CHARACTERIZATION OF THE WATER FLOW REGIME OF THE RIVERS FROM THE CĂLIMAN MOUNTAINS (1950-2010) BASED ON THE PARDÉ COEFFICIENT

C. HIRLAV[1], A. PORCUȚAN[2]

Abstract. ***Characterization of the water flow regime of the rivers from the Căliman Mountains (1950-2010) based on the Pardé Coefficient.*** The Pardé coefficient, first introduced by Maurice Pardé in 1933, is the most famous water regime classification system in the world, and can be calculated and adapted to any river on the globe, based only on the average flow of rivers. In the Căliman Mountains, an analysis of the river's water flow regime has not been performed according to this coefficient so far, this work being the first of its kind. Following the completion of this paper, it was observed that the variation of climatic elements (precipitation and temperatures) in the period 1950-2010 influenced more the regime at a seasonal than at a year level. Changes were observed at the level of the season with the lowest runoff, at the stations from Someș River basin, changing in the analyzed period from winter to the beginning of the period, in autumn after the year 2000.

Keywords: water flow regime, coefficient, Pardé, discharge, amplitude.

1. INTRODUCTION

One of the most important problems in current hydrology is the adaptation of human life to the hydrological effects of environmental changes. Therefore, knowledge of past and current changes in river drainage regimes is needed. The most important changes are in the average behavior, seasonally and in the extreme months. Floods as well as droughts seem to occur more frequently, and extremes appear to be more intense (van der Ploeg and Schweigert 2001; van der Ploeg et al. 2001).

In addition, an important thing in hydrological analysis, in addition to the frequency and intensity of extreme hydrological events, such as floods and droughts, is also the study of the average hydrological regime of rivers and the seasonal variability of runoff (flow regime according to Pardé, 1933). The runoff regime is closely related to the climate and the physiographic

[1] hirlavcostin@yahoo.com
[2] adrianaporcutan@gmail.com

characteristics of a river basin (eg topography, land use, soils, geology) and relatively easy to characterize. Therefore, they are often used to estimate the usable amount of water. The runoff regime is suitable for an efficient characterization of the runoff characteristics of rivers (Aschwanden and Weingärtner, 1985; Ujvari, 1972).

As remarkable global and regional climate change has been detected in Europe in recent decades (IPCC 2007), the question arises as to whether such seasonal and monthly changes do not occur in the Căliman Mountains. These mountains in the Eastern Carpathians represent a special area due to its morphology, geology and positioning in the space of the Carpathian chain (Fig. 1). The high altitude (over 2000 m), the positioning at the exit of the Eastern Carpathians and the massiveness given by the volcanic substrate, make it a source of rivers with a rich flow and a radial flow, belonging to three large river basins and an important barrier against western and eastern air masses. This is manifested in the water flow regime, with differentiations between the three large basins.

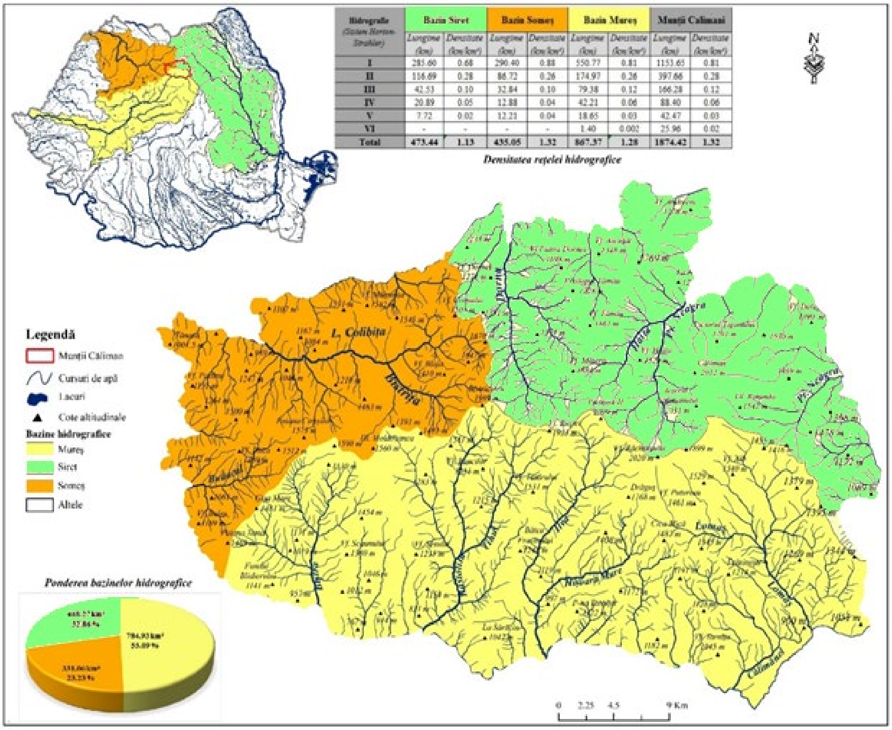

Fig. 1. Căliman Mountains and the hydrometric stations from them

To date, no comparative data analysis in the Căliman Mountains on changes in river runoff has been performed. Therefore, this study analyzed the data from the 11 hydrometric stations in the Căliman Mountains for the period 1950-2010 over a period of 10 years regarding the changes in the drainage regime. The increase (or decrease) of the extreme values of the lunar Pardé coefficients (Pardé, 1933) is investigated, as well as the impact of the consequences on the variability of the leakage and a potential temporal shift of the occurrence of the extremes of the lunar Pardé coefficients. This could be due to the previous melting of snow caused by regional warming.

2. DATA BASE AND METHOD

In this study, there are analyzed daily flow time series, observed at the 11 hydrometric stations in the Căliman Mountains (Table 1), of which 4 in the Siret basin, 3 in the Mureș basin and 4 in the Someș basin. The minimum length required for the time series is defined as 60 years (IKSE, 2005, quoted by Bormann, 2010) in order to be able to detect the long-term effects of environmental changes.

Table 1. Hydrometric stations from Căliman Mountains

No. Crt.	River	Hydrometric station	Hydrografic basin	F (km²)	H medie (m)
1	Dorna	Poiana Stampei	Siret	100	1376
2	Neagra	Gura Negrii	Siret	301	1256
3	Șărișor	Panaci	Siret	63	1427
4	Bistricioara	Bilbor	Siret	88	1123
5	Toplița	Toplița	Mureș	208	1149
6	Răstolița	Răstolița	Mureș	163	1174
7	Bistra	Bistra	Mureș	94	1104
8	Budac	Jelna	Someș	157	781
9	Bistrița	Mița	Someș	82	1230
10	Bistrița	Bistrița Bârgăului	Someș	612	1130
11	Straja	Mureșeni Bârgăului	Someș	71	860

Coeficientul Pardé. The flow regime of river water describes the variability of the runoff, influenced by the topographic, geological, climatic characteristics, etc. of the river basin (Pandi et all, 2011). The seasonal variation described by the runoff regime is due to the dominant supplying river regimes, consisting of precipitation (rainfall), melting snow (snow), melting ice (glacier), underground feeding. Depending on the time of occurrence of the seasonal maximums, there are several types of hydrological regimes. Pardé published the most famous classification system in 1933. He introduced the monthly Pardé coefficient (PC; the relationship between the average monthly runoff (MQ_{month}) and the annual average (MQ_{year}) to help compare different rivers. The Pardé coefficient therefore describes the average monthly runoff distribution over a year): $PC_{month} = MQ_{month} / MQ_{year}$.

Depending on the maximum number of Pardé monthly coefficients throughout the year, Pardé (1933) distinguished between unimodal (with a maximum) and complex (with more than a maximum, for example, bimodal) flow regimes. In addition, it differentiated between rainfall, snowfall and glacial regimes depending on the dominant feeding mechanism. In the case of complex drainage regimes, combinations of two or three feeding mechanisms are assumed. The difference between the maximum (PC_{max}) and minimum (PC_{min}) values of the monthly Pardé coefficients is called the amplitude - A. It characterizes the inter-annual variability of the average monthly flow: $A = PC_{max} – PC_{min}$.

The changes in drainage regimes are analyzed based on the modification of the seasonal behavior of the monthly Pardé coefficients; modification of the extreme values of the monthly Pardé coefficients (min, max), resulting in an increase or decrease in the seasonal variability of the runoff (= change in amplitude); and the modification of the synchronization of the extreme values of the monthly Pardé coefficients, indicating a year-on-year change of the dominant hydrological processes.

Finally, for all available time series, linear trends in average annual runoff (MQ) are calculated for the same time periods that were used in the analysis of changes in runoff regime (last 60 years of available data) (Bormann, 2010).

3. RESULTS AND DDISCUTIONS

Changes in the water flow regime

The river water flow in the Căliman Mountains vary depending on the altitude of the river basin and the positioning within the mountain group. The lowest value is being found at the Panaci station on the Sărișor brook (0.69 m^3/s), and the highest at the Poiana Negrii station from the Neagra River (4.20 m^3/s) (Table 2), both stations being located in the north of the mountain group, the differences being given by the basin size. Differences also occur at seasonal level, the highest percentage values being recorded during spring at all stations, while the lowest values appear in winter at the hydrometric stations in Siret and Mureș basins, and in autumn at the hydrometric stations in Someș basin, except

Jelna station, located in the westernmost, where the minimum is also recorded in autumn.

Table 2. Average annual (m^3/s) and seasonal (%) discharge values at the hydrometric stations from Călimani Mountains in the period 1950-2010

River	Hydrometric station	Average	Winter	Spring	Summer	Autumn
Dorna	**Poiana St.**	2,38	***9,06***	**43,88**	30,67	16,38
Neagra	**Gura Negrii**	*4,20*	***11,18***	**39,64**	32,12	17,06
Șărișor	**Panaci**	*0,69*	***13,10***	**37,95**	31,55	17,40
Bistricioara	**Bilbor**	0,96	***11,70***	**38,84**	31,68	17,79
Toplița	**Toplița**	2,86	***12,20***	**45,31**	27,45	15,04
Răstolița	**Răstolița**	3,49	***15,25***	**42,41**	25,75	16,59
Bistra	**Bistra**	2,39	***17,26***	**40,70**	24,74	17,30
Budac	**Jelna**	2,37	20,50	**40,56**	24,06	***14,87***
Bistrița Ard.	**Mița**	1,71	16,51	**41,72**	25,54	***16,24***
Bistrița Ard.	**Bistrița B.**	3,57	19,28	**38,54**	25,27	***16,91***
Straja	**Mureșenii B.**	1,29	19,58	**42,09**	22,37	***15,96***

Siret River basin

The drainage regimes of the rivers from Siret River basin vary from northwest to east. The regime type, according to the supply type in this basin is nivo-pluvial, with a maximum of the Pardé coefficient at the stations in April, except for the Gura Negrii, Gura Haitii and Drăgoiasa stations, where it appeared in May (Fig. 2). During the analyzed period, the month of recording the maximum varied, especially at the stations with maximum in May, towards the end of the 20th century, this being recorded one month faster, because of the winter heating, which caused a faster melting snow.

The minimum was recorded in January and February (in most cases, the values of the Pardé coefficient for these months are equal), with small long-term waters. The runoff regime of these rivers is thus close to the eastern Carpathian runoff subtype.

Regarding the average flow (MQ), all the stations in the Siret basin showed in the period 1950-2010 stationary trends or slight increase of the flows, the biggest differentiations being made at seasonal and monthly level. The maximums moved a month later at the stations located to the west (Poiana Stampei), while at the other stations the maximums flattened, causing the increase of flows during the autumn due to global warming at the beginning of the XXI century (Fig. 2). Minimum values were maintained at the end of winter.

In the period 1950-2010, the values of the coefficients decreased strongly at the stations in the Siret basin, the amplitude of the values of the Pardé coefficient varying between -0.21 at the Gura Haitii station and -1.36 at the Panaci station. This was due to the sharp decrease in the values of the coefficients during the spring months, with a minimum in May that reached a value of -1.13 at Panaci station.

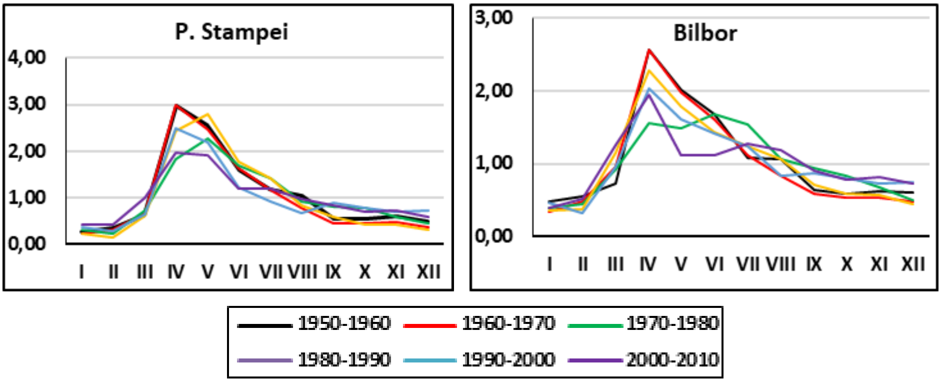

Fig. 2. Modifications of the Pardé coefficient, describing water flow regimes at the hydrometric stations from Siret River basin

Since the middle of the twentieth century, the Pardé winter and spring coefficients at the stations on the rivers in the Siret basin have increased slightly, while the values for summer and autumn have decreased slightly. Towards the end of the analyzed period the values of the winter coefficient approached those of autumn (Fig. 3), the values being almost equal at Gura Negrii and Panaci stations, positioned in the northeastern part of the Căliman Mountains.

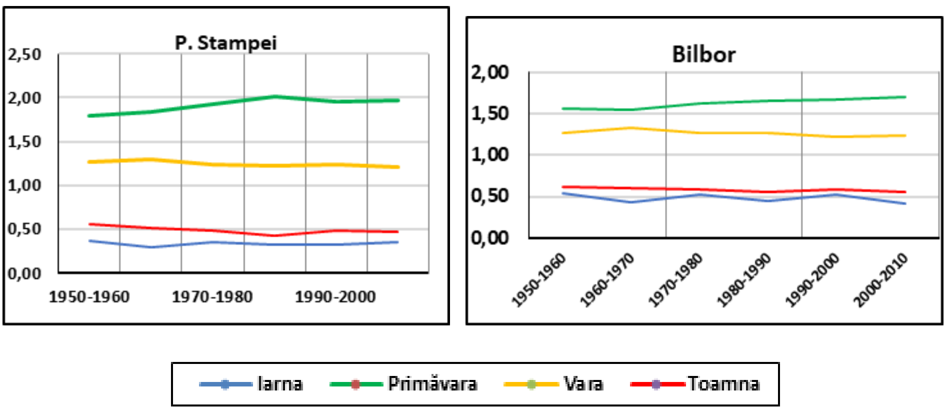

Fig. 3. Modifications of the seasonal Pardé coefficient for 10 years periods at the hydrometric stations from Siret River basin

The relatively stationary trends of river flow in the Siret basin was determined by an increase in winter and autumn discharges, which was combined with the decrease in the spring water flow, attributed to the increase in precipitation in the above two seasons. This phenomenon of warming in winter and rising temperatures occurred especially after 2000, which is in line with the general meteorological conclusions for the continent of Europe on global warming (IPCC, 2007), also valid for Romania.

Mureș River basin

In the Mureș basin, the drainage regimes of the rivers keep characteristics similar to those in the Siret basin, with small variations from east to west. The type of regime according to the power supply for the rivers in this basin is pluvio-nival, with a maximum in April (Fig. 4). Compared to the previous basin, in this basin, in addition to the unimodal regime, the maximum and minimum values are very well highlighted, with a maximum in April and a minimum in January, these maximums and minimums remaining constant throughout the analyzed period. , even though values have changed over the past six decades. Regarding the average flow (MQ), in the period 1950-2010 there were stationary trends of flows, the biggest differentiations being made at seasonal and monthly level.

During the period 1950-2010, the values of the coefficients decreased, the differences being very well observed in the decrease of the amplitude of the Pardé coefficient values, the highest being registered at the Răstolița station, of -0.90. This was due to the decrease in flows in the spring (especially in the peak month) and the summer and increase in the winter.

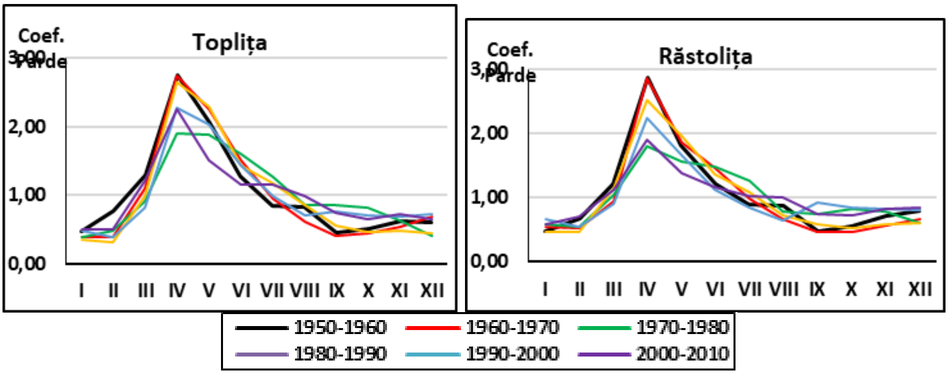

Fig. 4. Modificatios of the Pardé coefficient, describing water flow regimes at the hydrometric stations from Mureș River basin

At the seasonal level, a slight increase in spring runoff can be observed in the years 1970-1990 in all rivers in the basin, then returning to previous values. The summer remained constant in values. The most special things can be seen in the ratio between the values during autumn and winter, towards the end of the analyzed period, the values during winter exceeding those during autumn (Fig. 5).

These regime changes were due to the impact of climate change in the late twentieth and early twenty-first century, manifested by higher temperatures in winter and summer, which led to more rainfall that is abundant in winter and faster melting snow and stronger evaporation of water during the summer. This phenomenon was common during this period throughout Europe. Scherrer et al. (2004), Günther and Matthäus (2005) and (Schönwiese 1999) discovered similar processes in basins with the same altitude and exposure, like the Rhine and Danube in Germany, as a result of changing rainfall patterns, flows being influenced by an increase in summer evapotranspiration, resulting in higher discharges in winter and reduced discharges in summer.

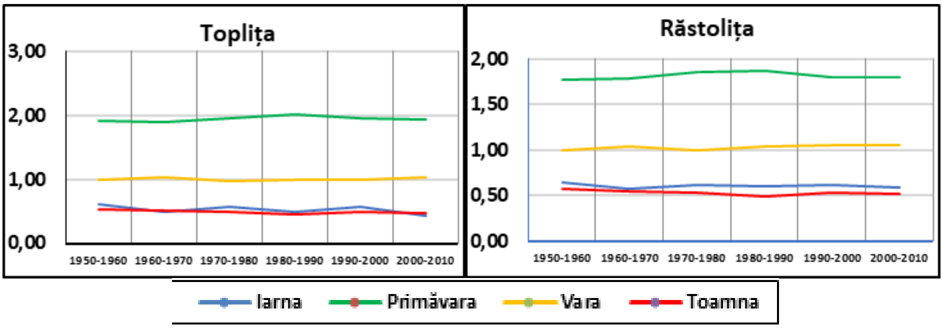

Fig. 5. Modifications of the seasonal Pardé coefficient for 10 years periods at the hydrometric stations from Mureș River basin

Someș River basin

The rivers in the Someș basin are located closest to the western climatic influences, with higher temperatures, which make their regime different from those in the other two basins. There are differences also between the stations in the basin. The type of regime according to the water supply for the rivers in this basin is pluvio-nival, unimodal, with a maximum of the Pardé coefficient at the stations in April, which was kept for decades, only at the Mureșenii Bârgăului station it moved to March (Fig. 6). Compared to the other two basins, the minimum was recorded at the beginning of autumn, which is specific to the rain-snow drainage regime. A separate case is the Mita station, where the minimum was recorded throughout the winter as in the other basins, this station being located to the east, inside the mountain sector, having the highest basin altitude among the stations in this basin.

As in the case of the other two basins, the average flow (MQ) at the stations in the Someș basin registered in the period 1950-2010 stationary or slightly decreasing trends, the biggest differentiations being made at seasonal and monthly level.

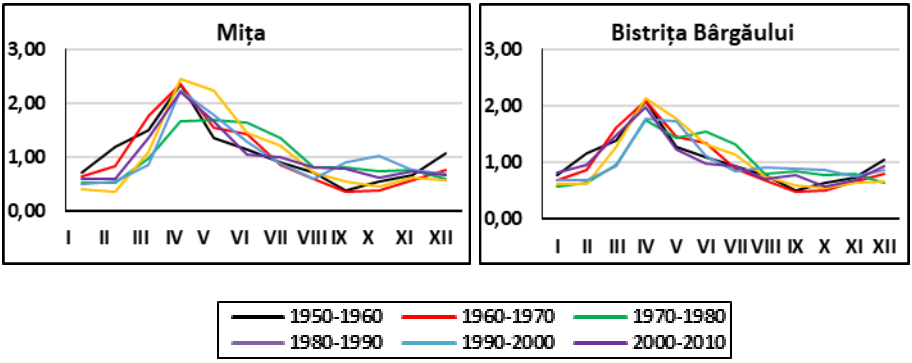

Fig. 6. Modificatios of the Pardé coefficient, describing water flow regimes at the hydrometric stations from Someș River basin

During the period 1950-2010, compared to the other basins, the values of the coefficients remained relatively constant, the differences in the amplitude of the Pardé coefficient values being small, the highest being recorded at the Jelna station, of -0.06. This was due to the decrease in flows in the spring (especially in the peak month) and the summer and increase in the winter.

At the seasonal level, it can be observed (Fig. 7) that the values were relatively constant during the spring, with slightly lower values at the Bistrița Bârgăului station. In summer and autumn, the valuesremained constant, with a slight downward trend in autumn. However, the winter values varied strongly during the analyzed period, exceeding those during the summer at the beginning of the period, due to stronger rainfall and higher winter temperatures than during the autumn west of the Căliman Mountains group.

The values of the Pardé coefficient for spring were relatively constant, being slightly lower (<1.6) at Bistrița Bârgului station. In contrast, winter values strongly exceeded those of autumn, approaching those of summer, even exceeding them at the beginning of the analyzed period, although towards the beginning of the 21st century they began to decrease again (Fig. 7). This was due to the strong influence in this basin of the western oceanic air masses that brought higher temperatures and abundant liquid precipitation during the winter, which caused the snow to melt.

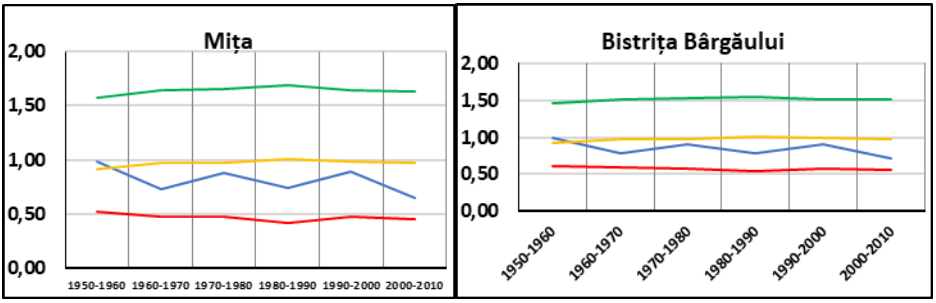

Fig. 7. Modifications of the seasonal Pardé coefficient for 10 years periods at the hydrometric stations from Someș River basin

Water flow regime for the most representative months of each season

For a more detailed and comparative analysis, a monthly analysis is very relevant and eloquent to present comparatively the evolution over the period 1950-2010 at all stations in a basin and between the three basins. For this, we took into account the flows recorded during the two extreme months - January and June. At the end, a comparison was made within the Căliman Mountains between the stations positioned in the four cardinal points Poiana Stampei (N, Siret basin), Bilbor (E, Siret basin), Răstolița (S, Mureș basin) and Bistrița Bârgăului (V, the Someș basin).

January

In January, the month with the lowest values of the Pardé coefficient in winter, values varied greatly depending on the location of each resort in the Căliman Mountains. Thus, in the Siret basin the values increased this month during the analyzed period, with the movement to the northeast (Panaci), these decreasing again at the Bilbor station (Fig. 8). However, these stations recorded the lowest values in January for the entire mountain group (with a minimum of 0.22 at Poiana Stampei station in the 1960s and 1970s), due to low temperatures and low rainfall this month. Only the Panaci station approached in the years 1990-2010 the values registered at the other stations in the Căliman Mountains.

The hydrometric stations in the Mureș basin registered higher values this month, varying between 0.34 (Toplița) in the decade 1980-1990, and 0.73 (Bistra) in the decade 2000-2010. The values increased from east to west, with the increase of western oceanic influences during this month, having a general increasing trend at all stations, with a decrease during the 1980-1990 decade, strongly affected by the decrease of precipitation, both at summer level as well as in winter.

The stations in the Someș basin recorded the highest values of flow rates and Pardé coefficients in the analyzed period, due to the highest exposure to western hot air masses, ranging between 0.4 (Mita) in the period 1980-1990 and 0.83 (Mureșenii Bârgăului) in the period 2000-2010. Some stations registering negative trends, others positive, but being very visible the decreases during the years 1980-1990, followed by increases in the period 2000-2010 (Fig. 8).

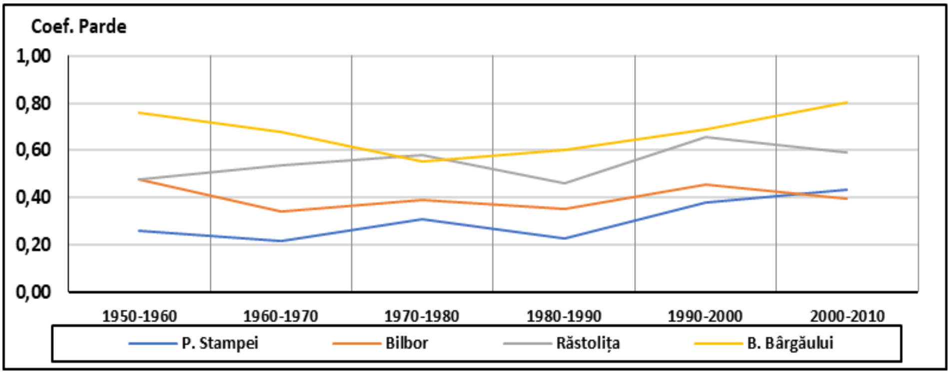

Fig. 8. Modifications of the Pardé coefficient for 10 years periods in January at the representative hydrometric stations from Siret, Mureș and Someș River basins.

A comparative analysis between the stations from the four cardinal points shows an interesting phenomenon, the highest values being recorded in the west at Bistrița Bârgăului station, and the lowest in the north at Poiana Stampei station, the northernmost, strongly affected by polar influences from north.

June

In July, there was a decreasing trend in the entire mountain group, similar to that during the summer, eloquent for the decrease of flows during the summer.

In the Siret basin, the values of the Pardé coefficient varied between 0.93 (Poiana Stampei) in the period 2000-2010 and 1.78 (Gura Negrii) in the period 1970-1980. The maximum amplitude of 0.73 was registered at Poiana Stampei station (Fig. 9), the worst affected by the temperature increases this month since the beginning of the 21st century, relevant for the decrease of summer runoff in the entire Siret river basin, both within the Căliman Mountains grou and in the entire basin on the Romanian territory.

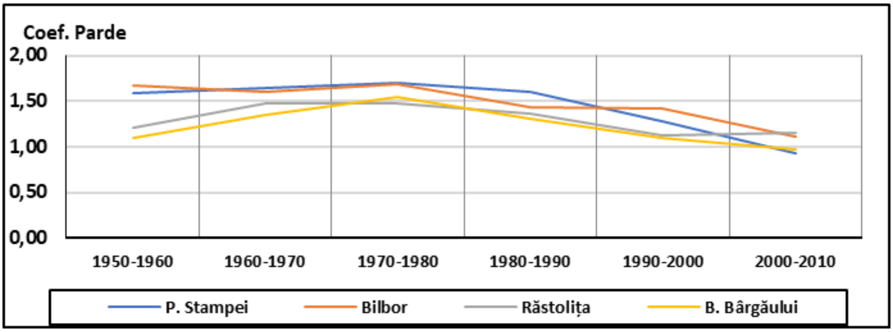

Fig. 9. Modifications of the Pardé coefficient for 10 years periods in June at the representative hydrometric stations from Siret, Mureș and Someș River basins.

The Mureș and Someș basins kept exactly the same trend as in the previous basin, with a maximum during 1970-1980, followed by a continuous decrease of flows and coefficient values, the highest amplitude being registered at Jelna station, with a difference of 0.86, reaching in the period 2000-2010 the minimum of 0.75.

The results show that, despite the environmental and anthropogenic changes, the types of general drainage regime of the rivers in the Căliman Mountains did not change in terms of the dominant supplying mechanism during the analyzed period. However, the characteristics of the regime types have changed over time, with maximum monthly Pardé coefficients and amplitudes decreasing sharply at all stations, more strongly in the north and east, in the Siret basin, while minimums have decreased. Therefore, the changing climate has affected runoff regimes, but has not changed the type of regime. Table 3 provides an overview of the changes identified for the rivers in the Căliman Mountains, with similar trends for certain periods or rivers.

For almost all stations on all rivers, the Pardé coefficients decreased in winter and autumn, and remained stationary or increased slightly in spring and summer, the impact being stronger seasonally and monthly than annually.

At the stations in the Siret basin, the spring maximum occurred in the last decades a month earlier, compared to the middle of the twentieth century, while at the other basins the maximum is maintained in the same month or the maximums are equalized between several months. The smaller snow layer generates lower flows during the summer, because the snow melts earlier due to the increase in temperature, the seasonal variability of the flow decreasing (= decreasing amplitude) (Bormann, 2010). The changes are strongly observed at the level of minimums, the most obvious being at the stations situated at lower altitudes, in the Mureș and Someș basins, where the Pardé coefficients increased, causing a strong decrease of amplitudes. In the Someș basin the winter values at the end of the analyzed period exceeded the autumn values, this becoming the last season as a share of runoff at these stations (Table 3).

Table 3. Modifications to Pardé coefficients in the period 1950-2010 at the hydrometric stations from Căliman Mountains (+ increase; - decrease; - - accentuated decrease; 0 stationary)

River basin	River	Hydrometric station	PC max	PC min	PC amplit	PC winter	PC spring	PC summer	PC autumn
Siret	Dorna	P. Stampei	-	+	--	0	+	-	-
	Dorna	Dornișoara	-	0	-	0	+	0	-
	Neagra	Gura Negrii	--	+	--	0	+	0	-
	Haita	Gura Haitii	+	-	--	-	+	0	0
	Sărișor	Panaci	--	+	--	-	+	0	0
	Tomnatec	Drăgoiasa	-	+	-	-	-	0	0
	Bistricioara	Bilbor	-	-	-	-	+	-	-
Mureș	Toplița	Toplița	-	+	--	-	0	0	-
	Răstolița	Răstolița	--	+	--	0	0	+	-
	Bistra	Bistra	-	+	--	0	0	0	0
Someș	Budacu	Jelna	0	+	-	-	0	+	-
	Bistrița Ard.	Mița	-	+	-	-	0	+	-
	Bistrița Ard.	B. Bârgăului	+	+	0	-	0	0	-
	Straja	M. Bârgăului	+	0	+	-	0	+	-

This is due to decreased rainfall and increased evapotranspiration due to rising temperatures. Trends in weather data show the correlation between changes in precipitation and runoff and the results of recent studies on climate change confirm these hypotheses.

Regarding the average annual flow (MQ), all the rivers in the Căliman Mountains show general stationary trends, with small differences, imperceptible. These differences manifested themselves at the decadal level, the years 1980-1990 disrupting a generalized upward trend, more visible in the Siret basin, in the other basins the flows in the '00s being lower than those in the' 90s. This corresponds to the sharp increase in annual rainfall between 1961 and 1990 reported by Schönwiese (1999).

The changes in the drainage regime of these small rivers can be attributed to climate change, because the only reservoir in the Căliman Mountains (Colibita reservoir) has so far changed only slightly the drainage regime of the Bistrița Ardelenească River. The data for this station are reconstituted, which are similar and in accordance with those from the other stations in the Someș basin. Also, the reduced use of mountain land for agricultural crops has very little influence on regime changes.

CONCLUSIONS

This study showed that climate change had a significant impact on the hydrological behavior of river basins and the average seasonal variability of river water flows in the analyzed mountain group. The average flow as well as the flow of river water in the Căliman Mountains were strongly changed during the period 1950-2010, as global warming accelerated from the middle of the twentieth century to the middle of the twentieth century. The variation of Pardé flows and coefficients is highly correlated with changes observed in European climates (Bormann, 2010). Therefore, it can be seen that much of the change in water runoff can be explained by climate change. These identified changes depend on the type of drainage regime. They partially induce an increase or decrease in seasonal variability.

In line with recent climatic trends in the Căliman Mountains, spring Pardé coefficients of decline are slightly decreasing, while winter Pardé coefficients increase (consistent with an increase in precipitation, generating more runoff). Also, a decreasing trend of autumn runoff can be observed, thus becoming the main minimum at the stations in the Someș basin towards the end of the analyzed period, compared to the beginning of the period when the season with the lowest runoff was winter.

The results of this study indicate that the hydrological regimes of the rivers in the Căliman Mountains have begun to change in recent decades due to climate change. Future climate change will further change hydrological regimes (IPCC, 2007). Hydrological modeling is needed to simulate runoff trends in order to be prepared for future possible changes in climate change-related regimes, as well as for better integration into hydrological simulations produced at European level.

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