FLOW CONTROL FACTORS AND RUNOFF CHARACTERISTICS IN THE VALEA CERBULUI RIVER BASIN

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ABSTRACT. CHARACTERISTICS OF THE AVERAGE LIQUID FLOW IN THE VALEA CERBULUI RIVER BASIN. This article aims to emphasize the characteristics of the average liquid flow in the Valea Cerbului Basin (a tributary of the upper course of Prahova River). Although it is a small hydrographic basin (26 km^2), it has distinct hydrological features, which are imposed by the morphological, morphometrical and climatic conditions of this area. In order to achieve this purpose, the hydrological data series (recorded on Valea Cerbului) on the average flow have been statistically analyzed. Analyses revealed as main hydrological features of this basin: a relatively reduced interannual variability of the average flow (Cv = 0.33); a hydrologic regime with high flow in July and reduced flow in January and February; a significant share of the annual flow (52%) from April to July and a reduced one during the winter (13% of the annual flow). According to Mann-Kendall test, at both monthly and seasonal level, average discharge shows (generally) ascending trends, but particularly significant are the trends between August and December and the trend calculated for the season autumn.

Keywords: average flow, temporal variability, trends, Bucegi Mountains.

1. INTRODUCTION

This paper aims to highlight the specific features of the average liquid flow in the Valea Cerbului River Basin, as a reflex of the action of the main control factors: climatic, lithological, morphological, land use. Based on statistical processing of data series, specific aspects are revealed for interannual and intra-annual variability of the average flow and for its trends.

Even though there are no studies that assess specifically, at a hydrological level, the Valea Cerbului Basin, geographical information on this basin is found in works of more comprehensive issues (which refer, generally, to the Bucegi Massif or to the Upper Prahova). Of these, we mention the following studies and papers: Wachner (1930), Cristea and Dumitriu (1964), Velcea (1974), Roşu (1980), Oprea (2004), Oprea and Oprea (2006), Moţoiu (2008), Nedelcu (2010). Aspects of the hydrological characteristics of the Valea Cerbului Basin are poorly known, from where resides the interest of this paper. Identifying trends in the discharge variability is a subject of interest in the context of international and national concerns on climate change adaptation. In this regard, we mention, for Romania, *the National plan of action regarding climate change* and *the Guide on adaptation to climate change effects* (Ministry of Environment and Forests, 2012 a, b).

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2. DATABASE AND METHODOLOGY

This paper is based on three main types of date: hydrological, climatic and carthographic. Hydrological data were obtained from the „Romanian Waters" National Administration (ANAR). There have been used monthly and annual average flows (period: 1950-2010), from Buşteni hydrometric station on Valea Cerbului River (it controls about 96% of the basin area). Climatic data are taken from *Clima României* (2008) and ECA&D Climatic Database (from periods ranging between 1961 and 2010) for three weather stations (WS): Vârful Omu, Sinaia and Predeal. For the use of cartographic information we used GIS techniques, based on: the topographic map scale 1: 25 000 (edited in 1985) and land use map made available by the European Environment Agency, through CORINE Land Cover 2006 program. The processing of hydro-climatic data has been carried out by specific statistical methods. We applied Mann-Kendall test, using the Makesens software in order to estimate trends and statistical significance of the average discharges.

3. FLOW CONTROL FACTORS IN THE VALEA CERBULUI CATCHEMENT

The Valea Cerbului Basin is a small basin (26 km^2) located entirely on the eastern slope of the Bucegi Massif (fig. 1). The maximum altitude of the basin is 2505 m (Peak Omu), and the minimum altitude is 861 m. The main collector of the basin is Valea Cerbului River, one of the most important tributaries of the upper course of the Prahova River. Most streams have a non-permanent flow regime. Valea Cerbului has a permanent character only on its last 7 km (its total length is about 12 km).

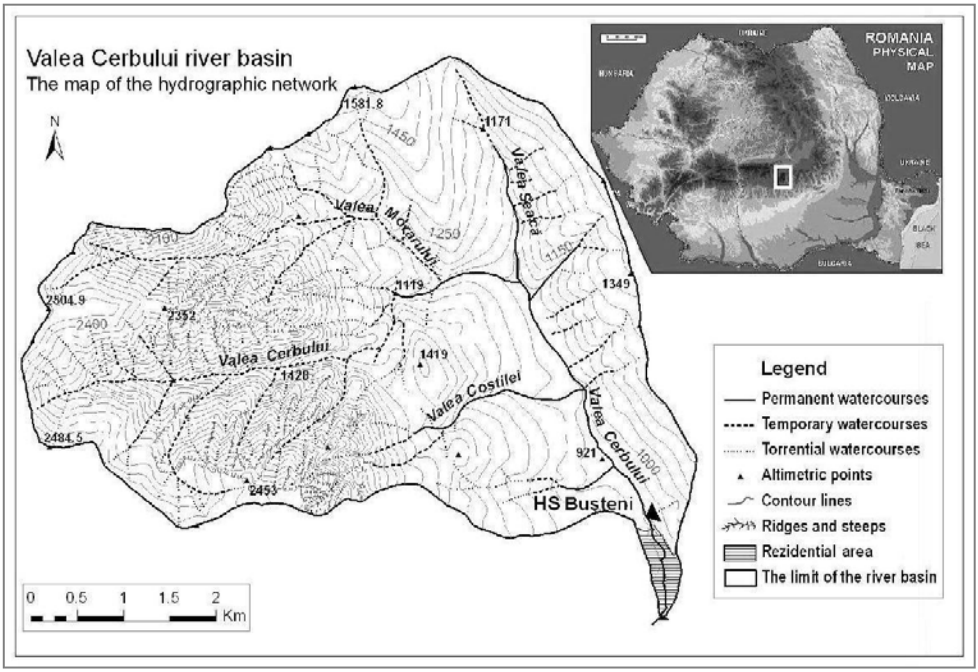
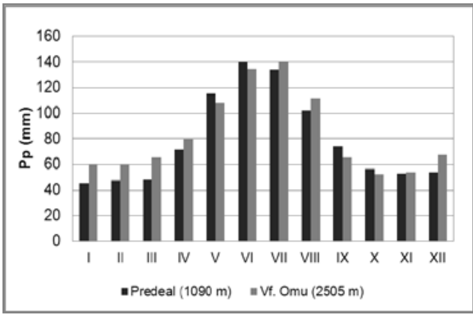


Fig. 1: ***Geographical position of Valea Cerbului Catchment*.**

3.1. Climatic conditions – a determinant factor of liquid flow

The most important factor for surface flow regime is the climatic one, of which the precipitation, the air temperature and the snow layer play a decisive role in the variations of the liquid flow.

Precipitation. The rainfall is the factor with the most important influence on transited flows on the valleys. The mean annual amounts of precipitation at Vârful Omu WS is 987.3 mm and Predeal registers an average of 941.7 mm (for the period 1961-2000, according to *Clima Romaniei*, 2008). Over a year, a period of low precipitation is recorded during autumn and winter (below 60 mm/ month). The period with rich precipitation (100 mm) occurs from May to August (fig. 2). Interannual variability of the amounts of precipitation at Vârful Omu WS is characterized by alternating intervals of rainy years (eg.: 1966-1978), with those with reduced precipitation (eg.: 1979-1990, 2000-2007). This alternation is highlighted by the polynomial trend (order 6) of data series (fig. 3).



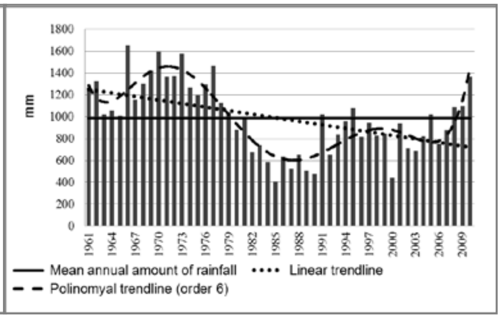


Fig. 2 (left): ***Average monthly precipitation at weather stations of Bucegi Mountains and their vicinity (1961-2000 according to Clima României, 2008);***
Fig. 3 ***(right): Interannual variability of precipitation at Vf. Omu weather station (1961-2010) (based on ECA&D Climatic Database)***

The air temperature. Although the surface of the Valea Cerbului basin is reduced, the temperatures show significant spatial variations, due to the difference in elevation and slopes orientation. On the highest areas, the mean annual temperature is negative (Vf. Omu WS, 2505 m: -2.5ºC). At lower altitudes, it reaches positive values (Sinaia WS, 1510 m: 3.7°C, Predeal WS, 1090 m: 4.9°C).

Regarding the mean annual temperature regime, at altitudes above 2500 m, positive temperatures are registered only during the warm season (May to September) and the 5ºC threshold is exceeded only in July and August (riching up to 5.5ºC in August). At lower altitudes (at Sinaia and Predeal), monthly mean temperature is positive for the period April – November, with values between 0.4°C (Nov.) and 12.5°C (July) at Sinaia WS and values between 1°C (Nov.) and 14.4°C (July) at Predeal WS. The lowest temperatures are recorded during the winter: the minimum mean temperature is recorded in January (-10.3°C at Vf. Omu, -5.2°C at Sinaia and -4.9°C at Predeal).

Temporary and spatial variation in temperature determines the form in which the precipitation falls (liquid or solid), and also the aparition and duration of the winter phenomena on rivers. The temperature variation also determines the accumulation of solid precipitation as snow layer and the melting of the ice and snow, resulting in rich flows and floods.

The frost and the snow layer. On the heights (Vf. Omu WS), the frost at the soil surface is almost permanent during the cold season (November-April). Although the frequency of frost decreases considerably in the warm season, it may occur even in the summer months (table 1). At lower altitudes (Predeal WS), there are no recorded data of negative minimum temperatures in July and August; the maximum frequency of frost is recorded between December and March.

Negative temperatures determine not only the occurance of solid precipitation, but their accumulation in the form of snow layer, which directly affects the volumes of water transited on the valleys. A consequence of the frost is storing river water as winter phenomena. This fact results in decreasing river flows up to temporarily drying up.

Table 1*: Data on frost and snow layer from weather stations of Bucegi Mountains and their vicinity (1961-2000) (data source: Clima României, 2008)*

Average monthly number of days with frost (min temp. <= 0)													
	VIII	**IX**	**X**	**XI**	**XII**	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**Annual**
Predeal (1090 m)	-	1.5	11.6	21.8	29.8	30.7	27.4	27.8	16.7	2.8	0.2	-	**170.3**
Vf. Omu (2505 m)	5.2	13.5	22.7	28.9	30.9	31	28.3	30.9	29.2	22.7	10.1	6.3	**259.7**
Average monthly number of days with snow layer													
Predeal (1090 m)	-	0.1	2.1	11.8	26.6	30.6	28	26.8	10.2	1	-	-	**137**
Sinaia (1510 m)	-	0.3	3	12.7	26.1	29.3	27.4	28.6	16.4	1.6	-	-	**145,3**
Vf. Omu (2505 m)	0.4	4	11.3	21	29.9	30.9	28.2	31	29.5	25.6	7.2	0.9	**219,8**
Average monthlydepth of snow (cm)													
Predeal (1090 m)	-	0.5	5.1	17	31.2	43.8	37	8.4	0.3	-	-	-	-
Sinaia (1510 m)	-	0.9	5.2	19.3	32.6	47.5	45.3	17	0.5	-	-	-	-
Vf. Omu (2505 m)	-	1.5	5	14.3	35.6	50.6	61.1	72	88.3	72.4	15.7	-	-

Noteworthy is the variation of monthly average thickness of the snow layer relative to the altitude: at altitudes of 1000 – 1500 m, the thickness of the deposited snow increases until January (average depth: 47.5 cm at Sinaia and 43,8 cm at Predeal) and then decreases until complete melting in May, in the alpine area, low temperatures favor the accumulation of solid precipitation until April-May (at Vf. Omu, average thickness of snow reaches 88.3 cm in April), then the melting of the snow is quite sudden (June: 15.7 cm) – which imposes to the annual flow regime some particular features (floods).

3.2. Lithological and morphological conditions

The Valea Cerbului Basin develops on a crystalline fundament, covered by Mesozoic sedimentary deposits (mainly Cretaceous) (Cristea and Dumitriu, 1964). In the western part of the basin, at altitudes above 1500 m, there are conglomerates (Bucegi Conglomerates), sandstones and grate flysch formed during Lower Cretaceous (Albian). In the plateau areas there are small areas with gravel, sand and leossoide deposits from Upper Pleistocene. At altitudes below 1500 m, there are found: grate flysch, grate-shale flysch and calcarenitic flysch – forming the Comarnic Layers (Barremian-Apţian) (*Geological Map,* 1: 200 000; edited in

1967). Because of their permeability, conglomerates from the upper basin have a great influence on surface flow, favouring the infiltration (for this reason, the upper areas of the valleys are characterized by a non-permanent flow character).

From morphological point of view, Valea Cerbului Basin has deep glacial cirques (the energy of relief between the ridges and the valley bottoms is approx. 600-700 m). This glacial cirques are the origins of the main rivers, which are separated by steep slopes, peaks, ridges, ”needles” and ”fangs”. The average altitude of the basin is 1536 m and the energy of relief is 1644 m. The influence of the lithologic and morphological factors on surface flow is illustrated by the correlation of annual amounts of precipitation (registered at Vf. Omu), with the average annual flows (registered on Valea Cerbului). The correlation coefficient is 0,44, so the correlation is weak: an important part of water volumes are lost through infiltration and interception.

3.3. Land cover

After the classification of the CORINE Land Cover 2006 methodology, the Valea Cerbului Basin is mostly covered by forests and semi-natural areas. The total share of forests is 73%, of which 25% are coniferous forests and 48% mixed. Grasslands extend for 19% of the basin. The high degree of vegetation coverage (especially forest) favors the interception and thus reduces the surface flow (fig. 4).

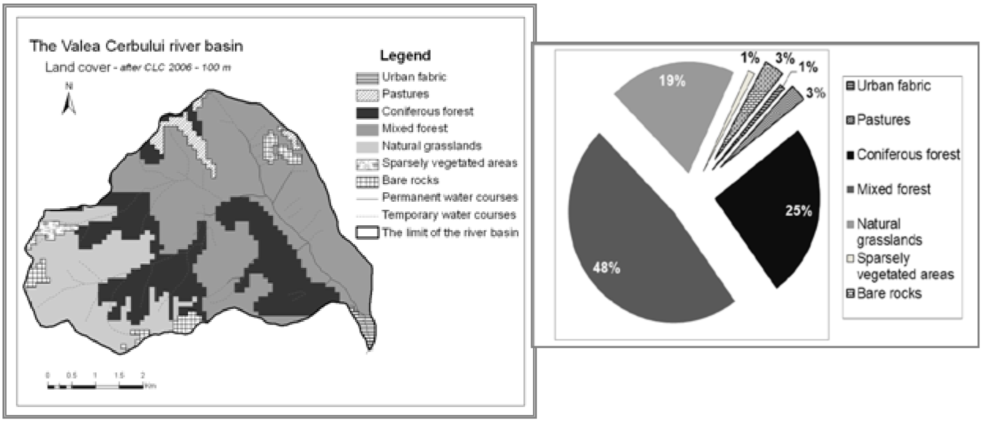


Fig. 4 ***The land use (left) and the weights of land use classes in the Valea Cerbului Catchment (according to CORINE Land Cover 2006, resolution 100x100m)***

4. MEAN LIQUID FLOW CHARACTERISTICS

The Valea Cerbului Basin is characterized by an annual average discharge of 0.496 m^3/ s (1950-2010). This discharge is equivalent to a mean specific discharge (q) of 19.08 l/ s/ km^2 , to a mean water layer (h) of 602 mm, and to a mean annual volume (W) of 15.64 million m^3.

4.1. The interannual variability of the average liquid flow

An important feature of the surface liquid flow is the variability of the annual average flow. The polynomial trend curve (order 6) (fig. 5A) reveals the alternating periods of high flow levels (for example: 1960-1981) and low flow levels (for example: 1983 - 1996, 2000 – 2009). These cycles of flows correspond only partially to the dry or the rainy periods identified at annual precipitation. This fact is caused by the permeability of the lythological substratum and by the degree of saturation of the aquifers. The interannual coefficient of variation of the mean flow is reduced: Cv = 0.33, fact which reflects a relatively uniform flow from one year to another. For the analyzed period (1950 – 2010), there is found a slightly ascending linear trend of the average discharge, reflected by the variability of the average annual discharge and of the module coefficients (ratio of annual discharge and multiannual discharge) (fig. 5A and 5B).

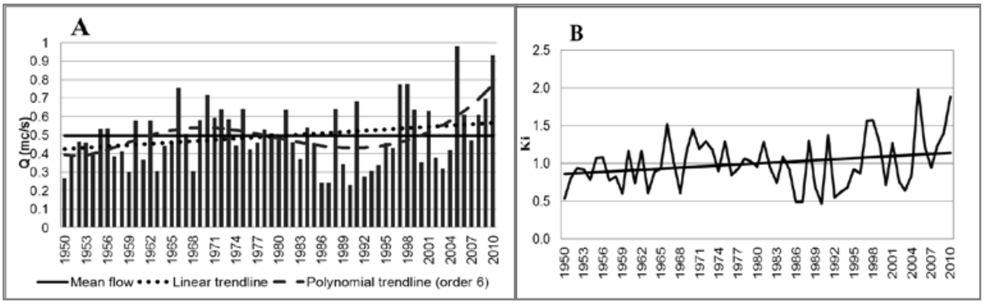


Fig. 5: ***Interannual variability of the mean annual flow (A) and the module coefficient – Ki (B) at Buşteni hydrometric station on Valea Cerbului River (1950-2010)***

4.2. The average annual flow regime

The average annual flow regime in Valea Cerbului Basin has a specific feature, by the fact that it is different from the average flow regim calculated at a national level for this area (Pişota and Zaharia, 2002). During winter months, reduced flows are recorded (due to the reduced precipitation, to the occurrence of frost, snow layer and winter phenomena). The spring is characterized by high amounts of water in April and May (caused by the association of rainfall and snow melting). But the highest monthly average flow occurs during the summer (June: 0.8 m^3/s, July: 0.89 m^3/ s, representing 13% and 15% of the annual average volume of water), when heavy rains, generally with a torrential character, are associated with the late melting of the snow layer (of the highest peaks of Bucegi Mountains): in June, the snow layer at Vf. Omu weather station has the average thickness of 15.7 cm and the maximum thickness of the snow layer (recorded in 1973) is 290 cm. During the autumn months, flows gradually decrease until the minimum from the middle of the winter (below 0.25 m^3/ s in January and February, which represents about 4% of annual average).

The sesonal distribution of the average annual flow highlights the particularity of the basin, namely the concentration of over a third of average flows recorded at Buşteni, during the summer (38% from the multiannual average volume). The warm season (March-August) counts almost 70% of the water drained in the basin within a year. During the spring, the share of the average discharge is 30% of the total of a year. During winter and autumn, there are the most redused average discharges scurgeri (13% and respectively 19%).

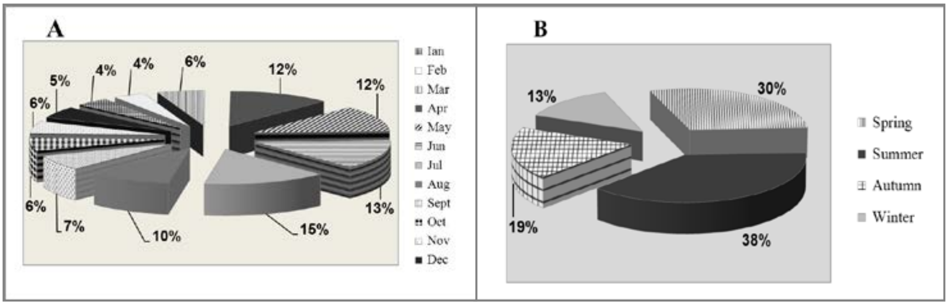


Fig. 6: T*he variation of monthly (A) and seasonal (B) average flow at Buşteni on Valea Cerbului River (1950-2010)*

4.3. Trends in the variability of the average discharge

For the analysis of the monthly and annual average flow trends we have used the Mann-Kendall test (table 2), which estimates whether a data series has a tendency to increase or decrease for the time interval considered (here 1950-2010) and if this trend is significant in statistical terms (Salmi et al., 2002). The values of "Z test" are calculated for different levels of significance ("α"): 0,001, 0.01, 0.05 and 0.1. Positive values indicate ascending trends and negative values indicate descending trends. Using the Mann-Kendall test there have been identified growth trends, statistically significant for six months of the year. The most significant ones are May, September and October (table 2). Only April and May are presenting downward trends, of which the trend for April is not statistically significant. The analysis aplied on a seasonal level reinforces the results of the test performed for the monthly data series: an ascending trend and an important level of significance for the season autumn and the absence of significance for the other seasons. The trend in mean annual flow variability is ascending, but it is not statistically significant.

Table 2: ***Mann-Kendall test applied to identify linear trends of the average discharge (Buşteni hydrometric st. – 1950-2010), where: ”Z test” - estimation of trend data series; ”Significance” - level of significance (α): 0,001 - ***, 0.01 - **, 0.05 - *; 0.1% - +)***

Time series	Test Z	Significance	Time series	Test Z	Significance
I	1.49		X	2.94	**
II	1.46		XI	2.03	*
III	1.59		XII	2.42	*
IV	-0.66		Spring	-1.22	
V	-2.64	**	Summer	1.57	
VI	0.78		Autumn	2.91	**
VII	1.53		Winter	1.56	
VIII	2.31	*	**Annual**	**1.59**	
IX	3.02	**			

5. CONCLUSIONS

The Valea Cerbului Basin shows specific features of the hydrological regime imposed by physical and geographical conditions, among which the most significant are: the high altitude and high energy of relief, rich precipitation, thickness and long duration of snow cover. In addition, an important role is played by the lithologic conditions, which, because of the high degree of permeability, causes the intermittent nature of the flow in the upper basin.

The high altitude of the basin and its specific climatic conditions cause a delay of high spring flow (specific to Romania in general), towards early summer. According to Mann-Kendall test, monthly flow trends are ascendant in five month (the most significant in September and October). The knowledge of trends in flow variability has practical importance for the adoption of appropriate adaptation measures for the society.

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