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TEMPORAL TRENDS OF HYDROCLIMATIC VARIABILITY IN THE LOWER BUZĂU CATCHMENT

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Abstract.
This paper examines the temporal trends of climatic water balance value and streamflow rate variability in the lower catchment of the Buzău River, as well as the statistical relationship between the two variables over the past five decades. The analysis is based on a series of climatic data provided by the Buzău and Brăila weather stations, and on hydrological data on the average streamflow rates of the Buzău River, between 1960 and 2009. Thus, the first phase aimed to quantify detailed annual, seasonal and monthly climatic and hydrological trends, using the non-parametric Mann-Kendall test. In the second phase, in order to describe the relationship between the independent variable (climatic factor) and the dependent one (average streamflow), statistical correlations between the two sets of data were analysed on the three temporal scales, and the statistical significance of the *r* correlation coefficient was identified with the Bravais-Pearson test. The results showed that, in terms of climate, the trends point to interannual and seasonal humidity deficit rises, except for the fall season, which generally shows a deficit decrease, due to higher average precipitation values. The situation is similar in the case of hydrological trends, characterized by interannual and seasonal streamflow values decreases, except for the fall season again, as a consequence of climatic trends. The correlations between the two variables proved the statistical relationship between the climatic and hydrological variabilities, with lower seasonal (winter) *r* correlation coefficient values, due to the solid precipitation that does not directly supply the Buzău River.

Keywords: Buzău catchment, climatic water balance, streamflow, variability, trend analysis.

1. INTRODUCTION

As water availability at global and regional scales is currently of paramount importance both socio-economically and environmentally (maintaining optimal functionality of ecosystems and geophysical processes), the analysis of their variability in specialized studies is of great scientific and pragmatic utility. In recent decades, against the background of global climate change, especially after the 1970's (Wijkman and Rockstrom, 2013), there were important changes in streamflow variability in many parts of the globe. Although the most important form of climate change corresponds to a global warming trend, which is also highlighted by means of statistical tests (such as the Mann-Kendall test) (Haidu, 2006), streamflow rate changes were mostly influenced by changes in rainfall quantities.

These changes are mainly related to the streamflow decrease recorded as a consequence of reduced precipitation values in numerous regions (Gou et al., 2007; Ma et al., 2010; He et al., 2013), as well as to streamflow intensification in areas in which the average amount of rainfall has risen over recent decades (Groisman et al., 2001; Pasquini and Depetris, 2007). Overall, on a global scale, descending precipitation values (and to some extent human activities) - related streamflow trends outweigh ascending ones (Dai et al., 2009).

At the same time, global warming has caused disruptions of hydrological cycles - a relevant example is found in the massive early spring streamflows resulting from accelerating snowmelt occurring in higher areas which supply rivers (Cayan et al., 2001; Mote, 2003; Regonda et al., 2005; Stewart et al., 2005; Bîrsan et al., 2013). Regarding the

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future streamflow evolution, according to climate models, it is estimated that, by 2050, 10-30% decreases in streamflow values will be recorded in many global regions (mid-latitude western North America, southern Europe, southern Africa, the Middle East), but also 10-40% increases in regions such as southern South America, eastern equatorial Africa and in high latitude regions of North America and Eurasia (Milly et al., 2005).

In Romania, following recent research covering 44 river catchments, it was found that streamflow trends over the past 50 years generally have downward evolutions during the spring and summer seasons, and upward ones during the autumn and winter seasons, which is mainly due to the countrywide climate change (Bîrsan et al., 2013).

The present study aims to quantify climate (climatic water balance) and streamflow (average volumetric flow rates) trends in the lower catchment of the Buzău River, as well as to analyse the statistical relationship between the studied climatic parameter's variability and streamflow fluctuations of the Buzău River.

2. STUDY AREA

The study area corresponds to the plain sector of the Buzău River catchment, located in the north-east of the Romanian Plain, from the limit of the Curvature Subcarpathians to the confluence of the Buzău and Siret rivers (Fig. 1). Landform altitude decreases from west to east, from over 250 m in the Râmnic piedmont Plain to about 6 m in the Lower Siret Plain (subsidence plain).

The Buzău River, with a total length of 308 km and a catchment area of 5505 km² (Diaconu, 2005), is the last of the major tributaries of the Siret River. In the lower catchment, Buzău covers a distance of 162 km, with a basin area corresponding to the lower sector of 1678 km² (about 30% of the total catchment area).

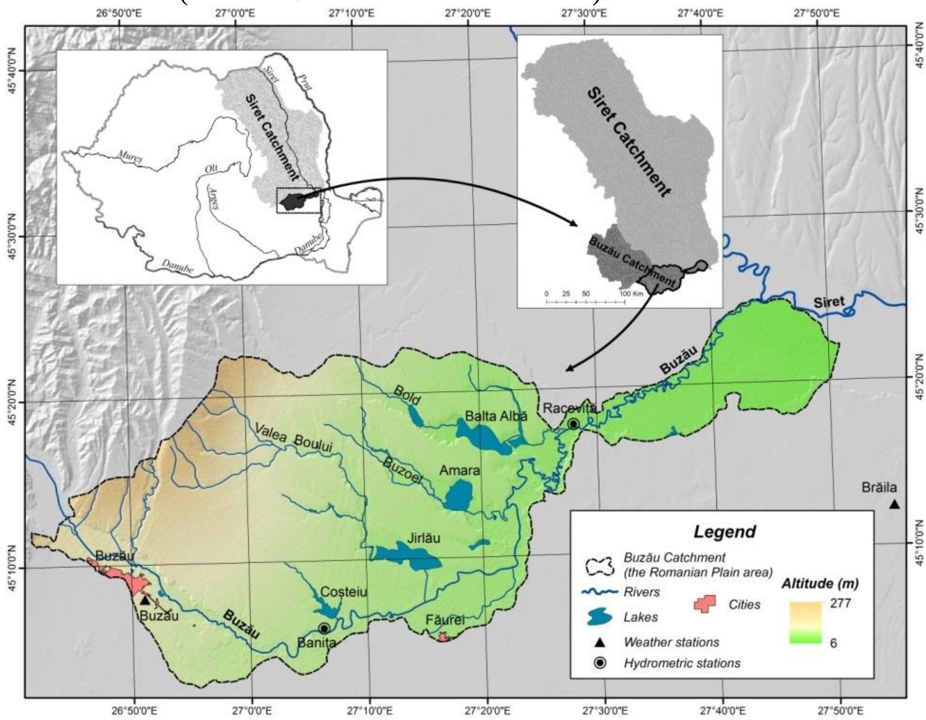


Fig. 1 Location of the study area in Romania

The Buzău catchment comprises all three major landforms, and their corresponding peculiarities are reflected in the main stem's morphohydrological aspects (Posea and Ielenicz, 1971). There is a close connection between the slope and the minor riverbed's morphometric characteristics, in that, in areas with mild slopes, the riverbed's average width increases, while the depth decreases (Gâștescu et al., 1979).

In terms of climate, the study area features high annual thermal amplitudes and an uneven distribution of rainfall both temporally and spatially. Average multiannual temperatures recorded between 1960 and 2009 at the Buzău and Brăila weather stations fall around 11°C. Average multiannual rainfall values range from 450 mm at Brăila to 520 mm at Buzău, and the annual potential evapotranspiration is around 700 mm. This leads to a negative water balance, ranging on average from -180 mm to -240 mm annually, with higher deficit values during the summer months and in particular at the Brăila weather station. Multiannually, there is an ascending evapotranspiration trend corresponding to rainfall decline, which determines a higher water deficit and implicitly a lower volumetric flow rate. Since the southern and eastern regions of Romania are considered to be increasingly vulnerable to droughts and climate aridity (Croitoru and Toma, 2010; Prăvălie, 2013; Prăvălie et al., 2014), a future amplification of the climatic water deficit is very possible, with increasingly adverse consequences on streamflow values.

Regarding the hydrological component, Buzău River's annual streamflow is characterized by a highly prominent spring peak, when heavy rains coincide with mountainous snowmelt. The autumn minimum values are determined by the low rainfall rate typical for this time of the year. It should be noted that the lower winter volumetric flow rate is influenced by freezing phenomena occurring on Buzău River's inferior course, with an average of about 70 days per year (Miță, 1986). Average multiannual streamflow values are of 28.2 m^3/s at the Banița gauging station and of 27.5 m^3/s at Racovița, which shows an upstream to downstream water volume loss. This phenomenon is more obvious during the summer season, when river water is lost through evaporation and infiltration into the permeable substrate or when it is used for crop irrigation (Chendeș, 2011).

3. DATA AND METHODS

The present study is based on the analysis of two data sets, namely climate data and hydrological data. The climate data (1960-2009 period) was provided by the Buzău and Brăila weather stations, which are considered to be representative for analyzing climatic peculiarities of the Buzău catchment plain sector. The analyzed climatic parameters are precipitation (P) (mm) and mean temperatures (°C), recorded at the two stations and, while for the Buzău station the data was provided by ECA&D (European Climate Assesment and Dataset) (Klein Tank et al., 2002), the Brăila weather station data were processed after the work of Vişinescu et al. (2003) (1960-2002), and supplemented with data collected from the National Meteorological Administration (2003-2009) (NMA, 2011).

The temperature data were processed to obtain potential evapotranspiration values (PET) (mm) using Thornthwaite's methodology (Thornthwaite, 1948), considered to be particularly advantageous due to the fact that it requires minimum data input and provides satisfactory results (Carrega, 1994). It is based on the formula (Clima României, 2008): $PET = 16 * \left(\frac{10t}{I}\right)^a F(\lambda)$, where: t – average monthly temperature (°C); I – annual thermal index calculated by means of the formula $I = \sum_{n=1}^{12} \mathrm{i_n}$, $\mathrm{i_n} = \left(\frac{\mathrm{t}}{5}\right)^{1.514}$; $a = 6{,}75 * 10^{-7} * I^3 - 7{,}71 * 10^{-5} * I^2 + 1{,}79 * 10^{-2} * I + 0{,}49$; F (λ) – adjustment factor depending on the latitude and the month of the year. Evapotranspiration data were needed to compute the climatic water balance (represented by excess or deficit), which resulted from the subtraction between precipitation and potential evapotranspiration (P-PET).

The hydrological data (1960-2009 period) covered average flow rates (m^3/s) recorded at the Banița and Racovița gauging stations (located on the Buzău River); the data was provided by the Buzău-Ialomița Water Administration (BIWA, 2013).

Both climate and hydrological data were first analyzed in terms of trends (the trend being defined as a slow, gradual change of the statistical properties of the data series throughout the analyzed period) (Haidu and Magyari-Saska, 2009), on three temporal scales: annual, seasonal (spring, summer, autumn and winter) and monthly. In order to assess temporal trend types (positive or negative) and their statistical significance, the nonparametric Mann-Kendall test was used (Salmi et al., 2002), representative for temporal trend analyses of hydroclimatic parameters. Finally, after having analyzed the temporal trends, a quantification of the statistical relationship between the two environmental variables was attempted by computing the determination (R^2) and the correlation (r) coefficients between the Buzău/Banița and Brăila/Racovița weather/gauging stations (depending on the distances between them) on the three temporal scales.

In order to find statistical correlations between climate and hydrological data, the first step was to check the normal (Gaussian) distribution of the data series (assessed by using the skewness and kurtosis statistical parameters), and, when the data series didn't have normal distributions, normalization statistical techniques were used. In order to assess the statistical significance of the r correlation coefficient, the present study applied the Bravais-Pearson statistical test (Minvielle and Souiah, 2003). In fact, by analysing the R^2 and r coefficients, the extent to which climate variables influenced the Buzău River streamflow variability was determined, as well as the intensity of the connection between the two variables over the past five decades.

4. RESULTS AND DISCUSSIONS

In terms of climate, the annual rainfall rates recorded during the 1960-2009 period at the Buzău and Brăila weather stations had descending trends, while annual potential evapotranspiration sums (computed with the Thornthwaite method based on air temperature values) showed ascending trends (Fig. 2).

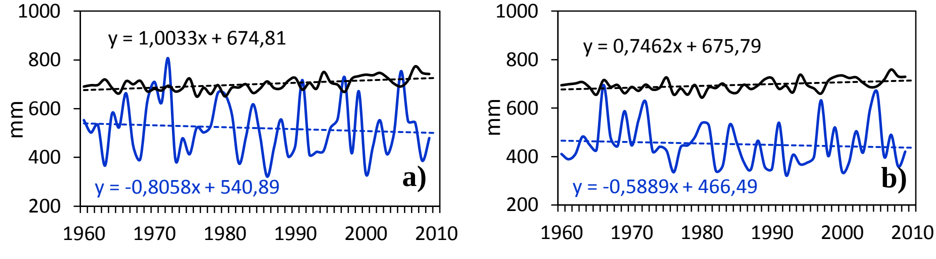
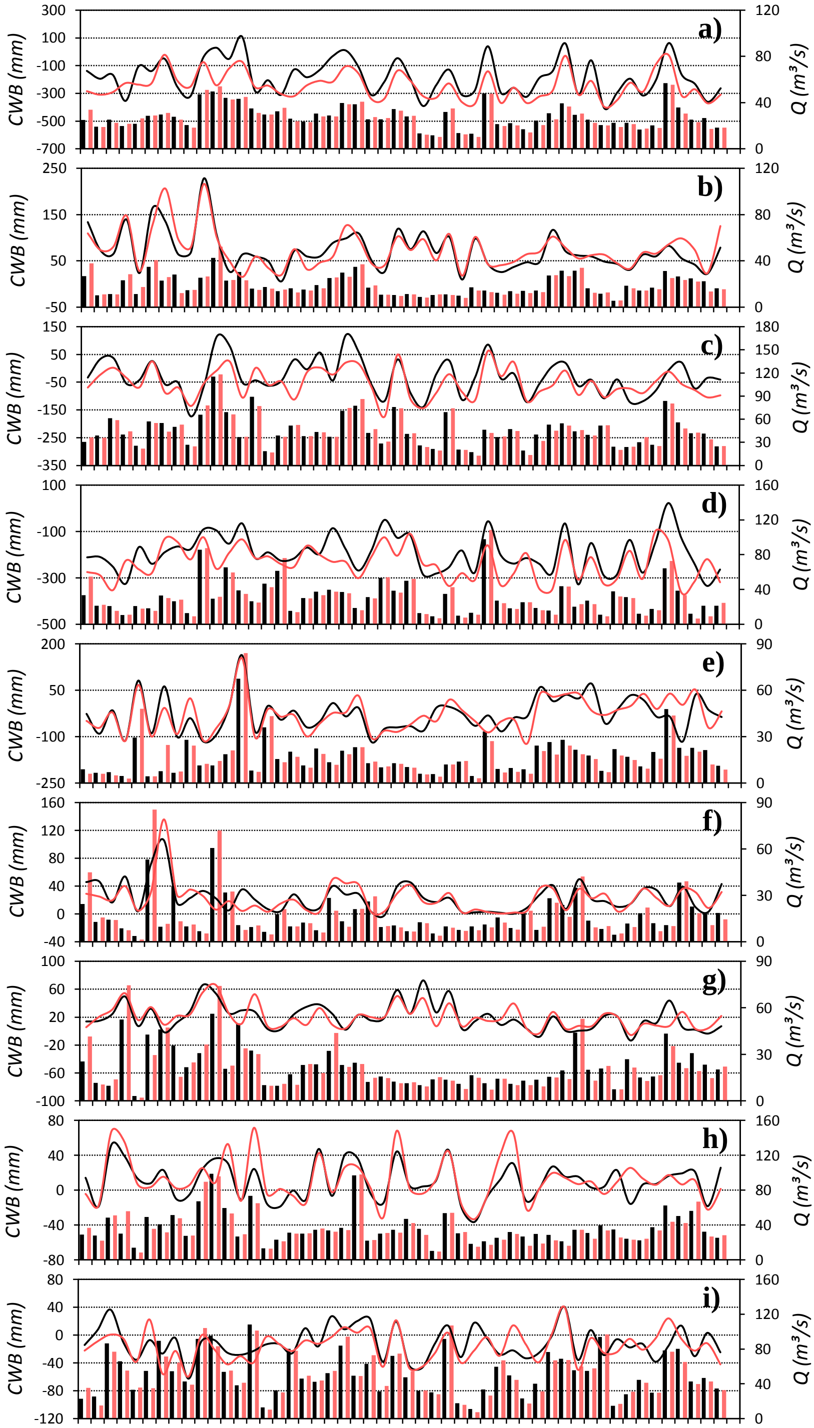


Fig. 2 Annual potential evapotranspiration sum (black line) and rainfall rate (blue line) variability, and corresponding trends at the Buzău (a) and Brăila (b) weather stations

Therefore, the water deficit escalated and caused an increasingly lower climatic water balance, directly influencing the Buzău River streamflow conditions. The graphs rendering climatic water balance and mean flow rate variations on the three temporal scales highlight the influence of the humidity surplus or deficit on the river's annual (Fig. 3a), seasonal (Fig. 3b - e) and monthly (Fig. 3f - q) volumetric flow rate.


a)
CWB (mm)
300
100
-100
-300
-500
-700
Q (m³/s)
120
80
40
0
b)
CWB (mm)
250
150
50
-50
Q (m³/s)
120
80
40
0
c)
CWB (mm)
150
50
-50
-150
-250
-350
Q (m³/s)
180
150
120
90
60
30
0
d)
CWB (mm)
100
-100
-300
-500
Q (m³/s)
160
120
80
40
0
e)
CWB (mm)
200
50
-100
-250
Q (m³/s)
90
60
30
0
f)
CWB (mm)
160
120
80
40
0
-40
Q (m³/s)
90
60
30
0
g)
CWB (mm)
100
60
20
-20
-60
-100
Q (m³/s)
90
60
30
0
h)
CWB (mm)
80
40
0
-40
-80
Q (m³/s)
160
120
80
40
0
i)
CWB (mm)
80
40
0
-40
-80
-120
Q (m³/s)
160
120
80
40
0

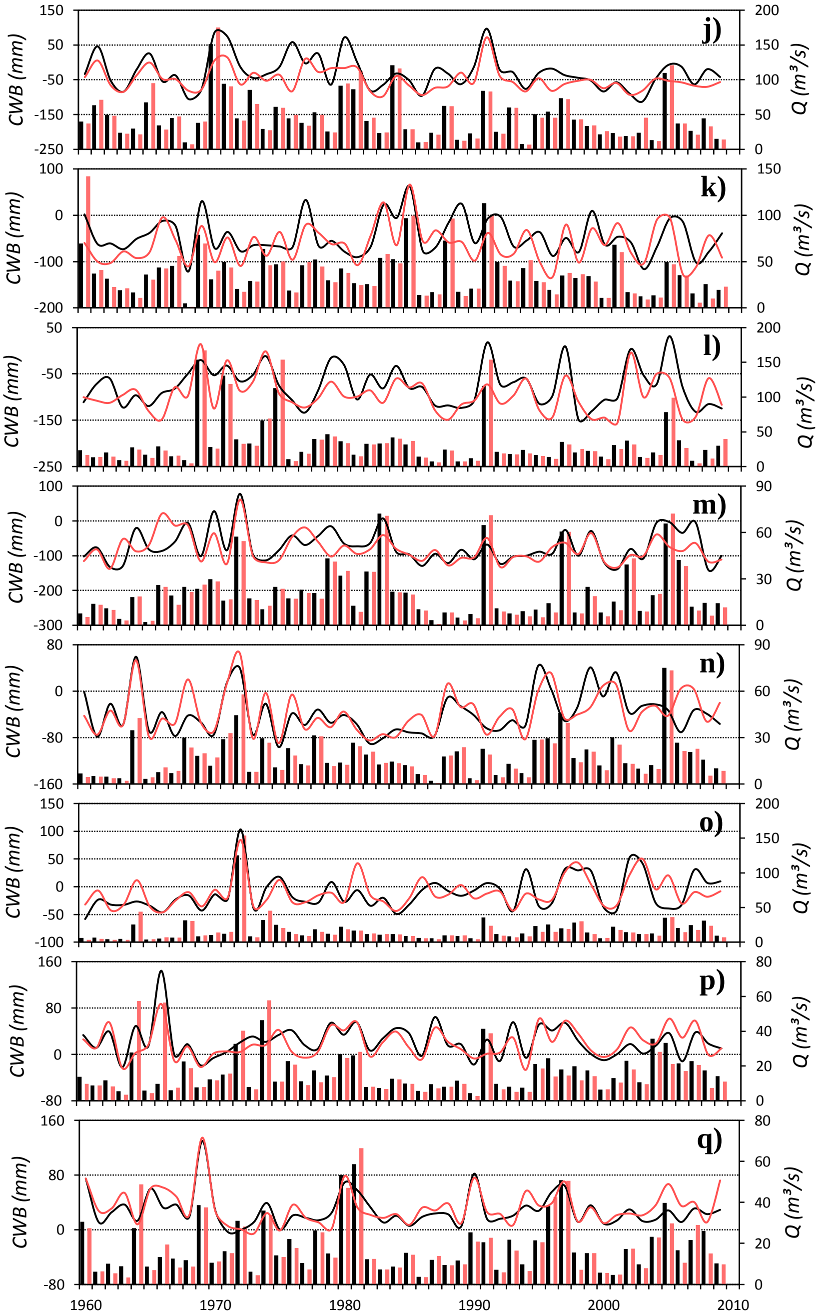


Fig. 3 Climatic water balance (CWB) at the Buzău (black line) and Brăila (red line) weather stations, and average river flow rates (Q) at the Banița (black columns) and Racovița (red columns) gauging stations. Interannual (a), seasonal (b - winter, c - spring, d - summer, e - autumn) and monthly (f - January, g - February, …, q - December) temporal variability between 1960 and 2009

As a result of the subtraction between annual rainfall amounts and annual potential evapotranspiration sums, a humidity surplus resulted only for the values recorded at the

Buzău weather station. Streamflow rates with values exceeding multiannual averages correspond to the years during which a rainfall surplus was recorded (1970, 1972, 1991, 1997, 2005). For instance, in 2005, when rainfall totalled 753 mm at the Buzău weather station, resulting in a positive balance (excess humidity) of 63 mm, the average annual flow rate of the Buzău River reached 56.8 m^3/s at Banița and 55.5 m^3/s at Racovița, with values twice as high as the normal flow rate (28.2 m^3/s at Banița and 27.5 m^3/s at Racovița).

Considering Buzău's average flow rate in 2005, there is a 1.3 m^3/s loss between upstream and downstream values, due to the overflows that occurred in the river's major floodplain during the flash-floods which developed on its inferior course. In 2000, when rainfall totalled 333 mm at the Buzău station and 338 mm at the Brăila station, under conditions of intense evaporation, a negative climatic water balance resulted, expressed by a deficit of about 400 mm which caused a streamflow rate inferior to the multiannual average, with average flow rates of 20.6 m^3/s at Banița and 20.3 m^3/s at Racovița. In this instance, the flow loss recorded on the river's lower sector was caused by strong river surface water evaporation.

In terms of interannual climatic water balance trends, a downward slope can be noticed, statistically significant (according to the Mann-Kendall test) only at the Brăila weather station, with an α significance level of 0.1 (Table 1). Seasonally, the climatic water balance declined during winter, spring and summer. In winter, the notable water balance drop recorded at the Buzău weather station ($\alpha = 0.05$) was mainly due to the month of February, when precipitation rates decreased over the past 50 years. The late winter (February) and summertime water balance diminution occurred at times when water supplies are important for crop germination and development (Croitoru and Toma, 2010).

During autumn, on the contrary, there were significant ascending trends of the water balance, especially in October ($\alpha = 0.05$ at the two weather stations) (Table 1), due to the increasing rainfall rates recorded throughout the month. A monthly analysis evinces spatial differences in water balance variation - at the Buzău weather station, located in the western sector of the study area, humidity declined (insignificantly statistically) in April, June, November and December, while at the Brăila weather station, located in the east, the trends were positive.

With regard to the Buzău River's hydrological variability, the effect of the humidity deficit increase in the area was transposed into a descending trend of average annual volumetric flow rates in the two sections of its lower catchment, Banița and Racovița. The annual streamflow variation therefore generally showed a downward trend, more strongly marked at the Racovița gauging station (at a 0.05 significance level), consistent with the substantial water balance drop recorded at the Brăila weather station. The seasonal trend analysis showed that during winter, spring and summer, Buzău's lower sector flow rate decreased over the past 50 years (Table 1). Streamflow rate downward trends (with statistical significance of 0.05 and 0.1) occurred mainly in May at both gauging stations, consistent with the humidity deficit increase recorded in the lower Buzău basin. The summer flow rate decrease trend can be explained by a countrywide increase of air temperatures and, implicitly, of evaporation (Busuioc et al., 2010; Bîrsan et al., 2013).

Autumn is the only season in which a flow rate increase was recorded, with more apparent trends noted in October (at a $\alpha = 0.05$ significance level at Banița section), when the water balance also had positive trends as a result of a multiannual rainfall rate increase in this month.

Temporal scale		Mann-Kendall test	*CWB*		*STREAMFLOW*	
			BUZĂU	**BRĂILA**	**BANIȚA**	**RACOVIȚA**
ANNUAL		*Sen's slope*	-1,917	-1,563	-0,103	-0,205
		Trend type	down	down	down	down
		Significance	-	+	-	*
SEASONAL	WINTER	*Sen's slope*	-0,754	-0,347	-0,024	-0,081
		Trend type	down	down	down	down
		Significance	*	-	-	-
	SPRING	*Sen's slope*	-0,801	-0,732	-0,212	-0,236
		Trend type	down	down	down	down
		Significance	-	-	-	-
	SUMMER	*Sen's slope*	-0,886	-1,163	-0,105	-0,158
		Trend type	down	down	down	down
		Significance	-	-	-	-
	AUTUMN	*Sen's slope*	1,125	1,303	0,163	0,060
		Trend type	up	up	up	up
		Significance	+	*	+	-
MONTHLY	January	*Sen's slope*	-0,210	-0,088	0,044	-0,013
		Trend type	down	down	up	down
		Significance	-	-	-	-
	February	*Sen's slope*	-0,418	-0,348	-0,072	-0,137
		Trend type	down	down	down	down
		Significance	**	*	-	-
	March	*Sen's slope*	-0,063	-0,075	-0,048	-0,176
		Trend type	down	down	down	down
		Significance	-	-	-	-
	April	*Sen's slope*	-0,104	0,105	-0,185	-0,169
		Trend type	down	up	down	down
		Significance	-	-	-	-
	May	*Sen's slope*	-0,591	-0,583	-0,419	-0,396
		Trend type	down	down	down	down
		Significance	-	+	*	+
	June	*Sen's slope*	-0,159	0,197	-0,254	-0,343
		Trend type	down	up	down	down
		Significance	-	-	-	+
	July	*Sen's slope*	-0,316	-0,310	-0,037	-0,033
		Trend type	down	down	down	down
		Significance	-	-	-	-
	August	*Sen's slope*	-0,272	-0,503	0,028	-0,024
		Trend type	down	down	up	down
		Significance	-	-	-	-
	September	*Sen's slope*	0,352	0,503	0,157	0,077
		Trend type	up	up	up	up
		Significance	-	-	-	-
	October	*Sen's slope*	0,734	0,442	0,184	0,126
		Trend type	up	up	up	up
		Significance	*	*	*	-
	November	*Sen's slope*	-0,082	0,296	0,124	0,023
		Trend type	down	up	up	up
		Significance	-	-	-	-
	December	*Sen's slope*	-0,072	0,089	0,063	0,050
		Trend type	down	up	up	up
		Significance	-	-	-	-

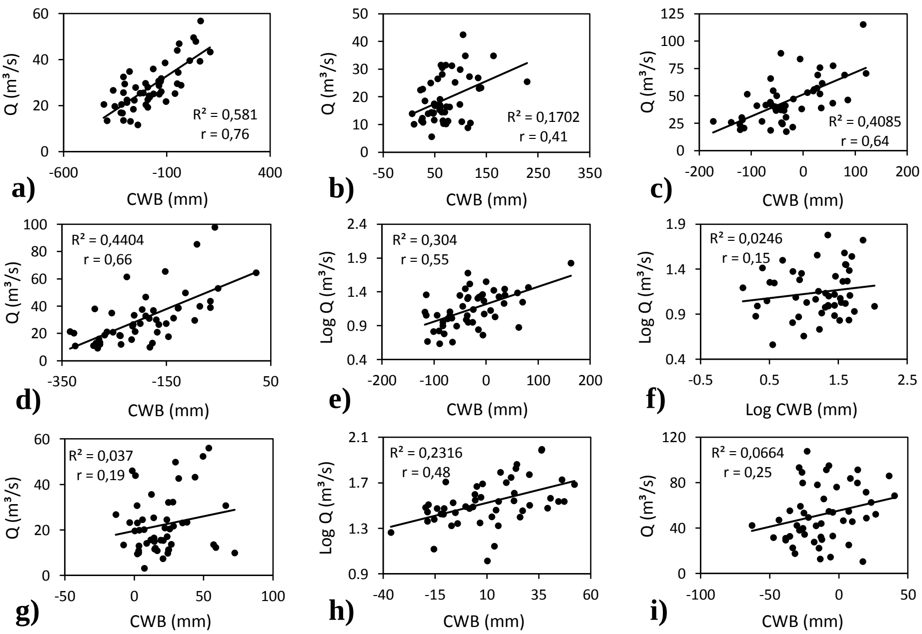
Tab. 1. Climatic water balance (CWB) and mean streamflow rate (at the weather and gauging stations) temporal trend specificities resulting from the Mann-Kendall non-parametric statistical test

Note: "+'', "*'', and "**" indicate significance at a 0.1, 0.05 and 0.01 *α* level, respectively; "-'' indicate statistical insignificance

In January and August, streamflow rate upward trends were recorded at Banița, while downstream, at Racovița, downward trends were found. These opposite developments can be attributed to the volumetric flow losses recorded on Buzău's inferior course; a similar situation can be seen in the plain sector of the Ialomița River (Chendeș, 2011). In January, due to freezing, a part of the volumetric flow is retained upstream by riverbed ice formations. In August, the flow rate loss is due to strong evaporation throughout Buzău's course, against the background of rainfall deficit.

A directly proportional relationship can be established between the climatic water balance and the streamflow rate of the Buzău River (Fig. 4, 5), with generally statistically significant correlations between these two variables (Table 2). However, given the fact that the average flow rate is influenced by both temporally dynamic genetic factors (precipitation, temperature, water supply from the previous year) and quasi-constant factors (catchment morphometric and physical-geographical characteristics) (Haidu et al., 1987), the correlations between the two analyzed variables don't generally indicate coefficients with very high values, close to 1.

The strongest statistical connection (with a 0.76 *r* correlation coefficient) was established interannually between the climatic water balance computed for the Buzău weather station and the streamflow rate recorded at the Banița gauging station (Fig. 4). Significant annual downward trends of the water balance and flow rate, recorded at the Brăila weather station and at the Racovița gauging station, allowed the identification of a statistically valid correlation, with a 0.68 *r* coefficient value (Fig. 5).



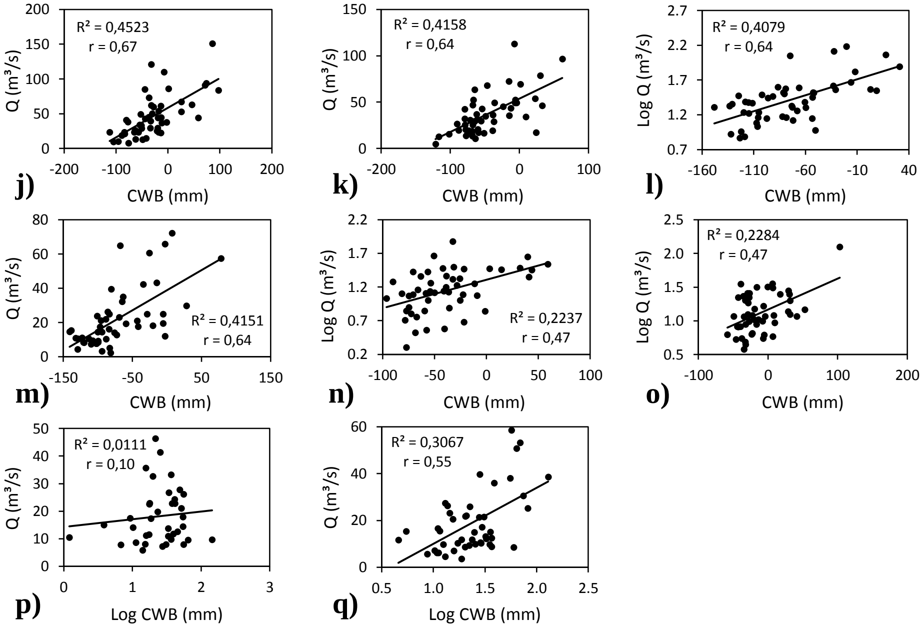
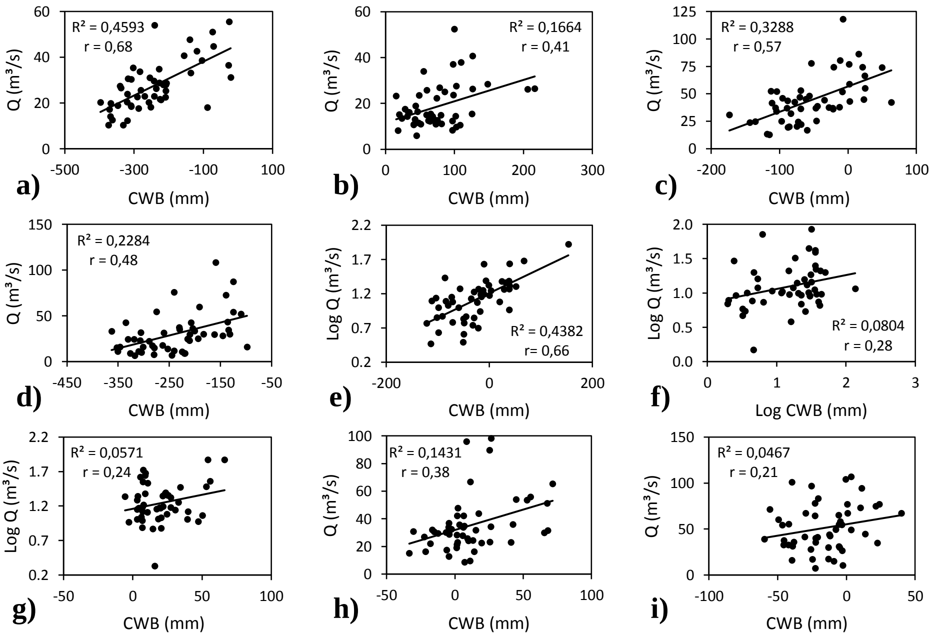


Fig. 4 Statistical correlations (1960 – 2009 period) between the climatic water balance (CWB) (Buzău weather station) and the average streamflow rates of the Buzău River (Banița gauging station) at annual (a), seasonal (b - winter, c - spring, d - summer, e - autumn) and monthly (f – January, g - February..., q - December) scale



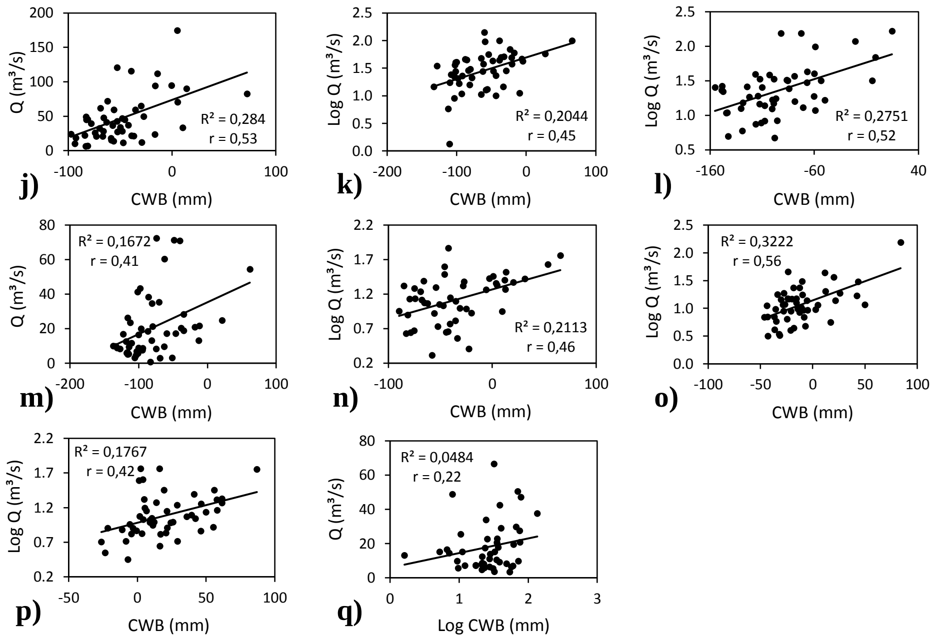


Fig. 5 Statistical correlations (1960 – 2009 period) between the climatic water balance (CWB) (Brăila weather station) and the average streamflow rates of the Buzău River (Racovița gauging station) at annual (a), seasonal (b - winter, c - spring, d - summer, e - autumn) and monthly (f – January, g - February..., q - December) scale

Temporal analysis scales		Buzău/Banița data couple		Brăila/Racovița data couple	
		Correlation coefficient *r*	Statistical significance	Correlation coefficient *r*	Statistical significance
	Annual	0,76	***	0,68	***
Seasonal	Winter	0,41	***	0,41	***
	Spring	0,64	***	0,57	***
	Summer	0,66	***	0,48	***
	Autumn	0,55	***	0,66	***
Monthly	January	0,15	-	0,28	**
	February	0,19	-	0,24	*
	March	0,48	***	0,38	***
	April	0,25	*	0,21	-
	May	0,67	***	0,53	***
	June	0,64	***	0,45	***
	July	0,64	***	0,52	***
	August	0,64	***	0,41	***
	September	0,47	***	0,46	***
	October	0,47	***	0,56	***
	November	0,10	-	0,42	***
	December	0,55	***	0,22	-

Tab. 2. *r* correlation coefficient values and statistical significance level of correlations between the climatic water balance (CWB) (Buzău and Brăila weather stations) and average flow rate of the Buzău River (Banița and Racovița gauging stations)

Note: "*'', "**'', and "***" indicate significance at a 0.1, 0.05 and 0.02 α level, respectively; "-'' indicate statistical insignificance (Bravais-Pearson statistical test)

In terms of seasons, the closest correlations (r = 0.66) resulted for the upstream section summer values (between the climatic water balance computed at the Buzău weather station and the average streamflow rates recorded at the Banița gauging station) and for the downstream section autumn values (Brăila/Racovița). While the winter season also had statistically significant correlations (r = 0.41 in both cases), they were weaker due to predominantly solid precipitation which does not supply the Buzău River directly.

Considering each month separately, the strongest correlations were found for May and summer months for the upstream section (r > 0.60) and for May, July and October for the downstream section (r > 0.50). For the winter months, there is a lag between the time of precipitation occurrence and the hydrological response (streamflow rate) of the Buzău River. Particularly low, statistically insignificant, monthly correlations therefore resulted (Table 2) between the climatic water balance (in which potential evapotranspiration becomes negligible due to low temperatures) and the river's streamflow rate, which is affected by frost. However, there are times when the Foehn, which appears in the Carpathian curvature region, causes sudden air temperature rises and snowmelt, generating a streamflow rate increase in the form of flash-flood occurrence (Beltrando and Zaharia, 2009).

5. CONCLUSIONS

Climate change over the past five decades (1960-2009), causing rainfall quantitative diminution and air temperature rises (thus leading to potential evapotranspiration acceleration), resulted in the reduction of the water balance. On the three analysis scales, the following trends in hydroclimatic variability in the lower catchment of the Buzău River were identified:

- annually, a climatic water balance - and implicitly a flow rate reduction - downward trend was found;
- seasonally, humidity recorded, on the one hand, decreases during winter, spring and summer and, on the other hand, increases during autumn which led to positive seasonal flow rate trends;
- monthly, notable decreases in climate water balance values were found in February, and significant rises in October. Regarding the flow rate, significant downward trends resulted in May for both sections of the river, and in June for the Racoviţa section; ascending trends (statistically significant) were recorded in October in the Banița section.

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