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Spatial and Time Analysis of Rainfall in the Tiber River Basin (Central Italy) in relation to Discharge Measurements (1920-2010)

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Abstract

Daily precipitation and river discharge (1920-2010) in the Tiber river basin (Central Italy) have been analyzed by means of standardized indices at the annual and seasonal scale; the existence of trends has been verified by means of the non parametric Mann-Kendall. Advantages/disadvantages arising from the use of standardized indices in order to identify the climatic signal at basin scale are discussed as well as the relation between rainfall signal at basin scale and climatic global indices (i.e. North Atlantic Oscillation Index).

Keywords: precipitation, climate change; NAO; central Italy

1. Introduction

In the broader context of global climate change, it is important to foresee the possible effects of extreme events on the local socio-economic texture. In this research, the use of standardized indices related to the main hydro-meteorological quantities (precipitation, river discharge) has been analyzed in the Tiber River Basin (Central Italy), in order to identify the climatic conditions that triggered the onset of water scarcity events in the past. Daily precipitation and river discharge data (1920-2010), gathered by the Regional Hydrographic Agencies in the Tiber river basin have been analyzed by means of standardized

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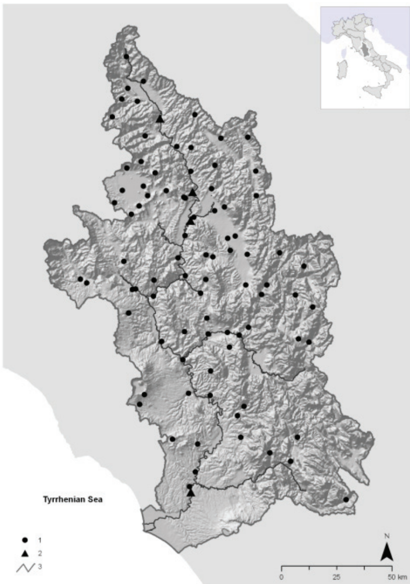

indices similar to the SPI [1] for different temporal and spatial scales. Possible cyclic behavior of the climate signal at basin scale is examined, as well as the relation between rainfall signal at basin scale and climatic global indices (i.e. North Atlantic Oscillation Index). The existence of trends both of precipitation and river discharge has been verified by means of the non parametric Mann-Kendall (MK) test.

The study area (Fig. 1) extends in Central Italy over 16,500 km^2. The mean altitude is 520 m a.s.l., although its highest reliefs reach nearly 2500 m. Mean annual precipitation has been estimated about 1020 mm for the period 1924-1930/1935-1992.

Fig. 1. Tiber river basin and location of the monitoring station (1: rainfall, 2: discharge; 3: basin boundaries).

2. Methodology

Rainfall gauge stations with at least 30 years of data (hydrologic year, September to August), although not consecutive, have been retained, totaling 88 stations (Fig.1). The measured discharge of Tiber at selected monitoring sites (Fig.1) was also considered.

Precipitation data have been analyzed at the annual scale, by means of a standardized index similar to SPI [1], assuming a gaussian distribution of data: $SPI_j^i = (P_j^i - \overline{P}_j)/\sigma_j$ where P_j^i is the value of the annual cumulated precipitation for the year i at the j station, $\overline{P}_j$ is the long-term mean annual cumulated precipitation at the j station and σ_i is the correspondent standard deviation.

In order to analyze the seasonal influence on the climate interannual variation, the precipitation data set was also aggregated at the seasonal time scale (Autumn: September to November; Winter: December to February; Spring: March to May; Summer: June to August). In order to verify the gaussian hypothesis, the Lilliefors test [2] has been applied to each time series: as for the annual index, most of the analyzed seasonal time series follow a Gaussian distribution (approximately 84%), justifying the adopted standardization procedure.

Precipitation intensity and rainy days number variation have been analyzed by means of the following standardised indices: 1) number of rainy days (PD): number of days in the aggregation period (year or season) in which precipitation exceeds 1 mm. 2) Mean precipitation intensity (MI): precipitation cumulated on the aggregation period (year or season) divided by the number of rainy days. Both indices have been standardized with respect to its mean and standard deviation.

Finally, precipitation indices at basin scale were obtained by means of a weighted average, where the weights are given by the areas of the Thiessen's polygons associated to each rainfall gauging station and normalized with respect to the total area. Area weighting has been performed in order to minimize regional biases arising from the uneven distributions of the stations. As the number and location of rain gauges vary for each hydrologic year, the Thiessen's polygons extension has been calculated for each year through a GIS procedure.

A similar standardized approach has been applied to the discharge data at the annual scale; an index for each discharge monitoring station was computed as $SQI_j^i = (Q_j^i - \overline{Q}_j)/\sigma_j$, where Q_j^i is the annual mean discharge at the site j, $\overline{Q}_j$ is the annual long term mean discharge at the site j and σ_j is the correspondent standard deviation.

3. Results

3.1. Space and time representativeness of the database

The variation coefficient (σ/m) of each rain gauge station (including those with a number of available year lower than 30) has been calculated in order to evaluate the influence of the number of data on the variability of the statistical moments. These values have been plotted against the number of years (Fig.2, left): when the number of available years exceeds 20 the variation coefficient is stationary, i.e. independent from the number of years. This finding shows that 20 years of data could be enough for the indices analysis.

P_{ann} does not show any dependency to its spatial variability, quantified by means of the standard deviation of the yearly values of P_{ann} ($R^2 = 0.11$), as it is shown in Figure 2 (symbol: empty triangles). This suggests that the spatial variability of P_{ann} in general is not related to the annual climatic conditions (i.e. the standard deviation does not increase nor decrease with P_{ann}). In order to clarify if the number of available stations does not affect the P_{ann} standard deviation, on the right side of Figure 2 the number of available stations is also plotted (symbol: crosses); the calculated R^2 (0.01) shows the lack of correlation.

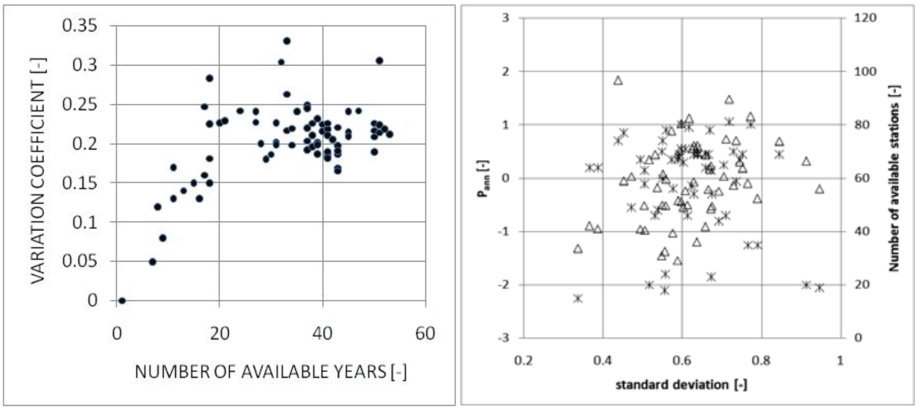

Fig. 2 – Variation coefficient of each rainfall station plotted against the number of available years (left). Index P_{ann} and number of available stations plotted against the standard deviation of the same index (right)

3.2. Rainfall analysis

The variation in time of P_{ann} is shown in Fig.3 (left), in which also the winter (December through March) NAO index is plotted. The Hurrell (1995) [3] index (http://www.cgd.ucar.edu/) was used. In order to enhance possible cyclicities, both the time series have been filtered by a 5-years centered moving average.

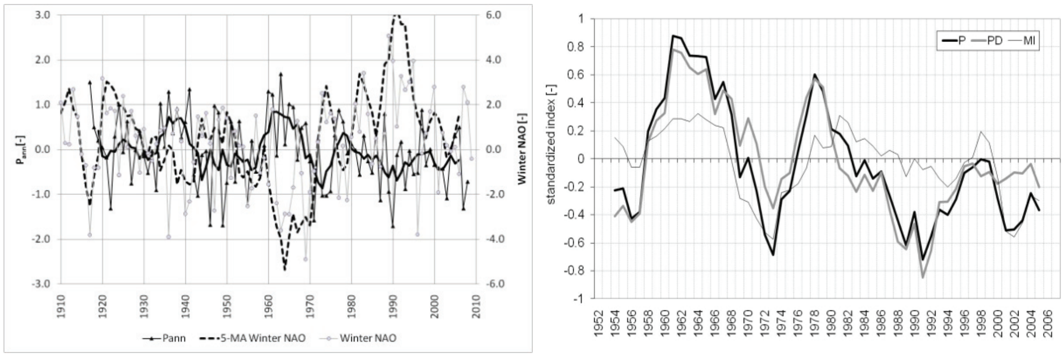

Fig. 3 Left: Comparison between P_{ann} (yearly values: dark line and triangles; 5 years moving average: dark solid line) and winter NAO (yearly values: grey line and circles; 5 years moving average: dotted dark line). Right: 5-years moving average of the indices P_{ann}, (thick dark line), PD_{ann} (thick grey line) and MI_{ann} (thin grey line)

The variation of P_{ann} ranges within ± 1.8, while the 5 years moving average ranges within ±1, which is approximately equal to a variation of 15% of the long term mean. The 5 years moving average enhance the existence of a cyclic behaviour with relatively humid periods (whose peaks fall in 1924; 1938; 1961; 1978 and 1998) and dry periods (around 1931; 1944; 1956; 1973; 1991; 2002). The periods between each maximum results equal to 14, 23, 17 and 20 years respectively. A relation between the observed cyclic behaviour and a global climate pattern was seek comparing the P_{ann} with NAO (Fig.3, left). A fair inverse correlation ($R^2 = 0.48$) was found, confirming the influence of global climate phenomena on precipitation pattern in southern Europe as already noted by e.g. Haylock & Goodess 2004 [4]; Pavan et al. 2008 [5]; Zanchettin et al. 2008 [6]. The same analysis was performed also at the seasonal scale (not shown here for seek of shortness): in this case neither the periodic time evolution nor the relation with NAO are so evident. In Fig. 3 (right) the P_{ann} is plotted against PD_{ann} and MI_{ann} for the period 1952-2007. PD and SPI indices are strongly related ($R^2 = 0.77$): a positive/negative variation of the yearly precipitation is strongly related to an increase/decrease of the rainy days. Similar results have been obtained on other data sets in Italy by e.g. Nanni et al. (2008) [7] and Gozzini et al. (2008) [8]. The behaviour of MI_{ann} is also related to P_{ann} but with a lower linear correlation coefficient ($R^2 = 0.45$); in general MI_{ann} shows lower correlation with P_{ann} and PD_{ann}, meaning that, in general, the mean intensity of precipitation exerts a lower influence on the annual precipitation than that exerted by the number of rainy days. In other words, an increase/decrease of the annual precipitation is more affected by an increase/decrease of the rainy days than by an increase/decrease of the mean intensity.

3.3. Discharge analysis

The *SQI* (standardised index of discharge) has been calculated for four discharge monitoring points (Fig.1). In Fig. 4 (left) the *SQI* for the Tiber at four gauging sites at different altitudes (Santa Lucia: 265 m a.s.l.; Ponte Felcino: 197 m a.s.l.; Ponte Nuovo : 165 m a.s.l.; Ripetta: 32 m a.s.l.;) are shown. Only Ripetta (at the end of the basin) has a continuous registration, while the others have gaps. However, the graphs show that the indices are in phase.

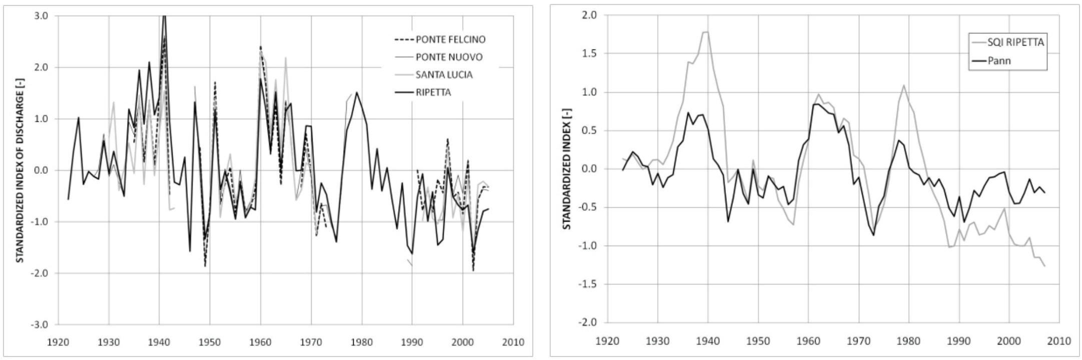

Fig. 4 – *SQI* for the stations of Ponte Felcino, Ponte Nuovo, Santa Lucia and Ripetta (left). 5-years moving average of the *SQI* of the Ripetta station and of P_{ann} (right)

The good correlation ($R^2 = 0.58$) between the Tiber *SQI* at Ripetta and the P_{ann} is shown in Fig. 4, right (5 years moving average). The cyclic behavior of precipitation can be clearly seen also on the river discharge regimen, although the absolute values of *SQI* are often higher than P_{ann}. The stronger negative values in the last decades could be related to an increase in the withdrawals, more difficult is to explain the higher positive values around the ‘30s and the ‘80s.

3.4. Trend Analysis

The existence of trends in the indices time series was verified by means of the Mann-Kendall (1945) test [9] for the period 1952-2008 and 1922-2010. In Tab. 1 the results for the precipitation are shown together with the percentage variation of each index with respect to its average in the considered time period. MK test confirms the existence of a negative trend (-8.4%) from 1952 to 2008 (58 years) for the annual precipitation in the study area, which is mainly due to winter precipitation (-16.2 %). It is worth to underline that from 1922 to 2008 the calculated trend is -0.13% per year, corresponding to -7.3% in 58 years, but such a trend was not verified by the MK test. It is hence evident that the choice of the period is extremely important in order to analyse trends. Winter NAO has an opposite behaviour as expected, with a verified positive trend in the period 1952-2008 (+ 0.04% per year); the annual trend is + 0.01% for the period 1920-2008 (but not verified by the MK test). Concerning river discharge, the calculated trends are shown in Tab. 1, both as percentage variation with respect to the long term mean, and as variation expressed in $m^3s^{-1}y^{-1}$ (data in brackets). They are always negative, steeper in the period 1952-2010. It is worth to remind that river discharge is affected also by anthropic effects diversions and withdrawals.

Table 1. Computed trends for the precipitation indices for the period 1952-2008 and 1922-2010. In grey we indicated the indices for which the Mann-Kendall test confirmed a trend at the 90% level of confidence

INDEX	VARIABLE	TREND 1952-2008 [%]	TREND 1922-2010 [%]
P_{ann}	Rainfall	-8.4	-11.4
P_{win}	Rainfall	-16.2	-19.2
P_{spr}	Rainfall	-2.7	+2.2
P_{sum}	Rainfall	-10.0	-9.1
P_{aut}	Rainfall	-2.5	-6.8
Santa Lucia	Discharge	-27.6 (-0.05)	-35.8 (-0.10)
Ponte Felcino	Discharge	-23.1 (-0.10)	-35.3 (-0.14)
Ponte Nuovo	Discharge	-21.4 (-0.19)	-35.0 (-0.29)
Ripetta	Discharge	-22.1 (-0.95)	-37.6 (-1.27)

4. Conclusions

Standardized indices are a powerful instrument to analyze regional phenomena such as precipitation pattern. The main advantage is that they allow to merge together many gauging sites independently from their absolute values, due to the fact that each variable is standardized to its mean and standard deviation. Additionally they allow to easily compare different magnitudes such as precipitation and discharge.

The computed indices time series show that: 1) Annual rainfall has significantly decreased all over the basin in the observation period (-8.4% from 1952 to 2008), mainly due to winter precipitation (-16.2%). 2) Tiber discharge has also decreased by 1.27 $m^3/s/y$ in the same period, -0.95 $m^3/s/y$ when starting in 1922. 3) At the annual scale, precipitation index is clearly related to the flow indices both of Tiber and of the main tributaries. 3) The 5 years moving averages enhance a cyclic behavior of both SPI and SQI at the annual time scale, with a period of approximately 15 years, in relation with the opposite of NAO; however, this oscillation has not been confirmed by the last 20 years data, during which the SPI is almost always negative. At the seasonal time scale the cyclic pattern is not observed. 4) The annual precipitation variation is mostly related to a variation of the PD, while MI has only e secondary influence.

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