STUDIA UBB GEOGRAPHIA, LXI, 2, 2016, pp. 63 – 72
(RECOMMENDED CITATION)

VARIABILITY AND TRENDS IN THE VIȘEU RIVER RUNOFF REGIME

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ABSTRACT. – Variability and Trends in the Vișeu River Runoff Regime. The classic hydrological water management dealt with the changing resources by assuming the existence of stationarity. Once stationarity is neglected in the design of hydraulic engineering, numerous errors and risk may exist in the operations and management strategies and will lead to unforeseen losses. Thus, one of the most important questions in today's hydrology are: *Did stationarity die*? and if it is true *How did stationarity die*? As we know the climatic change is widely accepted so it is sad that by 2050 the effects of climate change may have a generally larger effect on flow regimes than it is estimated that dams and water withdrawals. If this is so, we must consideration that in this moment one of the most important aspect/moment is the change point identification in a period, from where significant change has occurred in a time series, for this we choose to use the Ms Excel Addinsoft XLStat to assess the homogeneity of the data by the Pettitt's test, the von Neumann ratio test, the Buishand range test and also the standard normal homogeneity tests (SNHT). For the trend analysis we used the Mann-Kendall test and the classic linear regression test. Based on the results, we conclude that in case of the Vișeu watershed stationarity is questionable if not totally missing. As we see even if the precipitation values do not show significant changes regarding their homogeneity, the runoff series are changing, and in most cases this change is identified in the 20thcentury last decade. These results urge us to rethink and to reevaluate our sustainable water resource management for the future.

Keywords: *Vișeu Catchment, runoff trend, change point detection, statistical tests, Mann-Kendall test*

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INTRODUCTION

Over the last century, a global environmental change which seems to be the result of human activity mainly has become increasingly noticeable (Vitousek et al., 1997; Vorosmarty et al., 2000, IPCC 2014, Zhang et. al., 2016). The change is mainly due to climate change and is primarily characterized by the change in precipitation and temperature and in the magnitude and occurrence of extreme climatic phenomena like droughts and floods. Taking into considerations the significant global hydrological changes, they are characterized by reductions in water resources and significant increasing of extreme hydrological events.

In various areas due to the climate change and also due to human activities, which changed the land use/cover and implemented large-scale water management projects, the extremes are intensifying. In general, the man-made changes resulted in numerous complications, such as water shortages, floods, and droughts (Vorosmarty et al., 2010).

The classic hydrological water management dealt with the changing resources by assuming the existence of stationarity. As we know stationarity represents the notion that all natural systems fluctuate within an unchanging limit, is a fundamental assumption of designs and operations in water resource engineering. Once stationarity is neglected in the design of hydraulic engineering, numerous errors and risk may exist in the operations and management strategies and will lead to unforeseen losses.

Milly et al. (2008) rises the problem that stationarity in case of hydrological data series is continuing to decrease due to human disturbances in river basins. Thus, it is necessary to identify and study these variations in order to understand the changing hydrological processes and select the most appropriate methods for hydraulic engineering design and water resources management in the future (Galloway, 2011).

Thus, one of the most important questions in today's hydrology are: *Did stationarity die?* and if it is true *How did stationarity die?* As we know the climatic change is widely accepted so it is sad that by 2050 the effects of climate change may have a generally larger effect on flow regimes than it is estimated that dams and water withdrawals have had until now (Döll and Zhang, 2010). Taking this to consideration we can say that stationarity is dead because men's considerable impact on Earth's climate is altering the characteristics of precipitation, evapotranspiration and automatically the rivers runoff.

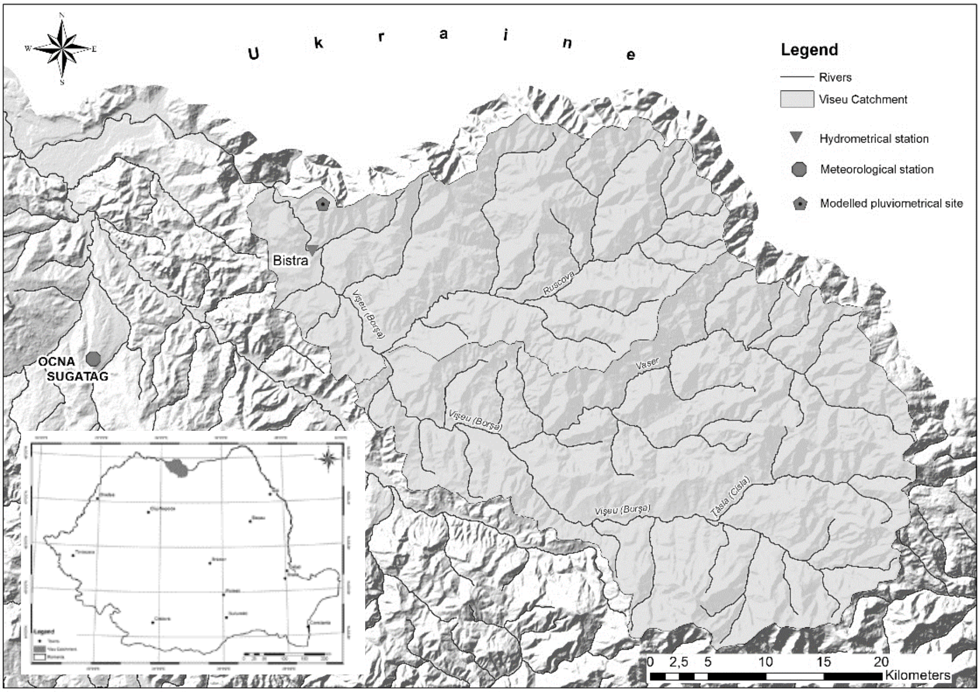

Fig. 1. Vișeu watershed – study area

STUDY AREA, DATA AND METHODS

As the main tributary of the Tisa River from Romania's Maramureș Basin, Vișeu River gathers its waters from a 1606 km^2 catchment and it is 80 km long. In significant parts (over 60%) the catchment is characterized by a mountainous relief, collecting the waters from the slopes of the Maramureș and Rodna Mountains with heights over 2300 meters. The high mean altitude (997 m) and the northern position give its runoff regime a moderately nival characteristic (Ujvari, 1972).

For the analysis we used mean monthly discharge data from Bistra hydrometric station, for the 1950-2008 period, the discharge data was taken from the GRDC (Global Runoff Data Centre) database. Even if in the Vișeu catchment there are several other hydrometric stations, we have chosen Bistra because all major tributaries flow into Vișeu River before this station; for this reason, the stream flow measured here can be considered the best indicator of stream flow in the study area

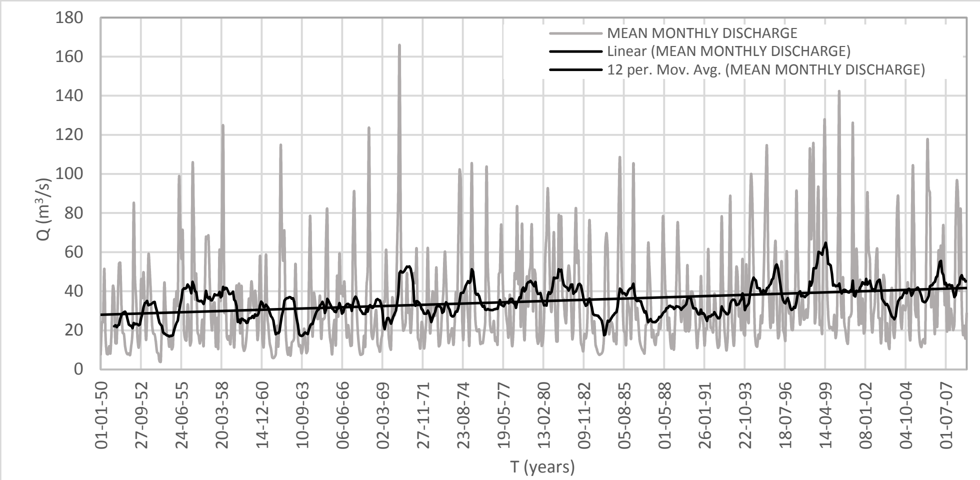

Fig. 2. Vișeu hydrometric station 1950-2008 mean monthly discharge data

Also we used mean monthly precipitation values from two sources, a measured one at Ocna Șugatag and a modeled one from the CARPATCLIM project. For this we choose the closest point generated by the models to the hydrometrical station, the correlation analysis between the two pluviometric data points shows a good coefficients of determination (R2): 0.85 (fig. 3), so we considered that the modeled data (which is closer) will be sufficient for the analysis.

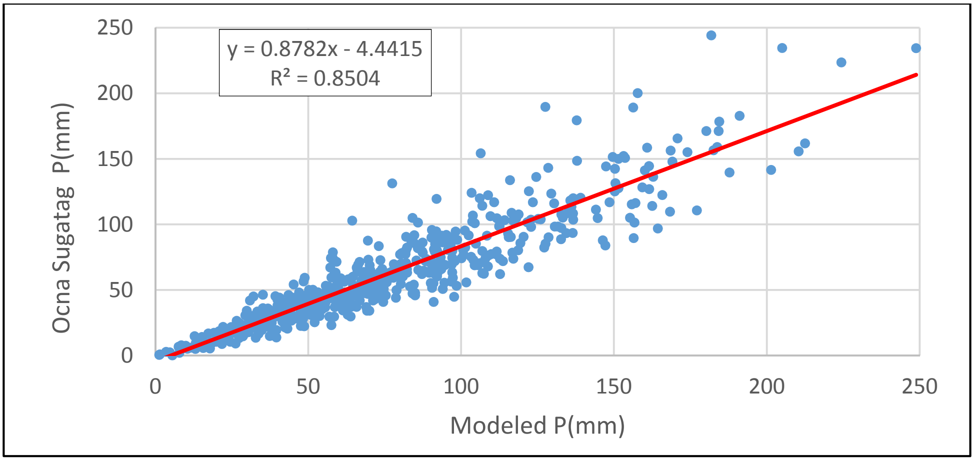

Fig. 3. Correlation between the measured and modeled (CarpatClim) precipitation data CARPATCLIM Database © European Commission - JRC, 2013

Taking into consideration that in this moment one of the most important aspect/moment is the change point identification in a period, from where significant change has occurred in a time series (Jaiswal et al., 2015), we choose to use the Ms Excel Addinsoft XLStat to assess the homogeneity of the data by the Pettitt's test, the von Neumann ratio test, the Buishand range test and also the standard normal homogeneity tests (SNHT). We summaries in a few lines the details of various change point tests applied in the study.

The Pettitt's test for change detection, developed by Pettitt (1979), is a well-documented non-parametric test, which is useful for evaluating the occurrence of abrupt changes in data series, it is the most commonly used test for change point detection because of its high sensitivity to breaks. The Pettitt's test is a method that detects a significant change in the mean of a time series when the exact time of the change is unknown (Winingaard, 2003, Jaiswal et al., 2015).

The von Neumann ratio test is closely related to first-order serial correlation coefficient (WMO 1966). According to the von Neumann ratio test, if the sample or series is homogeneous, then the expected Neumann value equals 2 under the null hypothesis with constant mean. When the sample has a break, then the value of the test must be lower than 2 otherwise we can imply that the sample has rapid variation in the mean (Jaiswal et al., 2015). The standard normal homogeneity (SNH) tests statistic is used to compare the mean of first n observations with the mean of the remaining (n-k) observations with n data points.

We analyzed also if we can identify a trend in the data series, for this we chose the widely used Mann-Kendall test which is recommended because it is a non-parametric test which does not require the data to be normally distributed; this test has also a low sensitivity to abrupt breaks due to inhomogeneous time series (Jeneiová et al., 2014, Jaiswal et al., 2015), which is important in case of hydrological data, also we analised the data with the classic linear regression test, which supposes that a straight line is fitted to the data and the slope of the line may be significantly different from zero or not.

ANALYSIS AND RESULTS

In the present study, first we ran various change point tests including Pettitt's test, von Neumann's ratio test, Buishand's range test and SNH test to detect change point in monthly, annual and seasonal discharge series at Bistra station (Jaiswal et al., 2015) and also at the nearby pluviometric modelled point.

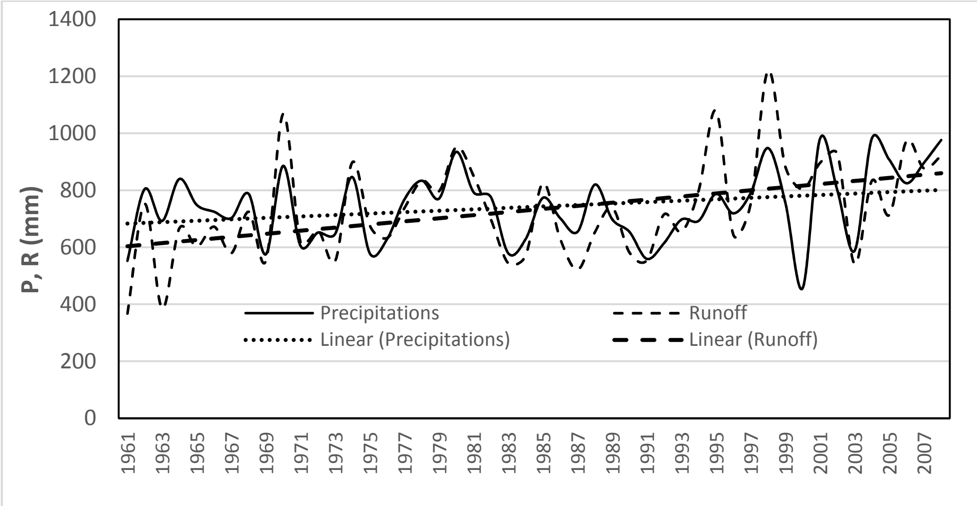

Fig. 4. Visual comparison of the mean yearly precipitation and runoff values

First, we analyzed the precipitation data series assuming a good correlation between the precipitation values and the runoff, because of the spatial nearness, as the Fig. 4 shows in part there is a one, until the 90s than the runoff values increase significantly returning to previous values only at the end of the 20th century. Change can be identified also in the precipitation data in this interval, besides the Pettitt's test which is also close (table 1), all tests present a change in the precipitation data series, thus they are not homogeneous. The von Neumann's test N value is 1.688 in case of the monthly data and 1.708 in case of the mean yearly data, this test doesn't identify the change point but it shows that there is one. All the other test identified change in the 90s (Table 1).

Table 1. Change point detection test results monthly precipitation data (1961-2008)

Buishand's test		**Standard normal homogeneity test**		**Pettitt's test**	
Q	32.636	T0	10.193	K	9304.000
t	01.04.1997	t	01.03.1998	t	01.05.1993
p-value	0.043	p-value	0.070	p-value	0.118
alpha	0.1	alpha	0.1	alpha	0.1

We must emphasize the fact that in case of the mean monthly or mean yearly data there are only a few cases when the test identified change, largely the results show homogeneous data series.

The results regarding the homogeneity of the runoff data are different, the tests show in numerous cases in the 90s a change in the data series (table 2).

Table 2. Change point detection test results runoff data (1950-2008)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Pettitt's test:	1992	1993	1993	1997	1977	1968	1968	1971	1974	1988
SNHT	2006	2006	1998	1997	1969	1964	2007	1954	1976	1990
Buishand's test:	1993	1993	1993	1993	1969	1964	1968	1954	1976	1990
Neumann's test										
	Nov	**Dec**	**Spring**	**Sum.**	**Aut.**	**Wint.**	**Year**	**Max**	**Min**	
Pettitt's test:	1968	1988	1993	1968	1988	1988	1993	1993	1992	
SNHT:	1989	1988	1993	1954	1989	1992	1993	1993	1994	
Buishand's test:	1989	1988	1993	1968	1988	1992	1993	1993	1994	
Neumann's test										

SNHT - Standard normal homogeneity test
- white squares - Data are homogeneous, no change detected
- grey squares - There is a date at which there is a change in the data

1993 is the year in which the test identified the most change points in runoff (March, Spring, year) (fig. 3).

The XLStat MS Excel Addin can automatically generate the chart form of the analysis, thus we can follow also visually the change in the data series evolution (fig. 5).

After the homogeneity analysis, we used the Mann-Kendall test to assess if there is a trend in the data series. In case of the monthly precipitation data there is no trend identified in the series but in case of runoff we identified an increasing trend in both form of the test, the classical and the seasonal. Regarding the other analyzed data intervals the results show and increasing trend in both cases, but in case of the precipitations only in one month (September) and in case of the runoff in six (table 3).

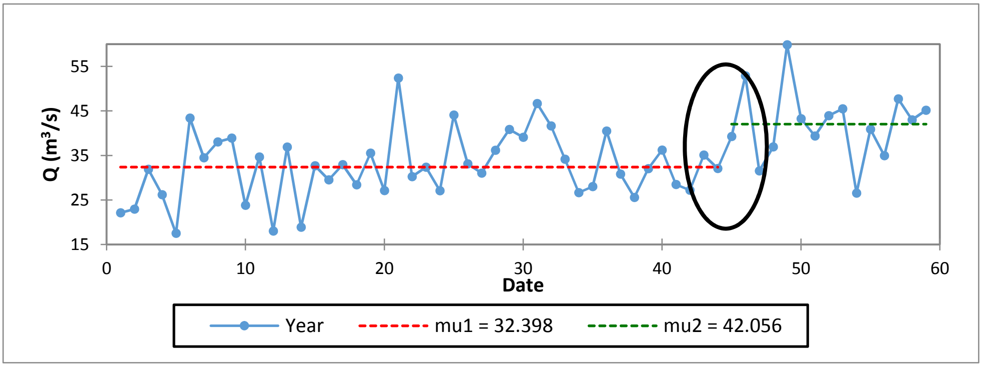

Fig. 5. Example of change point detection with the Standard normal homogeneity test (SNHT) yearly mean runoff 1950-2008

In case of the four seasons the precipitations shows an increase only in the autumn and the runoff increases in the winter and summer. The extremes show also an increase trend in case of the maxima for both series and also in case of the runoff for the minima. The Sen's slope it is positive in all cases for the runoff and in case of the precipitation shows negative values only in 3 months when the test doesn't identify a trend anyhow.

Table 3. Mann-Kendall test results interpretations

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Precipitations	-	-	-	-	-	-	-	-	↑	-
Runoff	↑	-	↑	-	↑	-	-	-	↑	↑
	Nov	**Dec**	**Winter**	**Spring**	**Summer**	**Autumn**	**Max**	**Min**	**Year**	
Precipitations	-	-	-	-	-	↑	↑	-	↑	
Runoff	↑	-	↑	-	↑	-	↑	↑	↑	

- There is no trend in the series
↑There is an increasing trend in the series

For the long-term variation of the data series we analyzed the data also with the classic linear regression test, which supposes that a straight line is fitted to the data and the slope of the line may be significantly different from zero or not, in case of the runoff all the data shows a positive increasing trend, only in case of the precipitations there are three month (June, November, December) in which the trend is negative, in case of the monthly values as shown in the Fig. 4 both trends show an increasing slope.

CONCLUSIONS

Assessing the temporal variation of various climatic variables due to a possible climate change or direct human intervention it is unquestionably important for water resources planning and management at both the regional and local scale. In the present study we used several change point detection tests which were followed by two type of trend analysis with different non-parametric statistical tests to identify these variations. The change point has been detected using Pettitt's test, von Neumann ratio test, Buishand's range test and standard normal homogeneity test on monthly, seasonal and annual long-term series, in case of the trend analysis for the same time intervals we used the Mann-Kendall test and the classic linear regression test to identify the variation's trend.

We must conclude taking into consideration the results of this study that in case of the Vișeu watershed stationarity is questionable. As we see even if the precipitation values don't show significant changes regarding their homogeneity, the runoff series are changing, and in most cases this change is identified in the 90s, the 20th century last decade. These results urge us to rethink and to reevaluate our sustainable water resource management for the future.

ACKNOWLEDGMENT

This work was supported by two projects the NATO Science for Peace NATO-984440 Project "*A model to predict and prevent possible disastrous effects of toxic pollution in the Tisza River watershed*" and the "*Integrated Study on the Contribution of Ecosystems in the protected Natura 2000 areas: Pricop-Huta-Certeze and the Upper Tisa to the Sustainable Development of Local Communities (SIENPHCTS)*" a RO02-0013 project funded by the EEA Grants – jointly financed by Iceland, Liechtenstein and Norway.

We would also like to thank for the necessary data which came from the ***Global Runoff Data Centre*** (Federal Institute of Hydrology, Koblenz, 56068, Germany)

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