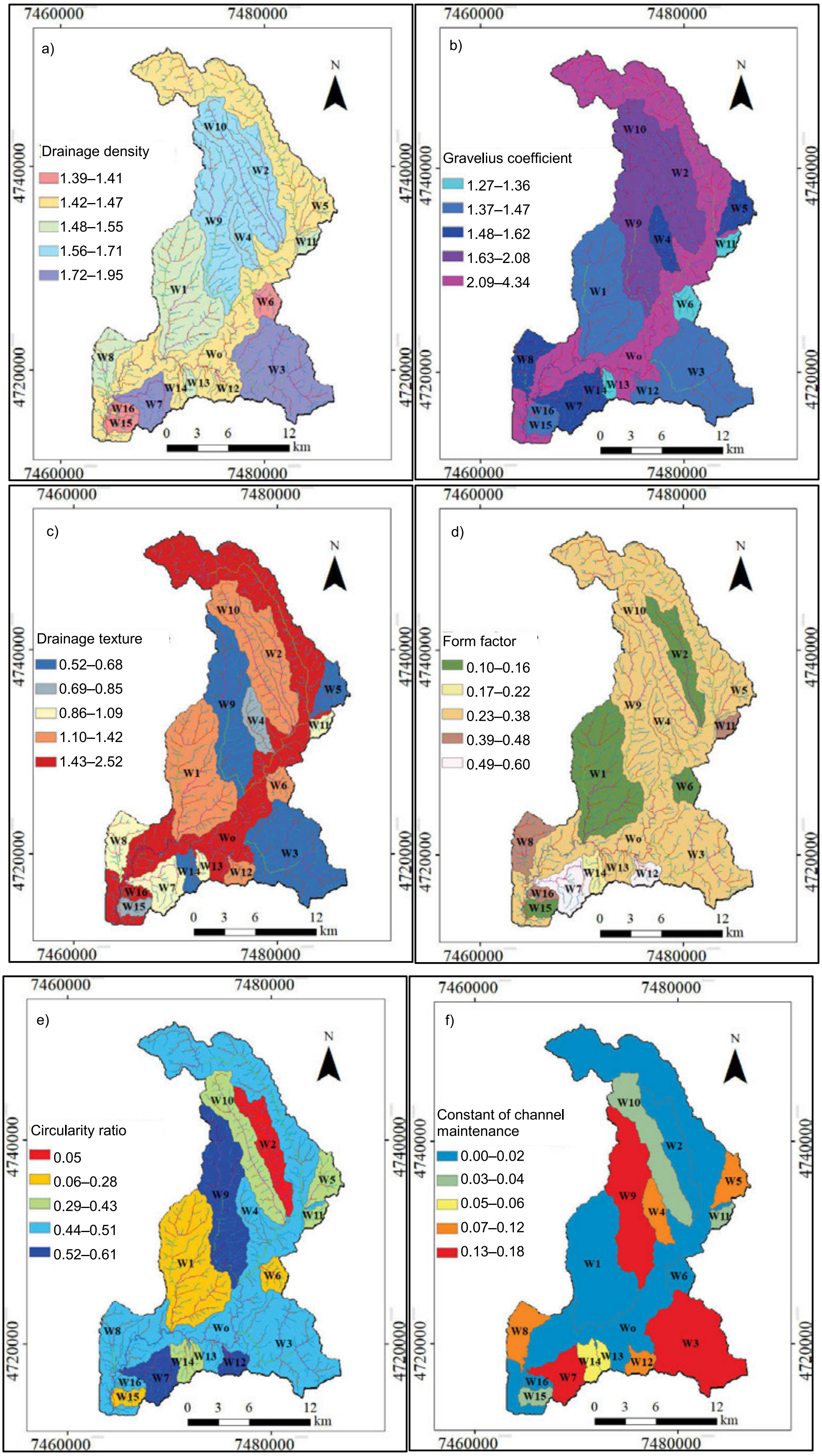
ID	A (km^2)	P (km)	K_G	D_d (km·km^{-2})	T	C	R_c	R_f	R_h	L (km)
W1	64.75	40.54	1.41	1.46	2.52	0.01	0.49	0.32	0.02	94.74
W2	22.82	35.47	2.08	1.39	0.85	0.03	0.23	0.12	0.03	31.66
W3	57.68	38.19	1.41	1.39	2.41	0.01	0.50	0.48	0.04	80.45
W4	10.77	17.65	1.51	1.44	0.68	0.06	0.43	0.22	0.03	15.55
W5	10.80	18.07	1.54	1.50	1.00	0.06	0.42	0.29	0.03	16.23
W6	7.09	12.08	1.27	1.47	1.32	0.10	0.61	0.58	0.09	10.40
W7	16.17	21.87	1.52	1.55	1.05	0.04	0.42	0.45	0.04	25.13
W8	14.12	21.74	1.62	1.62	1.20	0.04	0.38	0.30	0.02	22.81
W9	51.99	47.92	1.86	1.52	1.42	0.01	0.28	0.16	0.03	78.84
W10	34.70	42.15	2.00	1.41	1.38	0.02	0.25	0.12	0.03	49.01
W11	3.55	9.16	1.36	1.85	1.09	0.15	0.53	0.60	0.05	6.56
W12	5.68	12.27	1.44	1.52	0.98	0.12	0.47	0.46	0.05	8.66
W13	3.17	8.59	1.35	1.71	0.58	0.18	0.54	0.30	0.05	5.43
W14	5.97	13.94	1.60	1.47	0.65	0.11	0.39	0.32	0.04	8.76
W15	5.05	11.16	1.39	1.69	0.72	0.12	0.51	0.38	0.07	8.52
W16	3.34	9.60	1.47	1.95	0.52	0.15	0.46	0.34	0.11	6.50
Wo	159.35	195.74	4.34	1.60	1.32	0.00	0.05	0.10	0.03	254.32
Klina River basin	477	161	2.06	1.52	4.68	0.66	0.23	0.31	0.03	723.57

Explanations: A = area, P = perimeter, K_G = Gravelius compactness coefficient, D_d = drainage density, T = drainage texture, C = constant of channel maintenance, R_c = circularity ratio, R_f = form factor, R_h = relief ratio, L = length.
Source: own study.

Table 6. Classes of basin shapes according to the value of the Gravelius coefficient

Shape	Gravelius coefficient values acc. to Gravelius (1914)	No. of sub-basin in study area	ID for sub-basin	In %
Circular	(1–1.03]	0	–	–
Ovoid	(1.03–1.3]	1	W6	5.88
Amoeboid	(1.3–1.4]	7	W1, W3, W11, W12, W13, W15, W16	41.18
Stretched	(1.4–1.7]	5	W4, W5, W7, W8, W14	29.41
Very stretched with an amoeboid tendency (very elongated)	>1.7	4	W2, W9, W10, Wo	23.53

Source: own study.


a)
Drainage density
1.39–1.41
1.42–1.47
1.48–1.55
1.56–1.71
1.72–1.95
b)
Gravelius coefficient
1.27–1.36
1.37–1.47
1.48–1.62
1.63–2.08
2.09–4.34
c)
Drainage texture
0.52–0.68
0.69–0.85
0.86–1.09
1.10–1.42
1.43–2.52
d)
Form factor
0.10–0.16
0.17–0.22
0.23–0.38
0.39–0.48
0.49–0.60
e)
Circularity ratio
0.05
0.06–0.28
0.29–0.43
0.44–0.51
0.52–0.61
f)
Constant of channel maintenance
0.00–0.02
0.03–0.04
0.05–0.06
0.07–0.12
0.13–0.18
N
0 3 6 12 km
7460000
7480000
4740000
4720000
W1
W2
W3
W4
W5
W6
W7
W8
W9
W10
W11
W12
W13
W14
W15
W16
Wo

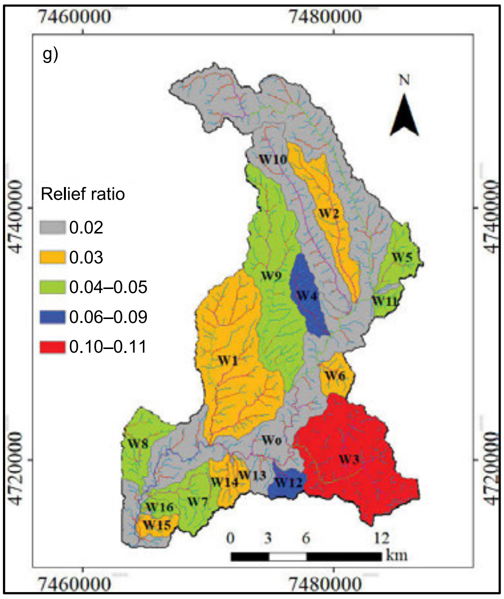


Fig. 5. Map of: a) drainage density (km·km−2), b) Gravelius compactness coefficient, c) drainage texture, d) form factor, e) circularity ratio, f) constant of channel maintenance, g) relief ratio; source: own study

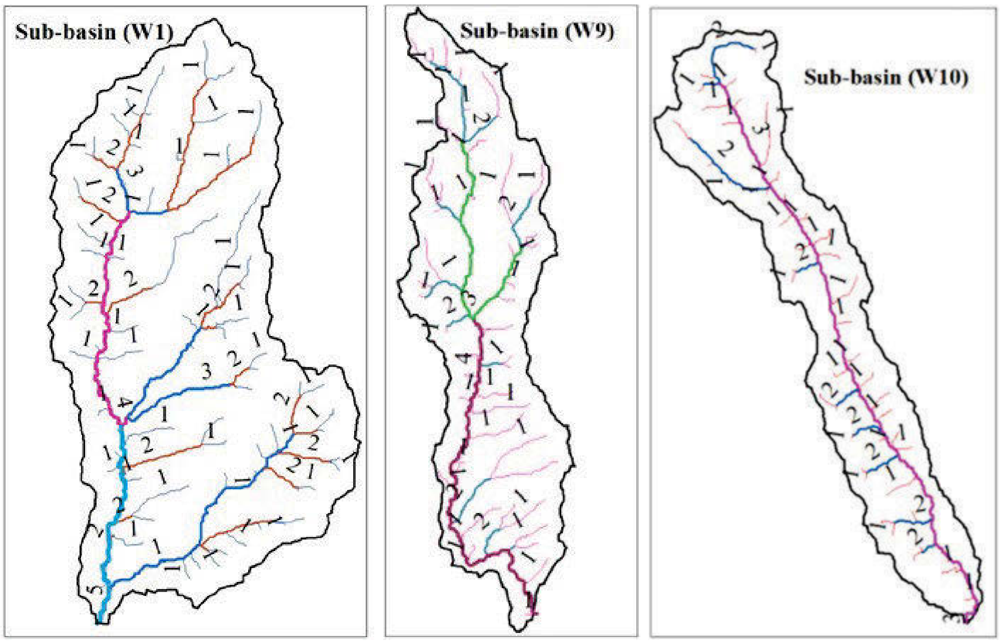


Fig. 6. Examples of sub-basins W1, W9, and W10; source: own study based on Strahler (1964) method

$$T = \frac{N}{P} \tag{10}$$

where: T = drainage texture, N = total number of streams of all order, P = basin perimeter.

Form factor (R_f), according to Horton (1932), indicates the flow intensity of abasing of a defined area. The form factor value for the study area ranges from 0.10 to 0.60 with an average value of 0.33. In general, the results for the form factor parameters are reflected in Table 5, Table 8 and Figure 5d. Form factor (R_f) can be found using the Equation (11) by Horton (1945):

$$R_f = \frac{A_u}{L_b^2} \tag{11}$$

where: R_f = form factor, A_u = basin area, L_b^2 = basin length.

The circularity ratio (R_c) value for the study area ranges from 0.05 (Wo) to 0.61 (W6) with an average value of 0.41 (Tab. 5, Fig. 5e). According to Miller (1953), the R_c helps to describe the best of the circularity ratio range from 0.4 to 0.5, which indicates strongly elongated and highly permeable homogeneous geologic materials. The circularity ratio (R_c) value can be found using the following Equation (12) by Horton (1945):

$$R_c = \frac{4\pi A}{P^2} \tag{12}$$

where: R_c = circularity ratio, P = perimeter, A = area.

According to Schumm (1956), the constant of channel maintenance (C) is the inverse drainage density. The constant of channel maintenance for the study area ranges from 0.0039 to 0.18 with an average value of 0.07 (Tab. 5, Fig. 5f). It indicates the magnitude of the surface area of the watershed needs to sustain the unit length of the stream segment. The constant of channel

Table 7. Value for drainage texture (T) and results in this study area

Drainage texture acc. to Smith (1950)	Class	Sub-basin in study area	In %
≥2	very coarse	W2, W4, W5, W6, W7, W8, W9, W10, W11, W12, W13 W14, W15, W16, Wo	88.24
(2–4]	coarse	W1, W3	11.76
(4–6]	moderate	–	–
(6–8]	fine	–	–
>8	very fine	–	–

Source: own study.

maintenance (C) Equation (13) was taken according to Horton (1945):

$$C = \frac{1}{D_d} \quad (13)$$

where: C = constant of channel maintenance, D_d = drainage density.

Relief ratio (R_h) is the ratio of the maximum relief to the horizontal distance (the difference between highest and lowest elevations) along the longest dimension of the basin parallel to the principal drainage line (Schumm, 1956). For the present study area the value of relief ratio ranges from 0.02 to 0.11 with an average value of 0.05. The results for relief ratio are presented in the Table 5 and Figure 5g.

$$R_h = \frac{H}{L_h} \quad (14)$$

where: R_h = relief ratio, H = relief (the difference between highest and lowest elevations), L_h = horizontal distance.

Table 8. Form factor values and shapes of sub-basins in this study area

Form factor (approximate value, acc. to Perez (1979)	Shape of the basin	Sub-basin in study area	In %
≤0.22	very long	W2, W4, W9, W10, Wo	29.41
(0.22–0.30]	elongated	W5, W8, W13	17.65
(0.30–0.37]	slightly elongated	W1, W3, W6, W7, W11, W12, W14, W15, W16	52.94
(0.37–0.45]	neither elongated nor widened	–	–
(0.45–0.60]	slightly widened	–	–
(0.60–0.80]	widened	–	–
(0.80–1.20]	very widened	–	–
>1.20	surrounding the drain	–	–

Source: own study.

CONCLUSIONS

The watershed can be considered as a system, which turns precipitation into runoff. For this reason, the characteristics of the watershed are very important to determine the shape of the flow hydrograph, etc. The Klina River basin (watershed) is the left branch of the Drini i Bardhë River basin. Its upper course forms a deep river valley creating relatively steep banks. Its maximum flows show marked variations in time. Its catchment area is 477 km^2. Rainfall varies from 571.70 to 1018.90 mm. The study area is characterised by mountainous and hilly terrain with altitudes from 362 to 1751 m and terrain slopes from <9% to ≥57%. Rock formations from the Paleozoic to the Quaternary take part in its geological construction. The Klina River basin, in terms of its area, was classified into basins with an area between 250 and 2500 km^2, which means medium. Based on the digital elevation model (DEM) and the application of the ArcMap 10.5 software on the surface of 477 km^2 of the study area, it was possible to divide 16 river sub-basins, of which the largest surface turned out to be sub-basin W1 (64.75 km^2 or 13.57%), while the one with the smallest surface is subbasin W13 (3.17 km^2 or 0.66%). This methodology applied using geospatial technology and open access datasets results in being quite efficient in determining and analysing morphometric parameters. In this way, it was defined that the area under study made a division of the stream order of six such. This stream order is of course highly dependent on the map scale used. Using the number of different stream orders, the indicators of the basin shape were determined, namely the bifurcation ratio (mean bifurcation ratio – 3.81). This parameter further provides information on the shape of the basin and therefore also on the shape of the complete hydrograph. The total stream segments present are 753 of which 602 or 79.95% are 1st order, 2nd order – 15.80%, 3rd order – 3.05%, 4th order – 0.80%, 5th order – 0.27%, and 6th order – 0.13%. Drainage density is influenced by geological and pedological factors, flow intensity, etc. The analysis showed that the Klina River basin has a drainage density of 1.52 $km \cdot km^{-2}$, placing this basin in the range of low density between 0.1 and 1.8 $km \cdot km^{-2}$. The Gravelius compactness coefficient showed values from 1.27 to 4.34 with an average value of 1.74. Based on the Gravelius coefficient, all subbasins are mainly divided into three groups; amoeboid, stretched, and very stretched with an amoeboid tendency (very elongated). The shape of the basin has a large influence on the shape of the peak flow of the entire hydrograph. The analysis also highlighted that the subbasins in the Klina River basin are grouped into two groups based on drainage texture as follows: very coarse and coarse. Also through this work, it was possible to generate a set of maps for morphometric parameters. In general, the analysis based on DEM and GIS with the morphometric parameters shows a relationship between the hydrological aspect, geological, topographical, and pedological which is useful for planning and management of watershed construction and watershed structure, which enables the solution of many issues such as requires the Water Framework Directive 2000/60 EC.

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