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CONSIDERATIONS REGARDING THE IMPACT OF THE GLOBAL CLIMATIC CHANGES ON THE MEAN DISCHARGES IN THE UPPER BASIN OF BÂRLAD RIVER

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Key words: climatic changes, discharge, trend analysis, polynomial trend, Mann-Kendall test, Sen's slope

Abstract. Assessing the potential impact of climate changes on a hydrologic time serie is based on identifying the trend of the annual mean discharges. Time series of annual mean liquid discharges from all the hydrometric posts situated in the upper basin of Bârlad river are studied: Băceşti and Negreşti on Bârlad (1950 – 2007), Ţibana and Tungujei on Şacovăţ (1987 – 2007), Frenciugi and Căzăneşti on Stavnic (1950 – 2007). Parametric (linear, second degree polynomial and exponential equations) and non-parametric methods (Mann-Kendall test and Sen's slope) are applied in order to detect a trend in data. The parametric testing shows that the polynomial model is the most apropiate, which means that during the interannual evolution of discharges a natural fluctuation seems to be more probable that an effect of the climate warming. The results of the non-parametric tests do not show a trend in data. We can conclude that in the studied area there is no clear impact of the climate change upon the annual mean liquid discharges.

Introduction

The response of the hydrologic variables to global climatic changes has been the subject of many studies during the last decades.

The theory of climate change has its supporters and skeptics. In numerous studies it is considered that the global warming is accepted in unanimity by the scientific community (Busuioc Aristiţa et al., 2007; Falloon & Betts, 2009), generally invoking the most recent Intergovernmental Panel on Climate Change report (IPCC, 2007). According to this report, the global climate changes resulted from the increasing of the human-induced greenhouse gases in the atmosphere are a certainty. The report states that in 1906–2005 period the global mean surface temperature has arisen by 0.74°C ± 0.18°C estimated by linear trend.

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On the other hand, the IPCC report has been largely criticized, considering that the climate models used are incorrect, that the report is part of a political agenda, that the role accorded to carbon dioxide is overestimated in the detriment of water vapors etc. (U.S. Senate Minority Report, 2009). There are opinions that very probably the whole geosystem is crossing a multimilenium thermical positive fluctuation (Chaline, 1985, cited in Ungureanu Irina, 2005), that these so-called global climatic changes are just weather changes (Teodoreanu Elena, 2007) and the proper expression for them would be meteorological variations (Rusu, 2007).

Even if we can hardly consider that there is a consensus in the theory of the climate change and its effects, it is a fact that the discharges regime will be one of the most affected environmental parameters.

The trend analysis of a hydrologic time series has been intensively used to assess the potential impacts of climatic changes upon the discharges regime. In some of these studies it is admitted that there is not sufficient information to consider that the trends observed in the discharges regime are caused exclusively by the climatic parameters and that the impact of the climatic changes over the environment is not uniformly distributed in space (Burn & Elnur, 2002). It is also considered the possibility that the changes in a hydrologic time series could mostly be an effect of the natural variability (Kahya & Kalayci, 2004).

In this article, to analyze the impact of the so-called global climatic changes on the annual mean liquid discharges in the upper basin of Bârlad river, the time series of hydrologic data from all the hydrometric posts in the area are analyzed.

In order to increase the confidence degree in the potential trend, two types of statistical methods, parametric and non-parametric, are applied. Generally, parametric trend testing is considered to be more powerful than non-parametric one (Chen et al., 2007). Non-parametric tests are an alternative to the parametric tests, because if the parametric ones require a normal distribution of data, the others are less sensitive to outliers (extreme values in the data) and do not assume that data follow a specific distribution. The parametric tests used in this study are the linear, second degree polynomial and exponential models calculated through the least squared method with Excel program. The non-parametric tests are Mann-Kendall and Sen's slope. Both non-parametric tests are widely used in detecting trend in a hydrologic time series (Kahya & Kalayci, 2004; Khaliq et al., 2009). The non-parametric testing was made with the Minitab software.

1. Data

The upper basin of Bârlad river belongs to the Central Moldavian Plateau physico-geographical subunit, part of the Moldavian Plateau. The study area has a temperate-continental climate with excessive influences. Bârlad River, left side

affluent of Siret, is monitored by the Prut Water Direction (subdivision of the „Romanian Waters" National Administration).

The hydrologic data are collected from all the six hydrometric posts situated on Bârlad and two of its tributaries: Şacovăţ and Stavnic. The hydrometric posts are: Băceşti and Negreşti on Bârlad, Ţibana and Tungujei on Şacovăţ, Frenciugi and Căzăneşti on Stavnic. The data record started in 1950 at the hydrometric posts situated on Bârlad and Stavnic, and only from 1987 on Şacovăţ. Because the time series of data has 58 terms for Bârlad and Stavnic and only 21 terms for Şacovăţ, the discharges analyze is based particularly on the data recorded on Bârlad and Stavnic.

Tab. 1 - Characteristics of the annual mean discharge (m3/s) in the upper basin of Bârlad

	Bârlad		Şacovăţ		Stavnic	
	Băceşti	Negreşti	Ţibana	Tungujei	Frenciugi	Căzăneşti
Discharge	0.34	1.52	0.34	0.47	0.37	0.41
Standard deviation	0.24	1.15	0.26	0.38	0.26	0.31

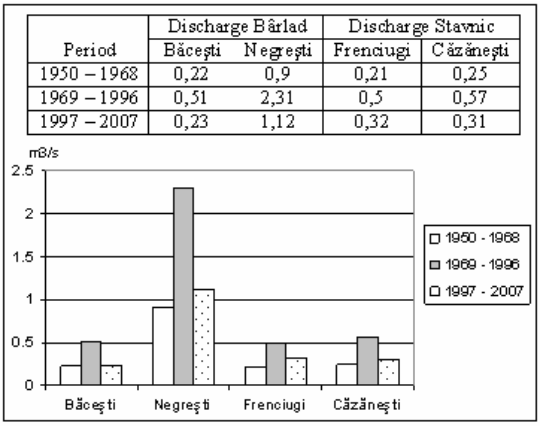

Fig. 1 - Characteristics of the mean annual discharges (m^3/s) of Bârlad and Stavnic

Bârlad, the main river of the basin, has an annual mean liquid discharge of about 0.34 m^3/s at Băceşti and 1.52 m^3/s at Negreşti (Table 1). The affluents have comparable values of the mean discharges, 0.34 m^3/s at Ţibana and 0.47 m^3/s at

Tungujei on Şacovăţ, 0.37 m^3/s at Frenciugi and 0.41 m^3/s at Căzăneşti on Stavnic. The increasing of Bârlad discharge, as for any other river, from upstream to downstream, is a natural consequence of the watershed surface increasing, reflected in the affluents discharge contributions. As it can be seen in table, the standard deviations values are comparable with discharge values, which means that the discharges varies in a quite large interval, expression of the continental climate.

The analysis of the annual mean discharges evolution in 1969 – 1991 period shows a general increasing tendency. This tendency is more obvious in the case of Bârlad hydrometric posts. In case of Stavnic, the increasing period is extended until 1996. The results for Şacovăţ are insignificant because the time series is too short. If we analyze the discharges on 3 subperiods it can be observed that there are significant differences between the mean values of these subperiods. The mean values from 1969 – 1996 are twice bigger than those from the precedent (1950 – 1968) and following periods (1997 – 2007) (Figure 1).

Another common characteristic, suggested in figure 1, is increasing of the discharge amplitude in the central part of the analyzed period, namely 1969 – 1991. Similarly to the mean annual discharge, in case of Stavnic this feature is extended until 1996. We consider that this variability of the annual discharges is firstly caused by the variability of the climatic elements regime, specific for the continental climate.

The highest values of the mean annual discharges are almost three times above the multiannual means, and the smallest are eleven times below them. This emphasizes that, regarding the hydro-climatic extreme phenomena, in the upper Bârlad basin the droughts are more frequent than the floods, both being more and more often during the last three decades.

3. Trend analysis

3.1. Parametric tests. In the parametric testing, for all the six time series, few adjusting functions are applied: linear, second degree polynomial (quadratic) and exponential. The linear model is the most commonly used for trend detecting in a time series. The polynomial model is used to emphasize a nonlinear trend, a long time periodical or unperiodical fluctuation. The exponential model is used rather to add one more comparison term.

The square correlation coefficient (R^2) value obtained in the quadratic trend model is the highest comparing with the correlation coefficients from the other applied models (Table 2). This means that the quadratic model is the most appropriate, even if the correlation indicated by R^2 is weak. This fact is valuable for all the hydrometric posts, except Tungujei. But, as we mentioned above, the results obtained for Şacovăţ are irrelevant, because these time series are too short, and their interpretation would be inconclusive. Thus, we can consider that in the

study area the discharges evolution is emphasized by adjusting the time series with the quadratic function.

Tab. 2 - R^2 values for linear, exponential and polynomial trend models

Water course	Hydrometric posts	R^2		
		linear	quadratic	exponential
Bârlad	Băceşti	0.002	0.2733	0.0156
	Negreşti	0.0092	0.2737	0.019
Şacovăţ	Ţibana	0.0034	0.0628	0.0039
	Tungujei	0.0734	0.0191	0.038
Stavnic	Frenciugi	0.0328	0.2377	0.0537
	Căzăneşti	0.007	0.2303	0.0015

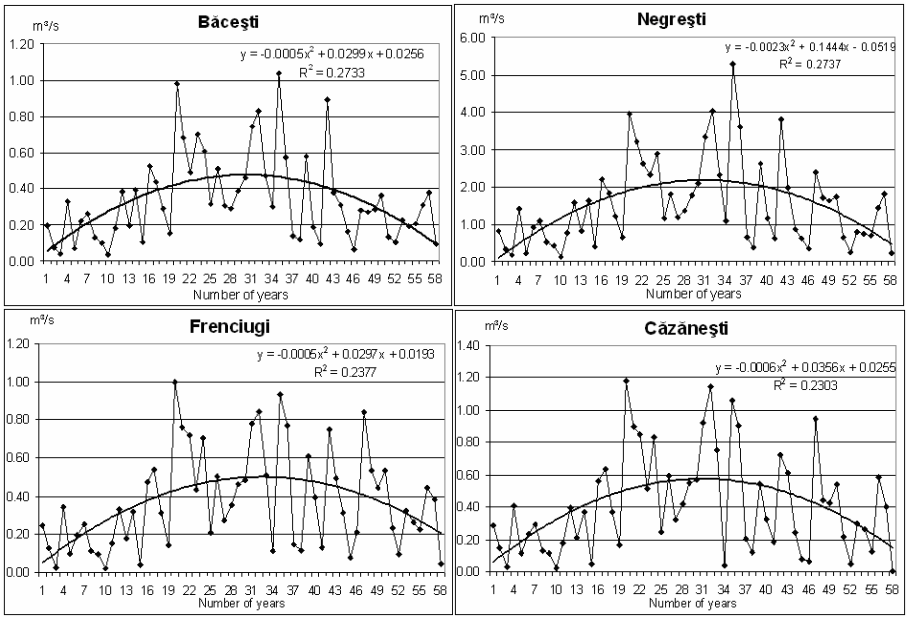

Fig. 2 - Annual mean discharge regime at the hydrometric posts Băceşti and Negreşti on Bârlad, Frenciugi and Căzăneşti on Stavnic (1950 – 2007)

The graphical representations of the polynomial trend (Figure 2) suggests the presence of a micro-cycle, the first part of the time series representing the ascendant branch and the second part the descendent branch. This potential micro-cycle is also sustained by the mean values of the subperiods previously presented in figure 1. Even if at the beginning and at the end of the polynomial curve the values are close, because the mean values of the last 10 years are slightly higher comparing with the first 18 years we can consider that this micro-cycle is not over yet or it is just a part of a larger natural fluctuation.

If we consider only the last two decades, we can say that a decreasing trend is revealed, and we might consider it as a climate change effect. Anyway, it is hard to believe that the mean annual discharge would react so promptly to a supposed climate change. Considering the complex geosystemical interactions, we believe that an effect like this could be observed after a longer period. Also, at the beginning of the data series the discharges values were quite smaller than these from the last few years, and the further increasing of discharge in the middle of the period cannot be explain by the incriminated global climate changes. Otherwise, if we analyze the whole time series, we have a different perspective because of the curved trend which seems to be more close to a natural variation.

The presence of this micro-cycle is supported by the similar behavior of other climatic parameters. The mean annual air temperature at the meteorological station Negreşti has the same micro-cyclic evolution emphasized by second degree polynomial regression (Hobai Roxana, 2009). A comparative analysis shows that there is a reverse correlation between temperature and discharges, discharge decreases as temperature increases. Even if apparently the correlation seems to be a simple one – discharges are decreasing because of precipitation decreasing as a consequence of temperature increasing – in reality this connection is much more complex. According to the model which says that the increasing of temperature leads to a larger number of condensation nucleus in the atmosphere, having the effect of precipitations increasing and thus discharge increasing, the correlation between temperature and discharges would be reverse.

3.2. Non-parametric test Mann-Kendal and Sen's slope. The Mann–Kendall trend test (Mann, 1945; Kendall, 1975) is based on the correlation between the ranks of a time series and their time order. This method has been suggested by the World Meteorological Organization to assess the trend in an environmental time series (Yu et al., 2002) and it is intensively used in hydro-climatic time series analysis. The test is considered to be very suitable for detecting trends in a hydrologic time series mostly because the discharge data series are usually skewed and have outliers, and this test is less sensitive to outliers and it is not affected by the real distribution of data.

The test consists in comparing each value of the time series with the remaining values (Helsel & Hirsch, 1992). The test is based on the statistic *S*, a measure of the monotonic dependence of discharge on time, defined as

$$S = P - M$$

where *P* is the number of"pluses", the number of times when the number of $y_i < y_j$, for all $i < j$ and *M* is the number of"minuses", the number of $y_i > y_j$, for $i < j$.

For all $i = 1, \ldots (n\text{-}1)$ and $j = (i+1), \ldots n$, there are $n(n\text{-}1)/2$ possible comparisons to made among the *n* data pairs.

Test results (Z_S) are assessed based as below:

$$Z_S = \begin{cases} \frac{S-1}{\sigma_S} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sigma_S} & if\ S < 0 \end{cases}$$

where the standard deviation is $\sigma_S = \sqrt{(n/18)(n-1)(2n+5)}$

The goal of the test is rejecting or accepting the null hypothesis (H_0) that there is no trend, against the alternative hypothesis (H_1), that there is an increasing or decreasing trend. H_0 is rejected at the significance level α if $|Z_S| > Z_{crit}$, where Z_{crit} is the value of the standard normal distribution with a probability of exceedance of $\alpha/2$. In this case α level is 0.05, which corresponds to 95 % confidence interval, and the value of Z_{crit} is 1.96.

To verify Mann-Kendall test we used another non-parametric method, namely Sen's slope estimator (Sen, 1968). This method is also less affected by non-normal distribution of data and presence of outliers, and it is suitable to estimate the magnitude of the trend slope (Helsel & Hirsch, 1992). Firstly the slopes for all the pairs of values are computed and then the overall slope is estimating by using the median of these slopes:

$$b_{Sen} = \text{Median}\ [(Y_i - Y_j)/(i - j)]$$

where b_{Sen} is the slope value, Y_i and Y_j are data values at time points *i* and *j*, $j < i$. If the time series has *n* values, the number of possible pairs is $n(n-1)/2$ and b_{Sen} is the median of these $n(n-1)/2$ values.

Practically, both Mann–Kendall and Sen tests are based on the same statistic procedure, which in the first method is used for hypotheses testing and in the second method for the slope estimation.

The results from the application of the non-parametric tests, Z_S and b_{Sen} values, are contained in table 3. In the case of Mann-Kendall test, none of the Z_S values modulus are higher that the critical value. In cased of Sen's method, as it was to be expected, considering the results of previous test, b_{Sen} values are very close to zero. Both results of tests have the significance that there are no sufficient clues to detect a trend in data.

Tab. 3 - Mann-Kendall and Sen's tests summary statistics

Water course	Hydrometric post	Mann-Kendall test		Sen's slope	
		Z_S	Significance	b_{Sen}	Signif.
Bârlad	Băceşti	0.449465	No trend	0.0006667	No trend
	Negreşti	0.831865		0.0064516	
Şacovăţ	Ţibana	-0.28220		-0.0014667	
	Tungujei	-1.23807		-0.017775	
Stavnic	Frenciugi	1.56300		0.0027857	
	Căzăneşti	0.764710		0.0014857	

Of course, this does not mean that it has been certainly established that there is no trend. We can rather consider that these two tests are not conclusively enough to detect a trend in data.

Conclusions

The discharge regime is influenced by many factors (anthropical interventions on the rivers channels, removal of the natural vegetation, inappropriate land practices etc.) but the climatic factors are the most important. The impact of the global climatic changes upon the mean annual liquid discharge can be observed through the trend analyses of their multiannual regime. In order to obtain a more reliable result regarding the existence of a trend, two types of tests are applied: parametric and non-parametric.

From the three regression equations applied, the quadratic one provides the better fit. The polynomial trend indicates that the variations could be an effect of the natural cyclic fluctuations of the climate parameters and the anthropic

interventions are manifesting by impelling the natural fluctuations. The non-parametric Mann-Kendall and Sen's slope methods show that there is no statistically significant trend in data. Thus, in this article it is suggested that there are no evidences for a clear impact of the climate changes upon the mean annual liquid discharges in the upper basin of Bârlad river.

The results are in accordance with other researches which are showing that the global climate changes effects are more perceptible in cases of extreme manifestations and neuniformity of the hydrologic regime, and the mean manifestation are less sensitive (Planton et al., 2008; Mareş et al., 2007). The real values of discharges, the amplitude and their succession in time are more important in this sense, because the mean parameters are leveling the extremes and they are rather general and vague. Even so, some of the studies are showing that there is no ubiquitous increase of flood parameters (magnitude, frequency) in the second half of the 20th century (Petrow & Merz, 2009). The maximum and minimum discharges should be further investigated in order to evidence the potential impact of the climatic changes upon the hydrologic regime in the upper basin of Bârlad river.

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