MORPHOMETRIC ANALYSIS OF LLAP RIVER WATERSHED (KOSOVO)

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Abstract. The Llap River is main tributary of Sitnica River, having a watershed of 780.23 km^2 which extends in northeast part of Republic of Kosovo. In this study, GIS and a high-resolution Digital Elevation Model have been utilized for estimation and analysis of the Llap River Watershed morphometric parameters. The drainage map generated from the ALOS-DEM was used for morphometric analysis of the watershed in terms of stream order, stream length, bifurcation ratio, drainage density, etc. This study identified the importance of watershed attributes for water resource management in line with the Water Framework Directive 2000/60 EC. Several morphometric parameters have been computed and analysed: linear aspects such as stream order, stream number, stream length, etc., areal aspects such as drainage density, drainage texture, form factor, etc. A total numbers of 1219 streams were identified. The number of streams belonging to the 1st, 2nd, 3rd, 4th, 5th and 6th order was found to be 959, 201, 48, 8, 2 and 1, respectively. The total length of the streams is 1240.85 km, while the mean bifurcation ratio is 3.92 and mean Gravelius coefficient is 1.77. The data and information presented in this study will be helpful for drafting the plan of the management of the Llap River Watershed within which is estimated to live about 100 thousand inhabitants.

1. INTRODUCTION

Integrated water management at the river basin level is very important for health and socio-economic development of a country. According to Wang *et al.* (2022), river networks are hierarchical systems with both natural and human dimensions. Morphometric parameters play an important role in understanding the geo-hydrological characteristics of a river watershed (Çadraku, 2022), where different morphometric features of the watershed determine different rates of surface water runoff characterized mainly by runoff coefficient and specific runoff (Bublaku and Beqiraj, 2015). Knowing the river network and morphometric parameters helps in effective planning and management of water resources. Morphometric analysis provides quantitative description of a basin watershed which is essential for watershed planning and development (Strahler, 1964; Panhalkar *et al.*, 2012; Panhalkar *et al.*, 2014; Yasmin *et al.*, 2013; Kumar and Lal, 2017). According to the Meshram *et al.* (2020), morphometric parameters are highly efficient in identifying erosion-prone areas. Scientific studies by many authors emphasize that the analysis of morphometric parameters has found a wide use in terms of assessing the sensitivity of water basins and their prioritization to natural risks such as floods, erosion, etc. (Magesh *et al.*, 2013; Taha *et al.*, 2017; Shivhare *et al.*, 2018; Asfaw and Workineh, 2019; Alam *et al.*, 2020). Morphometric analysis will help to quantify and understand the hydrological characters and the results will be useful input for a comprehensive water resource management plan (Jawahar Raj *et al.*, 1998; Kumaraswami and Sivagnanam, 1998; Sreedevi *et al.*, 2001). The morphometric analysis of different

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river basins has been done by different authors using the conventional methods given by Horton (1945), Smith (1950), Strahler (1957), and recently from data of earth observations and GIS methods (Narendra and Rao, 2006). Mark (1983) and Tarboton (1997) point out in their papers that digital models such as Shuttle Radar Topography Mission (SRTM), and other ones were used to extract diverse morphometric parameters of drainage watershed, including drainage networks, etc. On the other hand, many authors in their scientific works for the analysis of morphometric parameters of river basins, including the hydrographic network, use digital models from platforms such as: STRM (Shuttle Radar Topography Mission), ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), ALOS (Advanced Land Observing Satellite (ALOS), etc. Seeing the opportunity these models offer, in this paper the digital model from the ALOS platform was used. According to the Water Framework Directive 2000/60 EC, the river basin is considered the basic unit for integrated water resources management. In this aspect the definition of morphometric parameters, the delineation of watershed, the build of the thematic maps for river watershed help in fulfilling the Water Framework Directive 2000/60 EC.

2. STUDY AREA

The study area is located in the northeast part of the Republic of Kosovo (Fig. 1), between the geographical coordinates N 42°41'02" to N 43°08'13" and E 20°58'35" to E 21°26'35". The watershed area has a surface of 780.23 km^2 where two morphological units, mountain and plain, may be distinguished. The highest point is Pilatovica peak (1703 m) while the lowest point is at the estuary (518 m) (Fig. 2). The most pronounced mountainous relief is in the part where the river Llap starts its flow (spring part) course. The geomorphologic process which influences the shape of the relief of the fluvial system, consists of erosion forms in the upper part of the basin, and material deposition in the lower part of the river watershed. The lower parts of the Llap River catchment are mainly cultivated (Pllana, 1981). The air temperature varies from -2.1°C (January) up to 20.1°C (July, August), while annual average air temperature is 9.6°C. The rainfall ranges from the lowest value of 35.5 mm in August to the highest of 77.5 mm in May, having an average annual value of 697 mm (DPMP, 2016-2025). The study area is composed of Palaeozoic, Mesozoic, Neogene and Quaternary geological formations showing differences in both lithology and geomorphology (ICMM, 2006). From the hydrogeological point of view, the groundwater is related with three aquifer types: the intergranular porosity aquifer, the cracks and fissures porosity aquifer and the Palaeozoic formations aquifer (ICMM, 2006). Residents are mainly engaged with agriculture, handicrafts, construction, trade, while the industry sector is scarcely developed.

Slope-it is very important property as it affects the velocity, momentum of runoff and erosion potential of watershed. It also affects the ground water recharge. It also affects the rate change of the relief elevation along the main flow path. In the study area, the slope varies from less 5º to over 27º (Fig. 2).

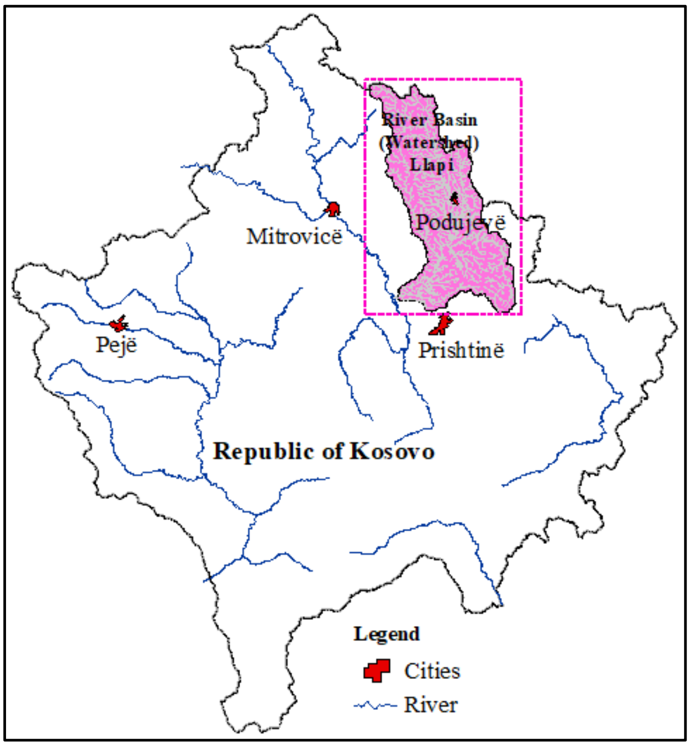


Fig. 1 – Physical-geographical position of the study area.

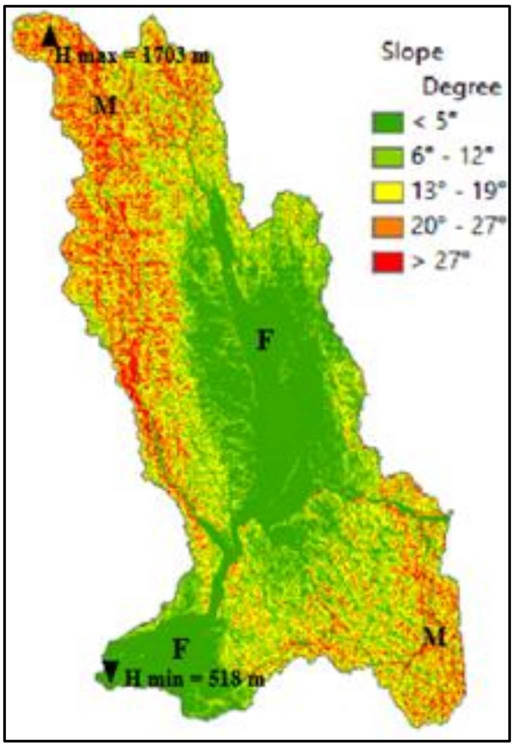


Fig. 2 – Relief and slope.

3. MATERIALS AND METHODS

According to Clarke (1996), morphometry is the measurement and mathematical analysis of the configuration of the earth surface, and shape and dimensions of its landforms. The morphometric analysis is carried out through measurement of linear, areal and relief aspects of the basin and slope contribution (Nag, 1998, Nag and Chakraborty, 2003). In principle, for the determination of morphometric characteristics, cartographic material is used that meets the requirements of these studies both in the authenticity of the presentation of the objects, and in their accuracy. Topographic maps of scale 1: 25 000 are the main maps used in these studies, because they present with clarity, precision and objectivity both the relief and the situation of the territory. The territory of the study area is constructed from 16 sheets (trapezoids) of the topographic map of scale 1:25 000, which have been carefully considered in this paper, although the purpose in this paper was to use the DEM model and ArcGIS software for morphometric analysis of the basin of the Llap river. Of course a quick comparison between the topographic map and the data generated by the DEM model showed some expected differences. The morphometric parameters of watershed were determined using Advanced Land Observation Satellite (ALOS)-Digital Elevation Model (DEM) with 20x20 m resolution. The determination of the watershed, stream network and maps, based in digital elevation models was accomplished using the hydrology tools in the ArcGIS 10.5 geoprocessing toolbox. With the help of the Spatial Analyst Tools from DEM the following layers have been created: DEM Fill, Flow Direction, Flow Accumulation, Basin, Stream order, Stream to feature, Watershed, etc. necessary for the analysis of morphological parameters. In connection with the determination of the flow accumulation threshold, several methods have been developed for the extraction of river networks. The flow accumulation method still dominates large-scale drainage network extraction from digital elevation model data because to its simple form and computational efficient design, widely used GIS tools apply 1% of the maximum flow accumulation value as a default flow accumulation threshold.

The work process is illustrated in (Fig. 3). The channels were classified according to drainage order following Strahler (1964). Watershed parameters, such as area, perimeter, length, stream length and stream order were also calculated. Later, these parameters were used to determine other influencing factors presented in the results section.

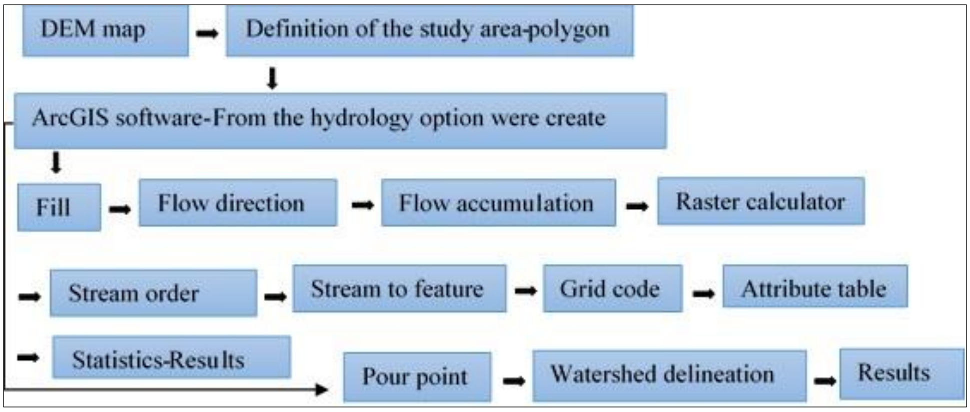


Fig. 3 – Flowchart of this paper's methodology.

4. DISCUSSION OF RESULTS

The morphometric analysis is carried out by linear, areal and relief aspects. The knowledge on the morphometric parameters of the river basin is of great importance in the study of their hydrology and especially of the water regime. According to Zavoianu (1985) morphometrical analysis of any river network requires demands first of all the adoption of a classification system.Then, each stream segment and drainage basin may be assigned an order according to the principles of the system and to the extent to which the network has developed. In the technical literature, several systems for weighting rivers can be found, of which the Strahler method is the most widely used, which is used in this paper. The river order depends on the scale of the map, e.g. a 1:50,000 scale map gives several orders of magnitude more than a 1:100,000 scale map. The drainage pattern is the planimetric arrangement of stream engraved into the land surface by a drainage system. The general drainage pattern of Llap River Watershed is dendritic. It is characterized by irregular branching of tributary streams in many directions joining the main channel (Sreedevi *et al*., 2009, 2013). The morphometric structures of the Llap River Watershed have been examined, and the results are discussed in the following paragraphs. In this study, area linear aspects include stream order, stream length, stream length ratio, bifurcation ratio which are calculated using different formulae suggested by various authors.

Area of the watershed (A)-surfaces are important elements that argue qualitatively and quantitatively many geographical phenomena. The space included within the watershed is called the watershed area. According to the Withanage *et al*. (2014) the area of the basin is defined as the total area projected upon a horizontal plane. According to Selenica (2000) the area included within the watershed is called the catchment area, while the length of the watershed is called its perimeter. Regarding the size of the basin, Rees (1984) made the classification into three groups: 1) Small Watersheds < 250 km^2, 2) Medium Watersheds between 250 to 2500 km^2, 3) Large Watersheds >2500 km^2. Based on this classification, it turns out that the size of the Llap river watershed (A = 780.23 km^2) belongs to the second group, with a medium size, while all other sub-basins entered the first group with an area of < 250 km^2 (Table 1).

By applying the equation (Talani, 2000) (eq. 1 and 2);

$$A_{p1} = \sum_{1}^{20} A_{1,20} \; eq.1. Talani\ 2000.$$
$$A_p = A_{p1} + A_{p2} \; eq.2. Talani\ 2000.$$

the total area is calculated as the sum of the areas of the sub-basins and the areas of other territories. Total area = Sum of sub-basin areas (Ap_1) + Sum of areas of other territories (Ap_2). $Ap = Ap_1 + Ap_2$ = 671.15 km^2 + 109.08 km^2 = 780.23 km^2 (Table 4 and Figure 4).

Where:

Ap_1 - sum of sub-basin areas = 671.15 km^2.

Ap_2 - sum of areas of other territories = 109.08 km^2.

The study area is divided in 20 sub-watershed (mini-basins) which cover an area of 617.14 km^2. The subdivision mapping and construction was accomplished through the Spatial Analyst Tool-Hydrology-Watershed toolbox. The sub-basin area ranges from 2.33 km^2 (SW4) to 126.31 km^2 (SW10). The summarized results for the whole study area are shown in Table 4). The data for the sub-basin area compared with the classification given by Singh (1994, 2014) and is found out that 12 sub-basins or 60% belong to the range with an area of 10 to 100 km^2, thus classifying them in mini-watershed.

Table 1

Classification of watershed (Singh, 1994)

Size (ha)	Size (km^2)	Watershed ID	No.of watershed	In (%)	Classification
50000–200000	500–2000		0	0	Watershed
10000–50000	100–500	SW10	1	5	Sub-watershed
1000–10000	10–100	SW2, SW7, SW9, SW11, SW12, SW13, SW14, SW15, SW16, SW18, SW19, SW20.	12	60	Mili-watershed
100–1000	1 to 10	SW1, SW3, SW4, SW5, SW6, SW8, SW17	7	35	Micro-watershed
10–100	0.1–1		0	0	Mini-watershed

Perimeter length (P)-is the linear length of the drainage basin perimeter. According to Zavoianu (1985) the perimeter of a drainage basin is defined as the horizontal projection of its water border. Length boundary of a basin in known as the perimeter of the basin. One can measure this length with a string, map wheel, or digitizer. The perimeter of the sub-basin ranges from 9.43 km (SW8) to 144.97 km (SWo) (Table 4, Fig. 5). This parameter is useful to differentiate the shape of the basin when comparing basins of the same area; that is, if it elongated or rounded.

Stream order (U)-the Llap River Watershed belongs to sixth order stream (Table 2) covering an area of 780.23 km^2. In the present study, the segment of the drainage watershed has been ranked according to Strahler (1964) stream ordering system (eq.3, Horton, 1945, Strahler, 1957). The stream order is a natural number representing the extent of branching or furcating in the drainage system of a river and has common usage in hydro-morphology.

$$\text{Hierarchical eq. 3. Horton 1945; Strahler 1957.}$$

Stream number (Nu)-for each sub-watershed, the streams of first order to the highest order are numbered from starting of each segment of the stream. In total, the study area has 1219 numbers of streams of which 956 are 1st order streams, 201 are 2nd orders, 48 are 3rd order, 8 are 4th order, 2 are 5th order and 1 is indicating 6th order streams (Tables 2, 3). Equation 4 is applied for the calculation of order rate.

$$N_u = N_1 + N_2 + \cdots + N_n \text{ eq. 4. Horton 1945.}$$

Stream lenght (Lu)-is an indicator of the area contribution to the watershed, steepness of the drainage watershed as well as the degree of drainage. The length of streams was calculated according to Horton (1945) law with the help of GIS tool (eq.5.). The total stream length of the study area is 1240.85 km (Table 2). The 1st order stream length is < 50%, which means that the 1st order streams were controlled by the slope and topography of the watershed. This factor gives an idea of the efficiency of the drainage network. A strong negative correlation (r = - 0.90) was found between stream order and its length (Fig. 18).

$$L_u = L_1 + L_2 + \cdots + L_n \text{ eq. 5. Horton 1945.}$$

Mean stream length (Lsm)-is a dimensional property and reveals the characteristic size of the drainage network components and its contribution watershed surfaces (Strahler 1964). The mean stream length in study area ranges from 0.64 to 22.57 (Table 2). This indicates the structural influence in the formation of stream in few areas Rama (2014). The equation 6 was used for calculating the mean stream length (Horton, 1945).

$$\bar{L}_u = \frac{\sum_{i=1}^{n} L_u}{N_u} \text{ eq. 6. Horton, 1945.}$$

Stream length ratio (R_L)-has an important relationship with the surface water discharge and erosional stage of the watershed.

The value of stream length ratio varies from 0.29 to 0.61 (Table 1). The equation 7 was used for its calculation (Horton, 1945).

$$R_L = \frac{\bar{L}_u}{\bar{L}_{u-1}} \text{ eq. 7. Horton, 1945.}$$

Bifurcation ratio (Rb)-the bifurcation ratio between different orders of a basin is a constant value for a natural river. This is the universal value for maturely dissected drainage basins (Rao and Babu, 1995). According to Horton (1945), Strahler (1964) and Schumm (1956) bifurcation ratio is the ratio of the streams number of an order to the streams number of the next higher order. The higher values of bifurcation ratio indicate strong structural control on the drainage pattern, while the lower values are indicative of watersheds that are not affect by structural disturbances. Thus, the bifurcation ratio is indicative parameters of shape of the basin. In the study area bifurcation ratio ranges from 2.00 to 4.77, having a mean of 4.19 (Tables 2, 3).

Table 2

Stream number and stream length

Stream order	Stream number	Stream length (km)	Mean stream length (km)	Cumulative stream length (km)	Stream Length Ratio
1 st order	959	613.31	0.64	0.64	
2 nd order	201	317.68	1.58	2.22	0.29
3 rd order	48	148.69	3.10	5.32	0.42
4 th order	8	102.97	12.87	18.19	0.29
5 th order	2	35.63	17.82	36.00	0.51
6 th order	1	22.57	22.57	58.57	0.61
Total		1240.85			Average 0.44
Bifurcation ratio					Mean bifurcation ratio
1st/2nd	2nd/3rd	3rd/4th	4rd/5th	5rd/6th	
4.77	4.19	6.00	4.00	2.00	4.19

Table 3

Some of the parameters of river sub-basins

Sub-watersheds ID	Number of streams (Nu) of different stream order (u)							In (%)	Bifurcation ratio (Rb)					Mean (Rb)
	1st	2nd	3rd	4th	5th	6th	∑Nu		1st/2nd	2nd/3rd	3rd/4th	4th/5th	5th/6th	
SW1	12	2	1	0	0	0	15	1.23	6.00	2.00				4.00
SW2	37	5	1	0	0	0	43	3.53	7.40	5.00				6.20
SW3	7	2	1	0	0	0	10	0.82	3.50	2.00				2.75
SW4	2	1	0	0	0	0	3	0.25	2.00					2.00
SW5	5	2	1	0	0	0	8	0.66	2.50	2.00				2.25
SW6	8	2	1	0	0	0	11	0.90	4.00	2.00				3.00
SW7	16	3	1	0	0	0	20	1.64	5.33	3.00				4.17
SW8	7	2	1	0	0	0	10	0.82	3.50	2.00				2.75
SW9	68	14	4	1	0	0	87	7.14	4.86	3.50	4.00			4.12
SW10	162	34	8	1	0	0	205	16.82	4.76	4.25	8.00			5.67
SW11	109	24	5	1	0	0	139	11.40	4.54	4.80	5.00			4.78
SW12	48	14	3	1	0	0	66	5.41	3.43	4.67	3.00			3.70
SW13	130	23	5	1	0	0	159	13.04	5.65	4.60	5.00			5.08
SW14	17	3	1	0	0	0	21	1.72	5.67	3.00				4.33
SW15	11	2	1	0	0	0	14	1.15	5.50	2.00				3.75
SW16	16	5	2	1	0	0	24	1.97	3.20	2.50	2.00			2.57
SW17	12	2	1	0	0	0	15	1.23	6.00	2.00				4.00
SW18	26	4	1	0	0	0	31	2.54	6.50	4.00	5.00			5.25
SW19	84	21	5	1	0	0	111	9.11	4.00	4.20	3.00			4.40
SW20	45	13	3	1	0	0	62	5.09	3.46	4.33				3.60
Wo (Others)	137	23	2	0	2	1	165	13.54	5.96	11.50			2.00	6.49
Total	959	201	48	8	2	1	1219	100						

Drainage density (Dd) – is one of the parameters which affects the hydrological process of the watershed. According to Selenica (2000) the drainage density of a catchment is the total length of all river tributaries per unit area and indicates the drainage intensity of the catchment. It reflects a balance between erosive forces of overland flow and the resistance of surface soil and rock formations. The drainage density is governed by the factors like rock type, runoff intensity, soil type, infiltration capacity and percentage of rocky area. Drainage density of the study area is 1.52 km/km^2. Table 4 and Fig. 6 show the drainage density values for all sub-basins in this study area. According to IBAL (2009) classification of drainage density (approximate values) the following classes are distinguished: 0.1 to 1.8 km/km^2 (Low), 1.9 to 3.6 km/km^2 (Moderate), 3.7 to 5.6 km/km^2 (High). Smith (1950) had classified drainage density into three classes i.e. D < 1.5 km/km^2 (Low), 1.5 to 2.5 km/km^2 (Medium), and D > 2.5 km/km^2 (Table 5). The high drainage density of 6.2 km/km^2. According to Melton (1957) high drainage density represents a highly dissected drainage basin with a moderately fast hydrological reaction to precipitation occasions. Regarding the drainage density Nag (1998), Nag and Chakraborty *et al*. (2003) states that the moderate drainage density indicates the basin is composed of highly permeable subsoil and vegetative cover, while in relation to the high density indicates that high drainage density is developed in regions of weak or impermeable subsurface materials, sparse vegetation and mountainous relief. Equation 8 is applied to the calculation (Horton, 1945).

$$D_d = \frac{\mathrm{L}}{\mathrm{A}} \ \text{eq. 8. Horton 1945.}$$

Table 4

Statistical summary of morphometric parameters in the study area

No	ID	A	P	Af	Ar	Rl	Sldr	Cm	Cc	Lrnsb	Dd	Cchm	Lof	Cr	Nu	Dt	Di	Fs	Tr
1	SW1	8.17	25.82	2.96	5.21	10.91	7.95	1.37	2.53	16.14	1.97	0.51	0.25	0.15	15.00	3.62	0.93	1.84	0.46
2	SW2	30.21	54.53	15.59	14.62	23.49	17.49	1.34	2.78	47.29	1.57	0.64	0.32	0.13	43.00	2.23	0.91	1.42	0.68
3	SW3	3.88	10.27	1.82	2.06	3.65	2.47	1.48	1.46	7.93	2.04	0.49	0.24	0.46	10.00	5.27	1.26	2.58	0.68
4	SW4	2.33	13.41	1.17	1.15	4.86	3.64	1.33	2.46	4.99	2.15	0.47	0.23	0.16	3.00	2.77	0.60	1.29	0.15
5	SW5	4.99	12.69	0.78	4.21	5.95	4.22	1.41	1.59	13.63	2.73	0.37	0.18	0.39	8.00	4.37	0.59	1.60	0.39
6	SW6	6.75	17.43	4.27	2.48	7.12	6.19	1.15	1.88	11.24	1.67	0.60	0.30	0.28	11.00	2.71	0.98	1.63	0.46
7	SW7	15.60	21.46	7.64	7.96	8.69	6.12	1.42	1.52	22.77	1.46	0.68	0.34	0.43	20.00	1.87	0.88	1.28	0.75
8	SW8	3.70	9.43	1.74	1.96	3.19	2.46	1.29	1.37	6.19	1.68	0.60	0.30	0.52	10.00	4.53	1.61	2.71	0.74
9	SW9	50.49	35.04	20.20	30.28	12.81	10.11	1.27	1.38	75.40	1.49	0.67	0.33	0.52	87.00	2.57	1.15	1.72	1.94
10	SW10	126.31	71.13	65.86	60.45	32.42	18.47	1.76	1.77	188.67	1.49	0.67	0.33	0.31	205.00	2.42	1.09	1.62	2.28
11	SW11	87.46	54.91	55.30	32.15	21.56	18.48	1.17	1.64	155.35	1.78	0.56	0.28	0.36	139.00	2.82	0.89	1.59	1.99
12	SW12	50.00	39.26	10.51	39.49	17.97	12.99	1.38	1.55	86.62	1.73	0.58	0.29	0.41	66.00	2.29	0.76	1.32	1.22
13	SW13	96.28	78.09	39.75	56.53	34.49	28.82	1.20	2.23	133.17	1.38	0.72	0.36	0.20	159.00	2.28	1.19	1.65	1.66
14	SW14	15.40	25.52	11.31	4.10	11.38	8.29	1.37	1.82	29.63	1.92	0.52	0.26	0.30	21.00	2.62	0.71	1.36	0.67
15	SW15	12.01	20.09	5.97	6.03	8.48	6.77	1.25	1.62	19.20	1.60	0.63	0.31	0.37	14.00	1.86	0.73	1.17	0.55
16	SW16	19.05	24.40	4.21	14.84	9.14	7.13	1.28	1.57	30.73	1.61	0.62	0.31	0.40	24.00	2.03	0.78	1.26	0.66
17	SW17	8.32	18.76	2.26	6.06	6.71	5.63	1.19	1.82	12.94	1.56	0.64	0.32	0.30	15.00	2.81	1.16	1.80	0.64
18	SW18	24.09	25.71	5.59	18.50	10.74	8.40	1.28	1.47	34.72	1.44	0.69	0.35	0.46	31.00	1.85	0.89	1.29	1.01
19	SW19	71.04	44.99	21.95	49.09	17.86	14.41	1.24	1.49	97.06	1.37	0.73	0.37	0.44	111.00	2.13	1.14	1.56	1.87
20	SW20	35.07	32.27	19.89	15.18	10.49	8.89	1.18	1.53	46.80	1.33	0.75	0.37	0.42	62.00	2.36	1.32	1.77	1.39
21	Wo	109.08	144.97	55.32	53.75	56.71	37.87	1.50	3.89	200.39	1.84	0.54	0.27	0.07	165.00	2.78	0.82	1.51	0.95
Min.		**2.33**	**9.43**	**0.78**	**1.15**	**3.19**	**2.46**	**1.15**	**1.37**	**4.99**	**1.33**	**0.37**	**0.18**	**0.07**	**3.00**	**1.85**	**0.59**	**1.17**	**0.15**
Max.		**126.31**	**144.97**	**65.86**	**60.45**	**56.71**	**37.87**	**1.76**	**3.89**	**200.39**	**2.73**	**0.75**	**0.37**	**0.52**	**205.00**	**5.27**	**1.61**	**2.71**	**2.28**
Mean		**37.15**	**37.15**	**16.86**	**20.29**	**15.17**	**11.28**	**1.33**	**1.87**	**59.09**	**1.71**	**0.60**	**0.30**	**0.34**	**58.05**	**2.77**	**0.97**	**1.62**	**1.01**
Std. error		8.43	6.84	4.37	4.43	2.81	1.95	0.03	0.13	13.46	0.07	0.02	0.01	0.03	13.49	0.20	0.06	0.09	0.13
Variance		1491.52	982.09	400.79	411.66	166.41	79.53	0.02	0.37	3805.81	0.11	0.01	0.00	0.02	3822.45	0.86	0.07	0.16	0.37
Stand. dev		38.62	31.34	20.02	20.29	12.90	8.92	0.14	0.61	61.69	0.33	0.10	0.05	0.13	61.83	0.93	0.26	0.39	0.61
Median		19.05	25.71	7.64	14.62	10.74	8.29	1.29	1.62	30.73	1.61	0.62	0.31	0.37	24.00	2.57	0.91	1.59	0.74
25 prcntil		7.46	18.10	2.61	4.16	6.92	5.88	1.22	1.51	13.29	1.48	0.53	0.27	0.24	12.50	2.18	0.77	1.31	0.60
75 prcntil		60.77	49.76	21.08	35.82	19.77	15.95	1.40	2.06	91.84	1.88	0.68	0.34	0.44	99.00	2.82	1.16	1.75	1.53
Skewness		1.14	2.29	1.48	0.92	2.00	1.74	1.44	2.15	1.27	1.65	-0.62	-0.65	-0.58	1.19	1.55	0.65	1.74	0.80
Kurtosis		0.08	6.42	1.04	-0.64	4.50	3.15	3.25	5.19	0.44	3.66	0.19	0.23	-0.64	0.19	1.83	0.36	3.20	-0.57
Geom. mean		20.06	28.86	8.09	10.92	11.53	8.73	1.32	1.80	33.68	1.68	0.60	0.30	0.30	31.69	2.65	0.94	1.58	0.83
Coeff. Var.		**103.95**	**84.35**	**118.73**	**100.00**	**85.02**	**79.09**	**10.63**	**32.50**	**104.40**	**19.20**	**15.90**	**16.42**	**38.85**	**106.51**	**33.46**	**26.38**	**24.35**	**60.69**

Table 5

Drainage density, range, value in study area and weight

	Range	Surface rock permeability	Run-off	Infiltration rate	Watershed in study area	Weight
Drainage density (km/km²)	< 1.5	High	Low	High	SW9, SW10, SW13, SW18, SW19, SW20.	3
	1.3 to 2.5	Medium	Medium	Medium	SW1, SW2, SW3, SW4, SW6, SW7, SW8, SW11, SW12, SW14, SW15, SW16, SW17.	2
	> 2.5	Low	High	Low	SW5.	1

Constant of channel maintenance (Cchm) – this morphometric parameter was first proposed by Schumm (1956). It is the number of square kilometres of catchment surface area required to support one linear kilometre of stream segment. This parameter in the study area ranges from 0.37 (min) to 0.75 (max) with an average value of 0.60 (Table 4, Fig. 7).

Length of overland flow (Lof) – describes the length of flow of water over the ground before it becomes concentrated in incised stream channels or permanent drainage channels. In the study area Lof ranges from 0.18 to 0.37 km (Table 4, Fig. 8). The equation 9 was used for calculation of Lof (Horton, 1945).

$$Lg = \frac{1}{2D_d} \text{ eq. 9. Horton, 1945.}$$

Stream frequency (Fs) – the stream frequency is calculated as the total number of stream segments of all orders per unit area (Horton, 1945). The stream frequency has a positive correlation with drainage density, the watershed indicating an increase in stream population with respect to increase in drainage density (Rao *et al.*, 2010; Waikar and Nilawar, 2014). In the study area, the stream frequency values range from 1.17 to 2.71 (Table 4, Fig. 9). The low stream frequency values of the study area are susceptible to high erosion and sedimentation load (Sreedevi *et al.* 2013). Equation 10 is applied for the calculation of Fs (Horton, 1932).

$$F_s = \frac{N_u}{A} \text{ eq. 10. Horton, 1932.}$$

Drainage texture (D_t) – is an important factor in the drainage morphometric analysis which is depending on the underlying lithology, infiltration capacity and relief aspect of the terrain. The following factors influence the drainage texture parameter: topographical factors-relief, climatic factors-precipitation, geological-lithological composition, pedological-soil type, land cover, etc. Based on the change in drainage, Smith (1950) distinguished five groups: < 2 Very Coarse, 2 to 4 Coarse, 4 to 6 Moderate, 6 to 8 Fine and > 8 Very fine, while the calculation of the drainage texture is done by the equation eq.11 (Smith, 1950).

$$\mathrm{D_t} = D_d \; x \; F_s \text{ eq. 11. Smith, 1950.}$$

Where
Dd = Drainage density
Fs = Stream frequency

This parameter in the Llap river basin ranges from 1.85 to 5.27 with an average value 2.77 (Table 4, Fig. 10). The results of the drainage texture parameters obtained in Llap river basin according to Smith (1950) classify the study area as very coarse, coarse and moderate (Table 6).

Table 6

Value for Dt, this study area

[1]	Dt rank	[2]	Class	[3]	Sub-basin in study area	[4]	%
[5]	> 2	[6]	Very coarse	[7]	SW7, SW15, SW18	[8]	14.29
[9]	2 to 4	[10]	Coarse	[11]	SW1, SW2, SW4, SW6, SW9, SW10, SW11, SW12, SW13, SW14, SW16, SW17, SW19, SW19, SW20, Swo.	[12]	71.43
[13]	4 to 6	[14]	Moderate	[15]	SW3, SW5, SW8.	[16]	14.29
[17]	6 to 8	[18]	Fine	[19]		[20]	-
[21]	> 8	[22]	Very fine	[23]		[24]	-

Drainage intensity (Di)-Faniran (1968) determined the drainage intensity through the equation 12, as the ratio of the stream frequency to the drainage density. For the study area, drainage intensity resulted between values 0.59 to 1.61 with an average value of 0.97 (Table 4, Fig. 11).

$$D_i = \frac{F_s}{D_d} \; eq. 12. Faniran, 1968.$$

Texture ratio (Tr)-It is an important parameter in the drainage morphometric analysis which dependnds on the underlying lithology, infiltration capacity and relief aspect on the terrain. Texture ratio in the Llap river basin, calculated with equation 13 (Schumm, 1965), ranges from 0.15 to 2.28 with an average value of 1.01 (Table 4, Fig. 12).

$$T_r = \frac{N_1}{P} \text{ eq. 13. Schumm, 1965.}$$

Circularity ratio (Cr)-Strahler (1964) determined that this morphometric parameter is influenced by the lithology of the basin-building rock formations, stream frequency and gradient of various orders. According to Vittala *et al.* (2004), Yangchan *et al.* (2015) and Vinutha *et al.* (2014), there is a relationship between circularity ratio value and the existence of structural disturbances. The value of (Rc) in the study area varies from 0.07 to 0.52, with an average value of 0.34 (Table 4, Fig. 13).

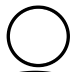
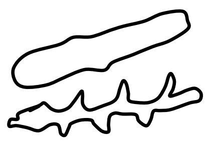
Compactness coefficient (Cc)-is defined as the ratio of the watershed perimeter to the circumference of equivalent circular area. It established the ratio of the perimeter of the basin to the perimeter of a circumference whose area is equivalent to the surface of the corresponding basin. This index represents the shape of the basin surface, according to its delimitation, and its influence on runoff and the hydrograph resulting from a precipitation (López Cadenas de Llano & Mintegui Aguirre, 1987). It is expressed by the following equation 9 (Gravelius, 1914).

$$Cc = \frac{P}{2\sqrt{\pi * A}} \approx 0.28 * \frac{P}{\sqrt{A}} \text{ eq. 14. Gravelius 1914.}$$

Where:
Cc-compactness coefficient;
P-perimeter of the basin in (km);
A-area of the basin in (km^2);
The compactness coefficient in the study area ranges from 1.37 to 3.89 with an average value of 1.87 (Table 4, Fig. 14), characterizing the Llap river basin as ameboid and stretched, according to the classification given by Gravelius (Table 7).

Table 7

Classes of oasis basin shapes according to the value of the Gravelius index

Shape	Gravelius index values	No. of Sub-basin in study area	Sub-basins in study area	In (%)	Stylized scheme
Circular	1 to 1.03	0	/	0.00	
Ovoid	1.03 to 1.3	1	W6	5.88	
Amoeboid	1.3 to 1.4	7	W1,W3,W11, W12, W13, W15, W16.	41.18	
Stretched	1.4 to 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	

The coefficient of meandering (Cm)-indicates the extent of the river meandering. The water flow courses of the Llap river basin have numerous meanderings affected by geological, geographical, climatic and topographic features. Meandering is more pronounced especially in those areas where the rivers come out on plains, i.e. downstream, in areas with low altitude, as well as with friable and unstable terrigenous geological composition where lateral erosion is more favourable. The equation 15 was used to determine the meandering coefficient:

$$C_m = \frac{L}{D} \text{ eq. 15. Talani, 2000.}$$

Where:
L-length of the river (km);
D-straight line length from the source to the outlet of the river (km);
The values of the coefficient of management in the basin of the Llap river vary from 1.15 (min.) to 1.76 (max.) and the average value of C_m = 1.33 (Table 4, Fig. 15). From the small meandering coefficient in Llap river basin, it seems evident that the deep and regressive erosion is more intensive the lateral probably due to the geological context.

The asymmetry of the watershed (Aw) – the asymmetry is a morphometric coefficient that determines the extent of erosion on both sides of a river which is influenced by the stability of rock formations on both sides of the basin and the intensity of neotectonic movements, etc. To determine the asymmetry coefficient, the areas to the left and right of the main river course in the watershed were measured. This coefficient is determined by the equation16 (Talani, 2000).

$$Aw = \frac{A_l - A_r}{A_l + A_r} \text{ eq. 16. Talani, 2000.}$$

Where:
A_l-surface to the left (km);
A_r-surface to the right (km);
A_w-coefficient of asymmetry;

The values of the asymmetry of the Llap river watershed vary from - 0.69 (min.) to 0.47 (max.) (Fig. 16). The smaller absolute value of the asymmetry coefficient, the more symmetrical the surface of that river basin is. The trends of tectonic lifting forces and the size and intensity of erosion and the tendency of intense or slow modelling of the relief are evaluated by applying this coefficient.

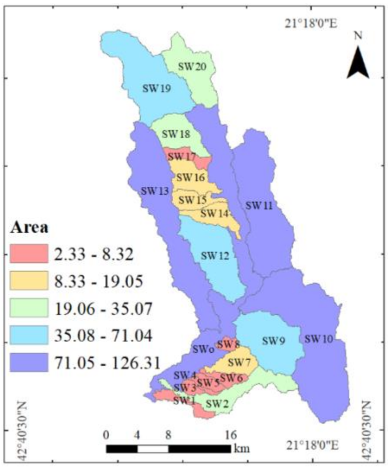


Fig. 4 – Area.

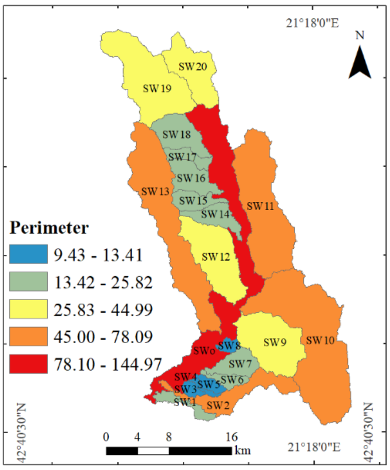


Fig. 5 – Perimeter.

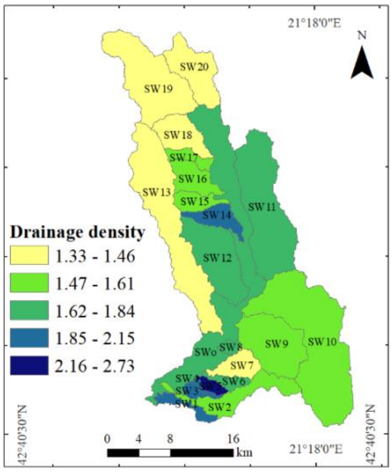


Fig. 6 – Drainage density.

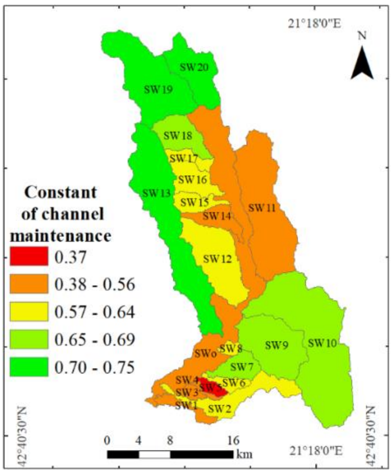


Fig. 7 – Constant of chanel maintenance

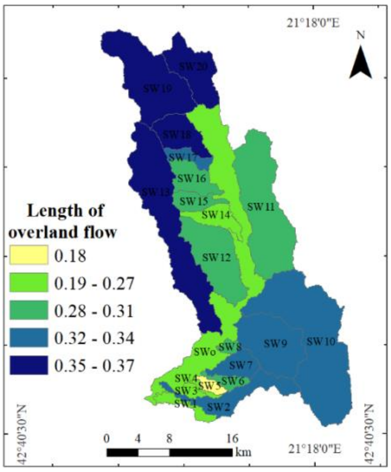


Fig. 8 – Lenght of overland flow.

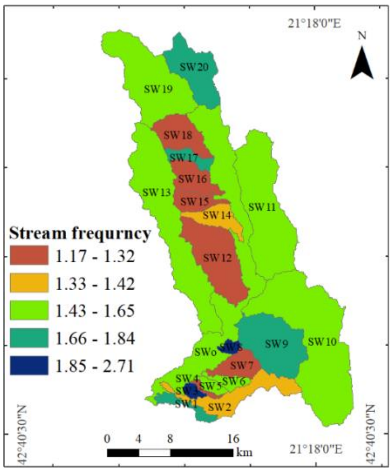


Fig. 9 – Stream frequency.

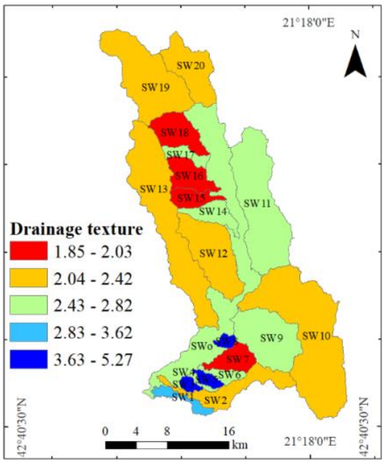


Fig. 10 – Drainage texture.

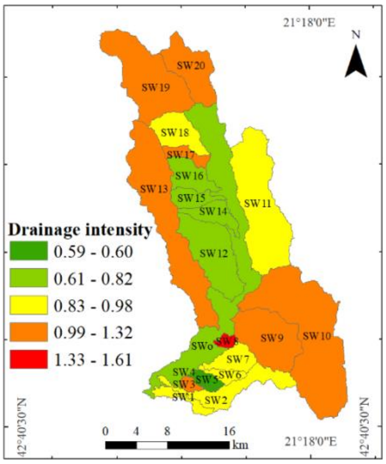


Fig. 11 – Drainage intensity.

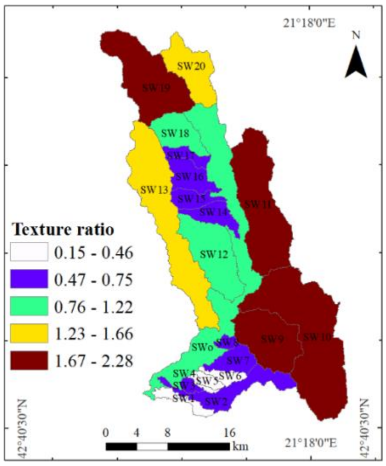


Fig. 12 – Texture ratio.

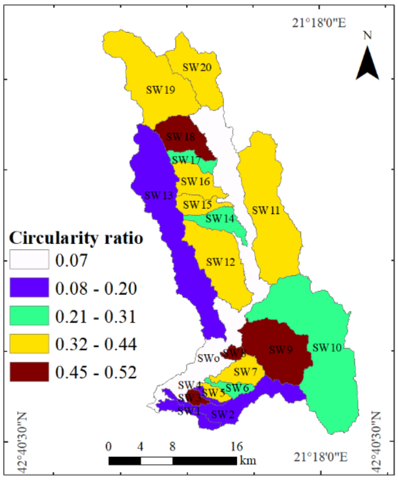


Fig. 13 – Circularity ratio.

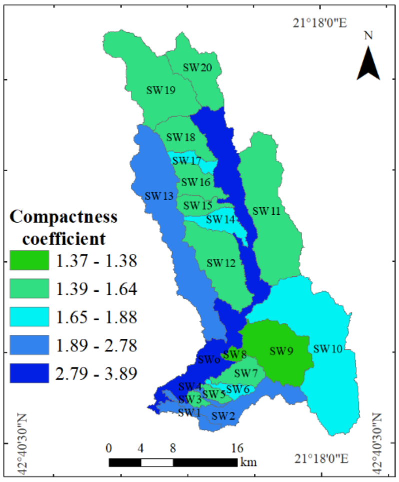


Fig. 14 – Compactness coefficient.

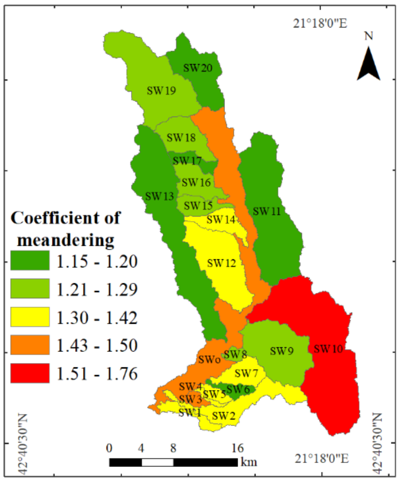


Fig. 15 – Coeficient of menadering.

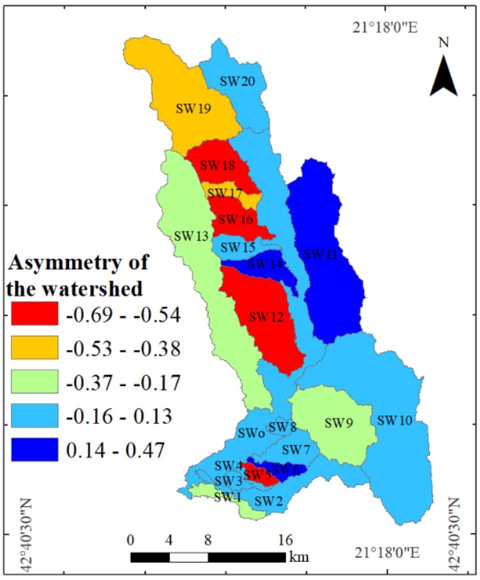


Fig. 16 – Asymmetry of the watershed.

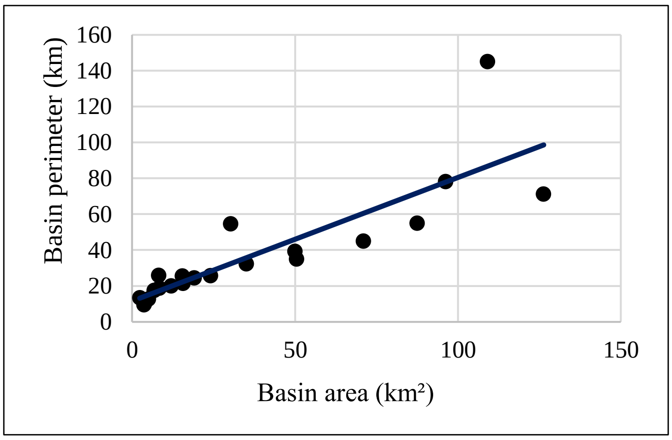


Fig. 17 – Basin area versus basin perimeter.

In Table 8 and Figure 17, the correlation of the morphometric parameters analysed for the Llap river basin is shown. There is a strong positive correlation between the surface and the perimeter (r = 0.85), and between the stream order and number of streams and stream order and stream lenght (Fig. 18).

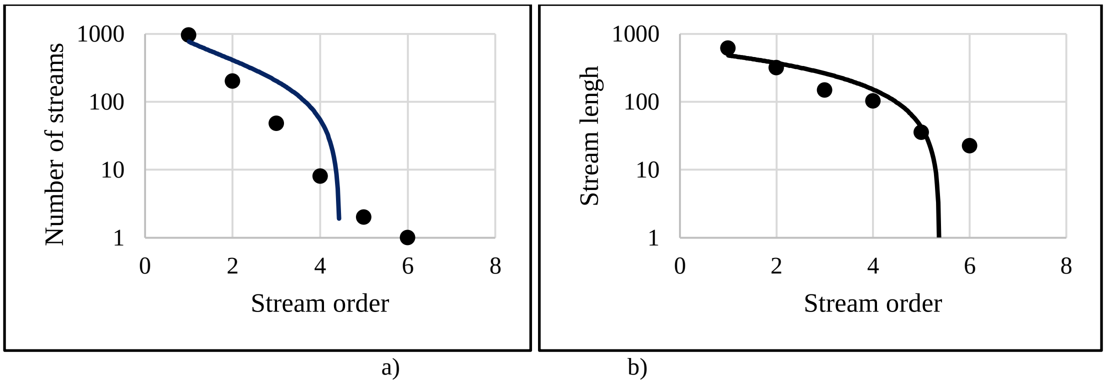


Fig. 18 – Correlation between the stream order and number of streams and stream order and stream lenght.

A dendrogram is a diagram that show the hierarchical relationship between objects. It is most commonly created as an output from hierarchical clustering. Dendrogram is useful for showing the existing cluster members according to the number of clusters that should be formed. The process of forming clusters at observation stations using the hierarchical method begins with calculating the distance matrix between variables using the Euclidean distance. Hierarchical clustering for the Llap river basin is shown in Figure 19. In Figure 19 one can see that SW3 and SW8, SW6 and SW17, etc., are more similar, since the height of the connection that joins them is smaller.

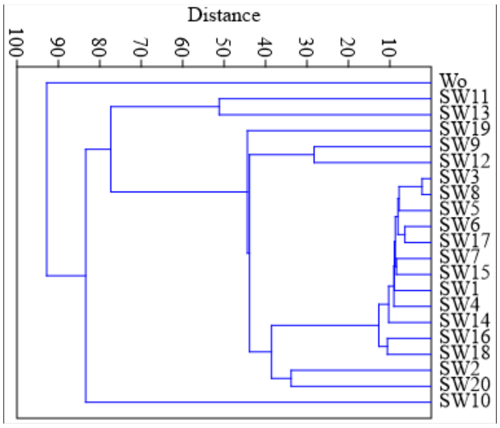


Fig. 19 – Hierarchical clustering (Algorithm-Single linkage Similarity index-Euclidean).

5. CONCLUSIONS

The basin of the Llap River turns out to be the largest water contributor from the right side of the Stnica River. The analysis shows that this basin has an area of 780.23 km^2 determined based on the DEM model and the application of ArcMap software. The use of the DEM model and the ArcGIS software proved to be very efficient in dividing river sub-basins and in extracting and analyzing morphometric parameters in this river basin. Based on the classification according to Singh 1994, it was confirmed that the Llap river basin belongs to river basins within the limit of 100 to 500 km^2, while 60% of its sub-basins belong to the limit of 10 to 100 km^2 (mili-watershed). In the area of the Llap river basin, 20 sub-basins were divided with a surface and perimeter from 2.33 km2 to 126.31 km^2, respectively 9.43 km to 144.97 km. A good correlative relationship was shown between surface area and circumference (r= 0.85). The study showed that this basin has 1219 number s of streams, also in this basin a hierarchy of six stream orders was shown, of which 78.42% belong to the first order. The river network showed a length of 1240.85 km, while the bifurcation ratio showed values from 2.00 to 4.77, indicating that the geological structure does not have dominant control. The study area showed a drainage density value of 1.52 km/km^2. The largest number of river subbasins showed (Dd) values in the range of 1.3 to 2.5, indicating that they belong to the average range according to surface rock permeability, runoff and infiltration rate. According to the drainage texture parameter, it turns out that 71% of the river subbasins belong to the range between values 2 and 4, thus indicating that they belong to the coarse class. The development of the hydrographic network in the basin of the Llap River and its sub-basins turns out to be conditioned by the slope of the terrain, relief, climate, geological construction, etc. This study with the data and information it contains can be useful in the planning, management and development of water resources. The work also helps institutional structures and individuals who follow the steps of the Water Framework Directive 2000/60EC and the concept of integrated management at the river basin level.

The correlation coefficients between morphometric parameters in the Llapi river basin are shown in Table 8. In principle correlation shows the relationship between two variables. In this paper, the Linear r (Pearson) method was used. The study of correlation (connection) often aims to show the statistical independence of two variables, that is, to prove that they are not related to each other (Selenica A, 2000). The correlation coefficient values 1 and (-1) correspond to functional dependence, while the value 0 corresponds to statistical independence. The results show that some correlation coefficient values have been more significant. The most significant positive correlations were found between: P-Rl (r = 0.99), A-P (r = 0.85), etc., The most significant negative correlations were found between: Cr-Cc (r = - 0.91), Lof-Dd (r = - 0.97), Cchm-Dd (r = - 0.97), etc.

Table 8

Correlation of morphometric parameters in the study area

	A	P	Af	Ar	Rl	Sldr	Cm	Cc	Lrnsb	Dd	Cchm	Lof	Cr	Nu	Dt	Di	Fs	Tr
A	1.00																	
P	0.85	1.00																
Af	0.96	0.83	1.00															
Ar	0.96	0.80	0.84	1.00														
Rl	0.87	0.99	0.84	0.83	1.00													
Sldr	0.86	0.98	0.82	0.83	0.98	1.00												
Cm	0.31	0.29	0.32	0.27	0.34	0.18	1.00											
Cc	0.31	0.71	0.34	0.24	0.69	0.66	0.23	1.00										
Lrnsb	0.99	0.89	0.96	0.93	0.90	0.88	0.33	0.38	1.00									
Dd	-0.35	-0.21	-0.28	-0.40	-0.21	-0.25	0.27	0.16	-0.27	1.00								
Cchm	0.36	0.19	0.27	0.43	0.19	0.24	-0.29	-0.22	0.26	-0.97	1.00							
Lof	0.36	0.19	0.27	0.43	0.19	0.24	-0.29	-0.22	0.26	-0.97	1.00	1.00						
Cr	-0.22	-0.53	-0.28	-0.15	-0.55	-0.54	-0.15	-0.91	-0.27	-0.18	0.24	0.24	1.00					
Nu	1.00	0.83	0.96	0.95	0.85	0.84	0.30	0.28	0.98	-0.36	0.37	0.37	-0.21	1.00				
Dt	-0.32	-0.27	-0.24	-0.37	-0.28	-0.32	0.21	-0.06	-0.28	0.65	-0.65	-0.65	0.13	-0.28	1.00			
Di	0.11	-0.03	0.10	0.12	-0.05	-0.03	-0.16	-0.28	0.04	-0.50	0.50	0.50	0.38	0.17	0.31	1.00		
Fs	-0.14	-0.18	-0.10	-0.18	-0.20	-0.21	0.05	-0.18	-0.15	0.11	-0.13	-0.13	0.29	-0.09	0.82	0.79	1.00	
Tr	0.82	0.45	0.76	0.81	0.47	0.49	0.08	-0.22	0.76	-0.53	0.56	0.56	0.26	0.84	-0.29	0.38	0.02	1.00

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