Trend detection in river runoff across Mediterranean river basins: evaluation of results from Moroccan case study

Ons Oueslati*,**, A. M. De Girolamo*, A. Lo Porto* and A. Abouabdillah*,***

* Water Research Institute, National Research Council, 5 Viale F. De Blasio 70123, Bari, Italy
(E-mail: ons.oueslati@ba.irsa.cnr.it; annamaria.degirolamo@ba.irsa.cnr.it; antonio.loporto@ba.irsa.cnr.it; aziz.abouabdillah@ba.irsa.cnr.it)
** Department of Engineering And Physics of the Environment , University of Basilicata, 85 Via Nazario Sauro, 85100, Potenza, Italy
*** Tuscia University, Via S. Camillo De Lellis, 01100, Viterbo, Italy

Abstract

The Mediterranean basin is considered among the ecosystems to be especially affected by climate change due to the net decline in precipitations during the last century. This study aims to identify trend in river discharges using a set of graphical and statistical procedures. Annual and monthly continuous streamflow time series from six Mediterranean flow gages in Morocco were checked for possible trend. The rescaled cumulative departure plots of monthly mean flows exhibit a net decreasing trend from 1980 until 1987 at all sites. The LOWESS-smoothed monthly mean flows have a generally decreasing trend which is more obvious from early 1970s. Standard statistical testing were applied to confirm the trends. Among these tests the non parametric Mann-Kendall test, which is widely used to detect trends in hydrologic data, was applied to detect trends in annual runoff. The results of this test showed that all the stations present negative trends indicating the decrease in runoff at 95 and 99 percent significant level.

Keywords

Trend analysis; streamflow; Mann-Kendall; LOWESS; Morocco

INTRODUCTION

Within the climate change debate, the subject of trend detection in hydrologic data has received greater attention during the last decades. Particularly, identification of trends in long term runoff is one of the important themes in hydrologic science (NRC, 1991). The reason is that the long-term runoff analysis is an important tool for detecting any modification in hydrological systems (Chang, 2007). Trends in historic streamflow series might be caused by anthropogenic influences in the catchment, e.g. river regulation, dam construction or irrigation. Another reason for trends is climatic change. According to the most recent IPCC report (IPCC, 2007), annual average river runoff is projected to increase by 10-40 % at high latitudes and in some wet tropical areas, and decrease by 10-30% over some dry regions at mid-latitudes and in the dry tropics by mid-century. There is also high confidence that many semi-arid areas (e.g. the Mediterranean Basin, western United States, southern Africa and north-eastern Brazil) will suffer a decrease in water resources due to climate change (IPCC, 2007). Mediterranean-type ecosystems is likely to be especially affected by climate change because of reduction in rainfall (IPCC, 2007). Future climatic changes may have substantial impact on river discharge patterns, as well as on extreme events, their magnitude and probability of occurrence (Krasovskaia and Gottschalk, 1993). River discharge time series have been extensively studied worldwide. For example, Svensson et al.

(2005) studied trends in 21 stations worldwide with flow records of up 100 years, while Kundzewicz et al. (2005) studied trends in 195 worldwide daily flow time series.

MATERIAL & METHODS

Study area

Trend analysis was done to a group of six flow gaging stations in Morocco (Figure 1). Annual and monthly mean flows time series were provided from the database of the Global Runoff Data Centre (GRDC) in Koblenz, Germany. The period of analysis is from 1960 to 1987.

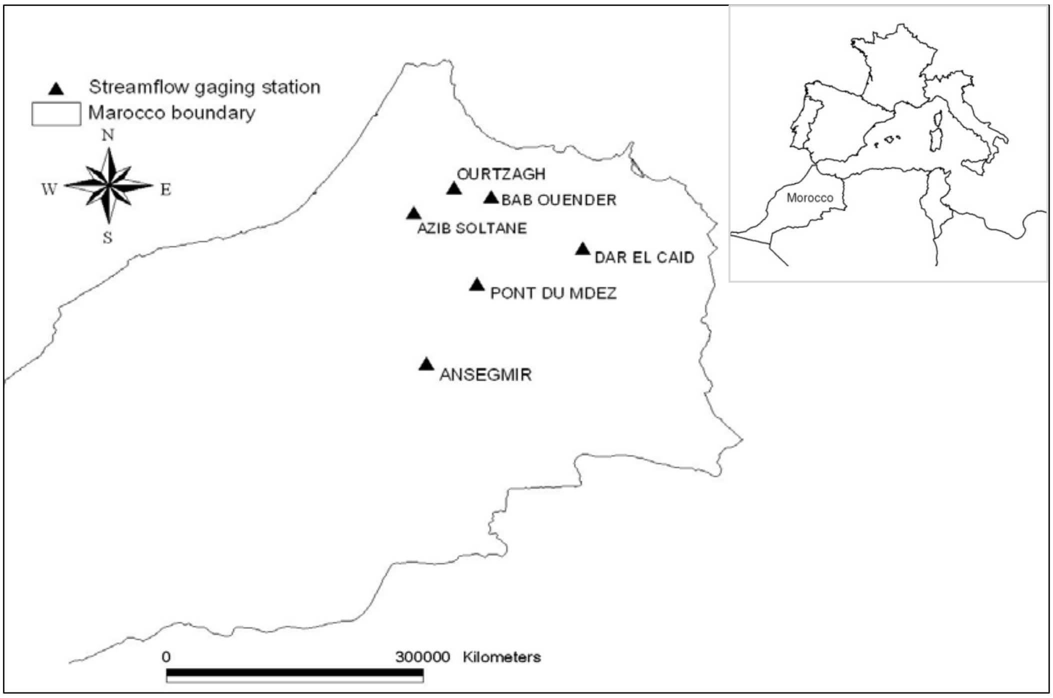


Figure 1: Location of streamflow stations

The selected stations (Table 1) belong to large important rivers in Morocco. These river basins are characterized by a semi-arid climate. The hydrological regime in these regions is then quite specific due to the high variability of rainfall regime. The differences between low and high water discharges can be extreme. This presents a major difficulty for the monitoring of rivers as well as for the analysis of the rainfall-runoff processes (Drobinski and Ducrocq, 2008). Then hydrologic records remain sparse in semi-arid areas which handicap long-term trend studies in hydrologic data.

Table 1: Streamflow stations used in analysis

grdc_no	River	Station	Area	Altitude
			Km^2	m
1308110	ANSGEMIR	ANSEGMIR	960	450
1308600	MOULOUYA	DAR EL CAID	24422	325
1309700	SEBOU	AZIB SOLTANE	17250	70

1309750	OUERGHA	OURTZAGH	4404	140
1309810	MDEZ	PONT DU MDEZ	3435	725
1309850	OUERGHA	BAB OUENDER	1758	540

Rescaled Cumulative Departures

The rescaled cumulative departures of the monthly mean streamflow at each streamflow site were computed as the cumulative sum of the differences between the monthly value and the monthly mean for the period of record, divided by the monthly standard deviation for the period of record (Garbrecht and Fernandez, 1994), the values are dimensionless. This procedure allows fluctuations and trends in flow to be visualized and was used to identify extended wet and dry periods and to compare general trends among the streamflow sites. Periods of negative slope indicate periods of monthly streamflow which are less than the mean; periods of positive slope indicate greater than normal streamflow conditions. The steepness of the slope indicates the magnitude of the deviations from normal conditions. Periods of relatively small changes in the rescaled cumulative departures, whether the slopes are positive or negative, indicate periods of near normal flows.

LOWESS technique

LOWESS is a locally weighted scatterplot smoothing (Cleveland, 1979). LOWESS is a data analysis technique for producing a “smooth” set of values from a time series which has been contaminated with noise. LOWESS is useful in identifying trends in highly variable time-series data. This technique was used to smooth the monthly flows and to further identify possible trends. The degree of smoothing can be controlled by varying the value of the smoothness factor, f, which reflects the size of the window used to compute a value on the LOWESS curve (Helsel and Hirsch, 1992). The smoothness factor can range from 0.01 to 0.99. Higher value of this factor means a larger window size resulting in smoother fitted curves but at the expense of loss of detail.

Mann-Kendall test

The Mann-Kendall trend test (Mann, 1945; Kendall, 1975) is one of the widely used non parametric tests to detect significant trends in time series. The Mann-Kendall trend test, being a function of the ranks of the observations rather than their actual values, is not affected by the actual distribution of the data and is less sensitive to outliers. On the other hand, parametric trend tests, although more powerful, require the data to be normally distributed and are more sensitive to outliers (Hamed, 2007). The Mann-Kendall test, as well as other non parametric trend tests, is therefore more suitable for detecting trends in hidrological time series, which are usually skewed and may be contaminated with outliers (Hamed, 2007). The Mann-Kendall trend test is based on the correlation between the ranks of a time series and their time order. For a time series X= $(x_1, x_2, x_3, \ldots, x_n)$, the test statisticis given by:

$$S = \sum_{i<j} a_{ij} \qquad (1)$$

where

$$a_{ij} = sign(x_j - x_i) = sign(R_j - R_i) = \begin{cases} 1 \\ 0 \\ -1 \end{cases} \qquad (2)$$

and Ri and Rj are the ranks of observations xi and xj of the times series, respectively.
Considering H_0 the null hypothesis for the test where there is no trend in the data.
If the null hypothesis Ho is true, then S is approximately normally distributed and the mean and variance of the S statistic are given by (Kendall, 1975)

$E(S)=0$
$V_0= n(n-1)(2n+5)/18$

The z-statistic is therefore (critical test statistic values for various significance levels can be obtained from normal probability tables):
$z = | S | / V_0{}^{\wedge 0.5}$

A positive value of S indicates that there is an increasing trend and vice versa.

Linear regression test

This is a parametric test that assumes that the data are normally distributed. It tests whether there is a linear trend by examining the relationship between time (x) and the variable of interest (y). The regression gradient is estimated by:

$$b = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

And the intercept is estimated as:
$$a = \bar{y} - b\bar{x}$$

The test statistic is:
$$S = \frac{b}{\sigma}$$

Where $\sigma = \sqrt{\frac{12\sum_{i=1}^{n}(y_i - a - b x_i)}{n(n-2)(n^2-1)}}$

The test statistic S follows a Student-t distribution with n-2 degrees of freedom under the null hypothesis (critical test statistic values for various significance levels can be obtained from Student’s t statistic tables). The linear regression test assumes that the data are normally distributed and that the errors (deviations from the trend) are independent and follows the same normal distribution with zero mean.

RESULTS AND DISCUSSION

Rescaled Cumulative Departures

The rescaled cumulative departures (RDCs) of monthly flows for the selected rivers exhibit the same general patterns for the period of record (Figure 2). For the period 1960-1962 flows were average for all the rivers expect for the Bab Ouender station where flows were greater than average in 1960 and less than average in 1961. From 1962 to 1966 flows were greater than average. During this period, the RCDs present steep slopes reflecting high magnitudes floods. From 1966 until April 1967 flows were less than normal in all the stations. From Mai 1967 to mid 1972 flows were greater than average as indicated by the positive slope in the RDCs (Figure 2). From autumn 1972 until late 1975 flows were average or less than average. Then a new wet period is observed until mid 1976. From Summer 1976 until 1980, different pattern can be observed. Finally the period 1980-1987 was one of less-than-normal runoff. This drought appears to have been the longest on record (1960-1987) at all sites.

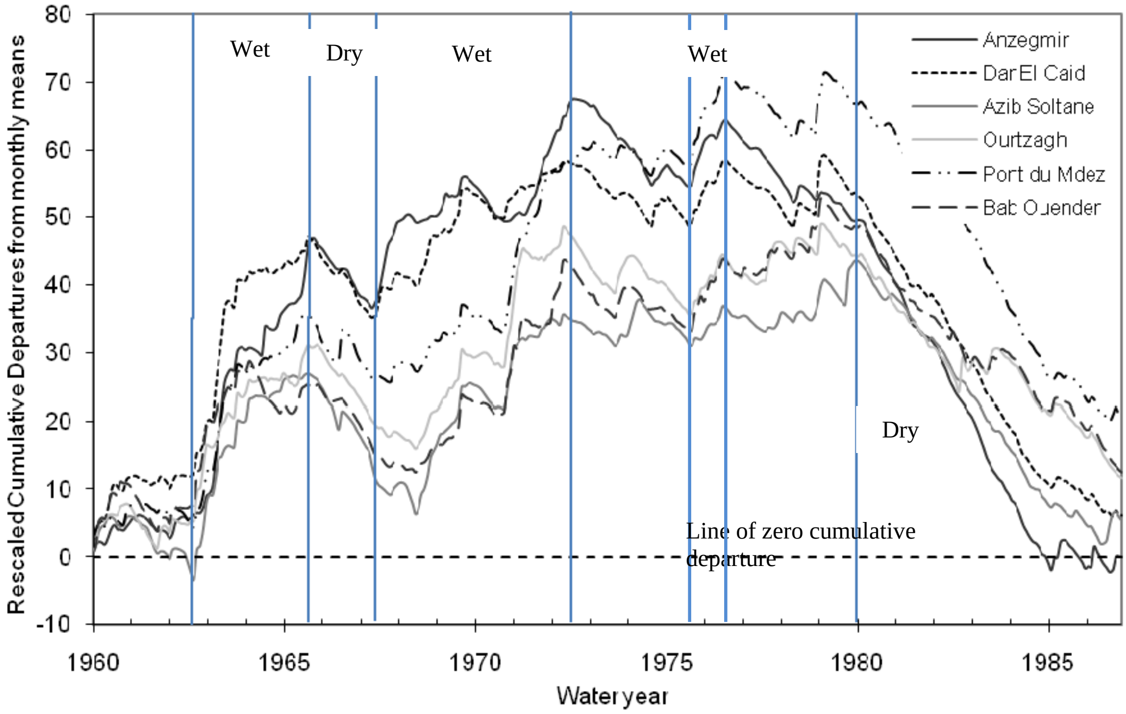
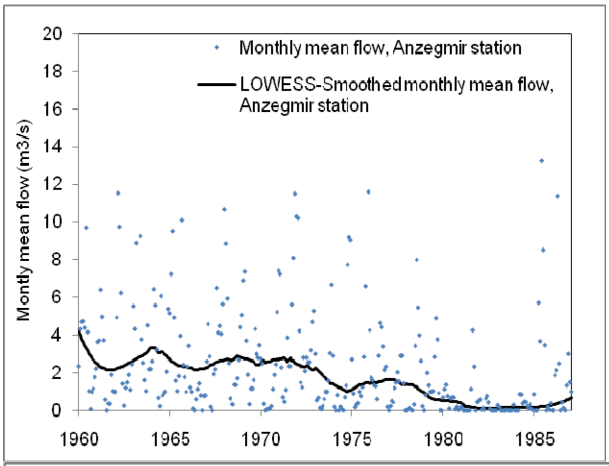
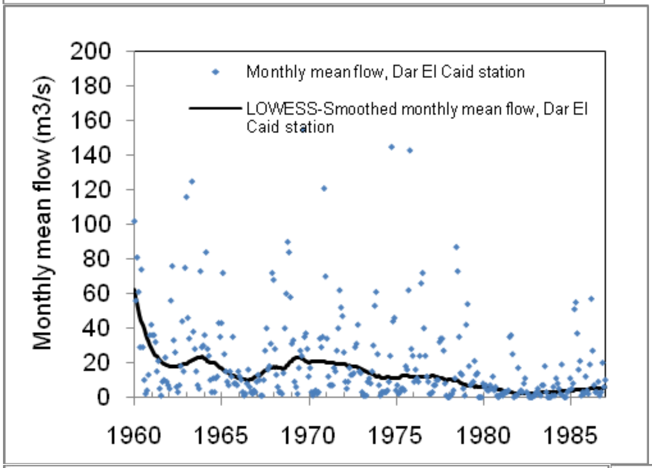


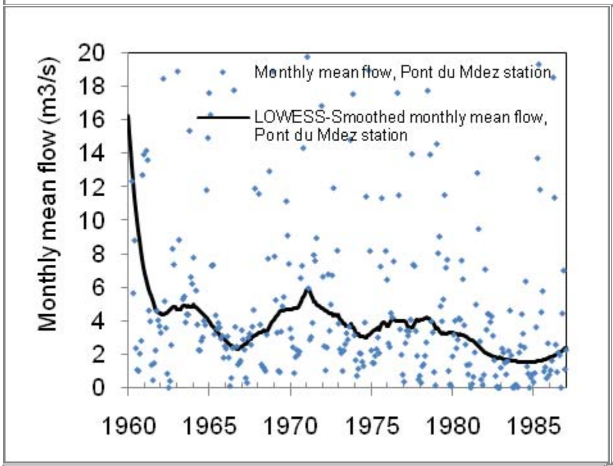
Figure 2: Recaled Cumulative Departures of montlhly mean streamflow, 1960-1987

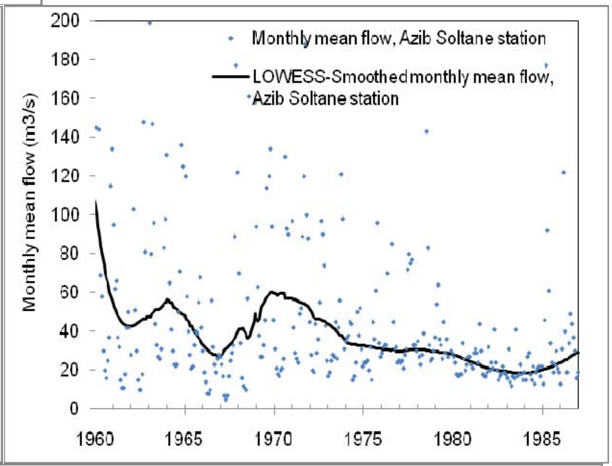
LOWESS-Smoothed records

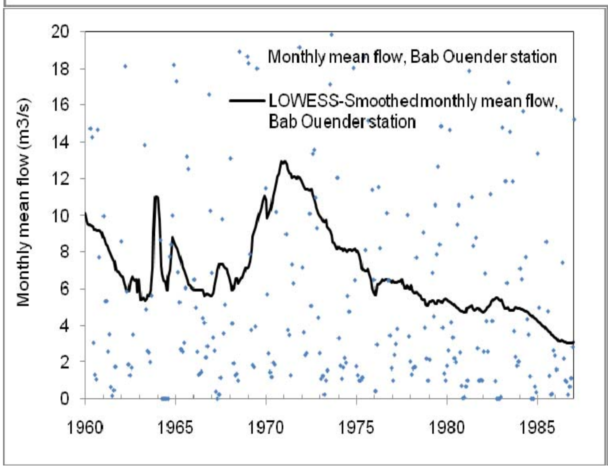
The 1960-1987 records of monthly mean flows for the selected stations were smoothed using the LOWESS technique with a smoothness factor of 0.5 to identify trends in monthly streamflows (Figure 3). LOWESS-smoothed monthly mean flows have the same general pattern for the period of record. Flows exhibited a generally decreasing trend which is more obvious from early 1970s. However, a net increasing trend can be observed in the second half of the 1960s particularly in: Pont du Mdez, Bab Ouender and Azib Soltane stations.


Monthly mean flow, Anzegmir station
LOWESS-Smoothed monthly mean flow, Anzegmir station
Montly mean flow (m3/s)
1960 1965 1970 1975 1980 1985


Monthly mean flow, Dar El Caid station
LOWESS-Smoothed monthly mean flow, Dar El Caid station
Monthly mean flow (m3/s)
1960 1965 1970 1975 1980 1985


Monthly mean flow, Pont du Mdez station
LOWESS-Smoothed monthly mean flow, Pont du Mdez station
Monthly mean flow (m3/s)
1960 1965 1970 1975 1980 1985


Monthly mean flow, Azib Soltane station
LOWESS-Smoothed monthly mean flow, Azib Soltane station
Monthly mean flow (m3/s)
1960 1965 1970 1975 1980 1985


Monthly mean flow, Bab Ouender station
LOWESS-Smoothed monthly mean flow, Bab Ouender station
Monthly mean flow (m3/s)
1960 1965 1970 1975 1980 1985

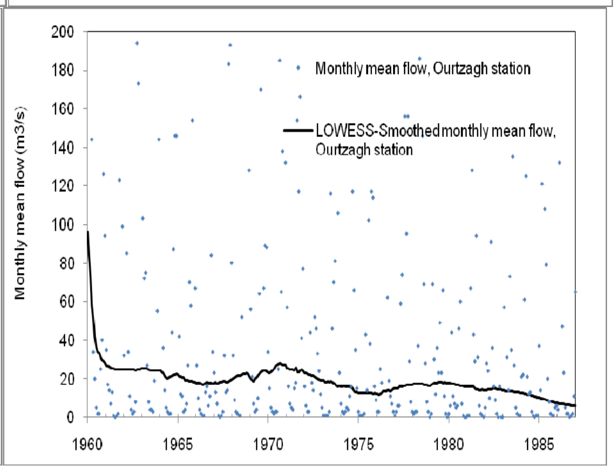

Monthly mean flow, Ourtzagh station
LOWESS-Smoothed monthly mean flow, Ourtzagh station
Monthly mean flow (m3/s)
1960 1965 1970 1975 1980 1985

Figure 3: LOWESS-Smoothed plots of monthly mean flow, 1960-1987

Trends in annual runoff

The Mann-Kendall trend test and linear regression analysis were used to determine if a statistically significant monotonic trend was present in annual mean flows (Tables 2 and 3). Long-term annual runoff trend using both statistics showed that all stations have a statistically significant decreasing trend at 5% and 1% confidence level expect for the Ourtzagh station where the linear regression analysis suggests that there is a decreasing trend at 10% siginificance level.

Table 2: Mann-Kendall trend test results

Station	Test statistic	Critical values (Statistical table)			Result
		a=0.1	a=0.05	a=0.01	
Anzegmir	-3.095	1.645	1.96	2.576	S (0.01)
Dar El Caid	-2.498	1.645	1.96	2.576	S (0.05)
Azib Soltane	-3.433	1.645	1.96	2.576	S (0.01)
Ourtzagh	-1.962	1.645	1.96	2.576	S (0.05)
Pont du Mdez	-2.34	1.645	1.96	2.576	S (0.05)
Bab Ouender	-2.087	1.645	1.96	2.576	S (0.05)

Table 3: Linear regression analysis results

Station	Test statistic	Critical values (Statistical table)			Result
		a=0.1	a=0.05	a=0.01	
Anzegmir	-3.155	1.703	2.052	2.771	S (0.01)
Dar El Caid	-2.896	1.699	2.045	2.756	S (0.01)
Azib Soltane	-3.668	1.703	2.052	2.771	S (0.01)
Ourtzagh	-1.916	1.69	2.031	2.727	S (0.1)
Pont du Mdez	-2.654	1.696	2.04	2.745	S (0.05)
Bab Ouender	-2.134	1.689	2.029	2.722	S (0.05)

CONCLUSIONS

Identification of changes in streamflow records is challenging. As presented in this work a set of different procedures can be used to search for changes in streamflow conditions. The rescaled cumulative departures time series of monthly flows exhibit a long drought starting from 1980 to 1987 in all sites. LOWESS-smoothed monthly mean flows have the same general pattern during the period of record(1960-1987). Flows exhibited a generally decreasing trend which is more obvious from early 1970s. Statistical testing using the Mann-Kendall test and linear regression analysis show a significant decreasing trend in annual runoff.

REFERENCES

Chang, H. (2007). Comparative streamflow characteristics in urbanizing basins in the Portland Metropolitan Area, Oregon, USA. In: Hydrological Processes, 21(2), pp: 211-222.

Cleveland W. S. (1979). Robust Locally Weighted Regression and Smoothing Scatterplots. In: Journal of the American Statistical association 74, pp: 829-836.

Drobinski P. and Ducrocq V. (2008). HYdrological cycle in the Mediterranean EXperiment (HYMEX). Towards a major field experiment in 2010-2020. White Book. February 2008. http://www.cnrm.meteo.fr/hymex/.

Garbrecht J. and Fernandez G.P. (1994). Visualization of trends and fluctuations in climatic records. Water Resources Bulletin 30 (2), pp: 297-306.

GRDC (Global Runoff Data Centre), 2009. Dataset of 6 monthly and annual river discharge time series from the global Runoff Data Centre, D-56068 Koblenz, Germany, http://grdc.bafg.de.

Hamed K. H. (2007). Trend detection in hydrologic data: the Mann-Kendall test under the scaling hypothesis. In: Journal of Hydrology (2008) 349, pp: 350-363.

Helsel D. R. and Hirsch R. M. (1992). Statistical Methods in Water Resources. In: Elsevier Science Publishers, Amesterdam, 522 pp.

IPCC (Intergovernmental Panel on Climate Change) (2007). Summary for Policymakers. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Climate change 2007, Impcats, adaptation, and vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 11.

Kendall M. G. (1975). Rank Correlation Methods. Griffin, London.

Krasovskaia I. and Gottschalk L. (1993). Frequency of extremes and its relation to climate fluctuations. In: Nordic Hydrol. 24, pp: 1-12.

Kundzewicz Z. W., Graczyk D., Maurer T., Pinskwar I., Radziejewski M., Svenson C. and Szwed M. (2005). Trend detection in river flow series: 1. Annual maximum flow. In: Hydrol. Sci. J. 50 (5), pp. 797-809.

Mann H. B. (1945). Non parametric tests against trend. Econometrica 13, pp: 245-259.

NRC (National Research Council) (1991). Opportunities in the Hydrologic Sciences. Washington, D.C.: National Academy Press.

Svensson C., Kundzewicz Z. W. and Maurer T. (2005). Trend detection in river flow series: 2. Flood and low –flow index series. In: Hydrol. Sci. J. 50 (5), pp. 811-824.

14-WWW-YES-2009-France-Oueslati-paper.doc