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MULTISCALE CLIMATOLOGY OF DAILY RUNOFF AND MONTHLY TEMPERATURE AND PRECIPITATION SINCE THE MID 19TH CENTURY IN TWO ALPINE RIVERS

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ABSTRACT

Daily runoff data of the Adda and of the Adige river basins, in northern Italy, were recovered by digitizing old yearbooks for the 1845-2016 and 1862-2011 period, respectively. Monthly areal precipitation, temperature and potential evapotranspiration were estimated for the same period at the spatial scale of the two catchments. A statistical analysis applying the Mann-Kendall and Theil-Sen trend tests shows, for the common 1862-2011 observation period, a small decline of precipitation and a more significant one of runoff. To analyse changes occurred at different time scales a wavelet spectrum points out one drought in the 2005s which is more severe than that of the 1940s. The Fourier power spectrum of the daily runoff data shows a signal of higher energy corresponding to a period between 11 and 13 years, close to the sunspots cycle period, but the coherence of solar energy and runoff in terms of wavelet co-spectrum results not to be significant. The co-spectrum of monthly runoff and the North Atlantic Oscillation, instead, exhibits a slightly significant coherence for the 11-13 years scale. More relevant than the precipitation decrease is the decline of runoff, which can be explained only in part as a result of increased evapotranspiration losses due to the temperature increase, estimated by monthly indexes. Therefore, other anthropic factors need to be considered, as enhanced water needs for irrigation or land use changes, to explain the increased water losses. The meteorological and hydrological data sets collected are useful to explain long term variability and better assess the impact of climate change and other forcing factors on the hydrological cycle and resulting water resources management practices in the Alps.

Keywords: Trend detection, Adda River, Adige river, wavelet transforms, long- term records

1 INTRODUCTION

Climate change and its impact of water resources is a central topic not only in the agenda of politicians and media but also in that of water engineering, as also in the design and water resources management practices (Kolokhyta et al., 2017) changes in hydrological variables observed or projected needs to be taken in account more and more frequently. As a consequence, the collection and analysis of long-term time series of hydrological data is becoming crucial not only for improving the understanding of the Earth's climate variability, but also for their practical implication.

The community of climatologists and meteorologists has been dedicated for decades in collecting, sharing and processing long-term meteorological data in large geographical areas (Brunetti et al., 2009). This did not occur at the same for creating multi-century data sets of daily runoff series.

Multi-decadal analyses of variability and trends of runoff are available at regional and global scale. Su et al. (2018) recently published the results of the trend analysis for the period 1948–2004 of the monthly and annual outflows of 916 rivers worldwide, flowing into the oceans, showing that for 120 of them the trends are positive, while for 51 they are negative with a statistical significance of 5%. Considering extremes, an important study on a European scale has made it possible to identify variations in the last fifty years, not so much in the intensity of the floods, as in their seasonal distribution (Blöschl et al., 2017). However, because a clear pattern of climate change impact on hydrological extremes and mean annual and monthly riverflows has not been achieved yet at the global scale, this paper intends to provide a small contribution by presenting some steps forward in the analysis of two long term time series of the Adda and Adige river basins, partially discussed already in Ranzi et al. (2017).

2 DATA ANALYSIS AND DISCUSSION

The analysis was carried out in two of the most important river basins of Italy- namely Adda and Adige, located in the alpine region of Northern Italy- by collecting daily runoff data and reconstructing when necessary, for the periods 1845-2016 and 1862-2011, respectively. The Adda study basin has an area of 4508 km^2 with outlet at Lecco, while Adige is found adjacent to Adda, with an area of 9763 km^2 and with an outlet in Trento (Figure 1). Precipitation data were provided by processing observations collected in the HISTALP project (Brunetti et al., 2009) and further completed by a more comprehensive data collection and processing (Crespi et al., 2018). Runoff data were provided by completing the official hydrographic series with observations recorded in old yearbooks, after a careful quality check.

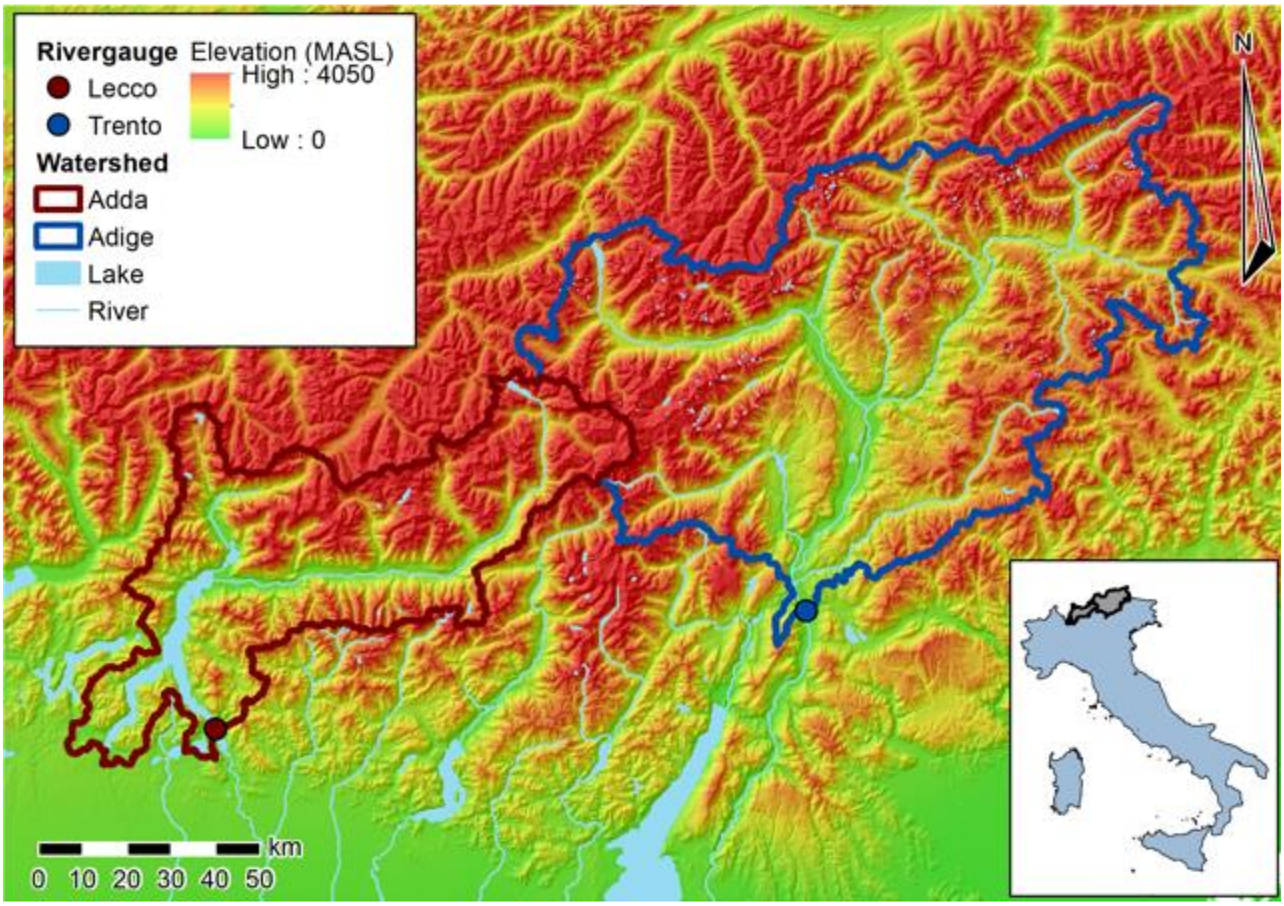

Figure 1. The area investigated in our multiscale analysis of precipitation and runoff over a 150-year time period.

Table 1. Mann-Kendall Z statistic, along with p-values and Theil-Sen slope for the annual runoff, precipitation and temperature of Adda and Adige river basin over the common monitoring period 1862-2011. In bold statistics significant at 5% level.

		Z_{MK}	P-VALUE	THEIL-SEN (MM YR^{-1} OR ^{o}C YR^{-1})
ADDA (4508 KM^2)	RUNOFF	**-2.55**	**0.01**	**-1.09**
	PRECIPITATION	-0.91	0.36	-0.48
	TEMPERATURE	**8.095**	**0.00**	**0.0107**
ADIGE (9763 KM^2)	RUNOFF	**-5.49**	**0.00**	**-1.34**
	PRECIPITATION	-1.04	0.30	-0.31
	TEMPERATURE	**3.885**	**0.00**	**0.0057**
ADDA AND ADIGE (14271 KM^2)	RUNOFF	**-4.28**	**0.00**	**-1.26**
	PRECIPITATION	-1.03	0.30	-0.37
	TEMPERATURE	**5.249**	**0.00**	**0.0073**

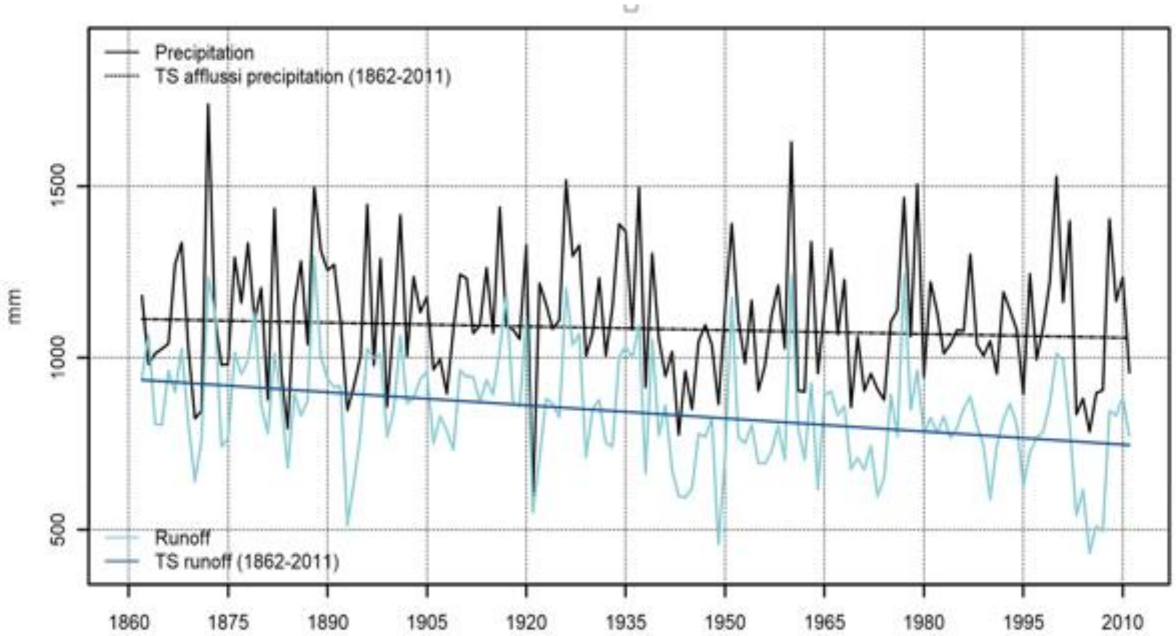

Figure 2. Theil-Sen trend of annual precipitation (a) and annual runoff (b) of the Adda + Adige riverbasin (1862-2011).

Trend tests with the Sen-Theil estimator were carried out in both basins for their respective runoff, precipitation and temperatures and their results demonstrated a striking similarity (Table 1). A general decrease of runoff in the entire period was observed for both basins, with -10.9 and -13.4 mm/decade for the Adda and Adige, respectively. At the same time precipitation showed a decreasing but not significant trend in both cases (Figure 2), while the mean annual temperature increased significantly with a trend of +1.07 and +0. 57 ^{o}C century^{-1} for Adda and Adige, respectively. Possible reasons for this significant decrease in runoff were sought through spectral analysis.

In the fictitious basin obtained by combining the Adda and Adige river basins precipitation exhibits a decreasing trend of -3.7 mm decade^{-1}, but not significant at 5% significance level, while runoff is significantly decreasing with a -12.6 mm decade^{-1} tendency. This means that the runoff coefficient decreases.

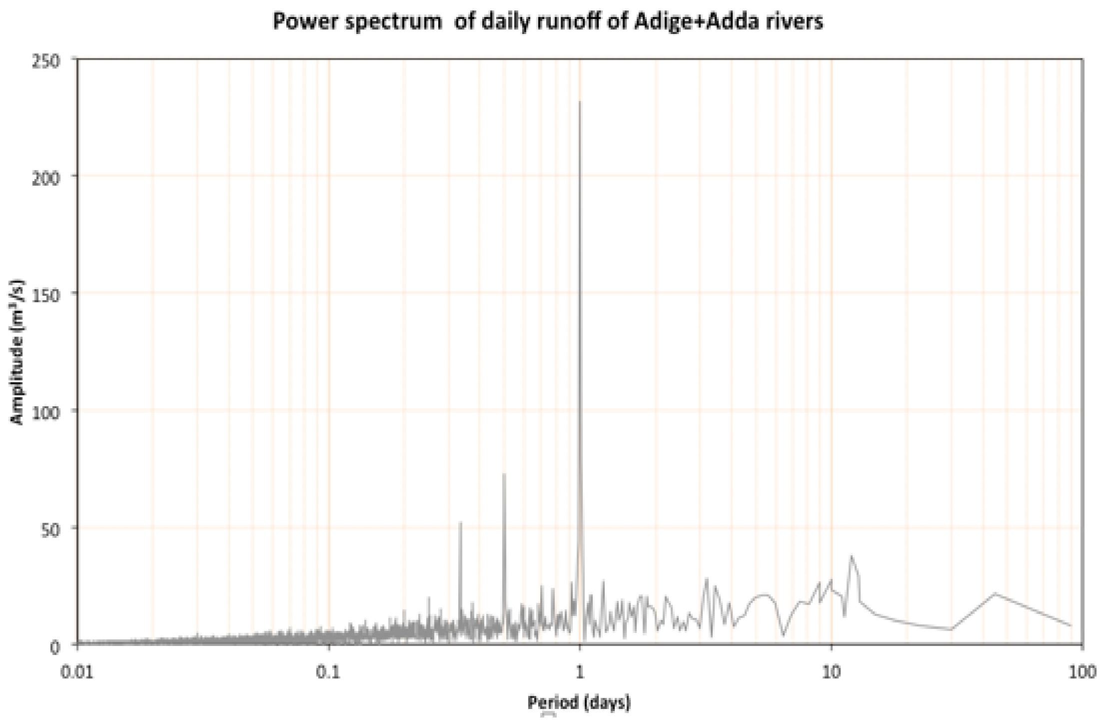

Figure 3: Fourier spectrum of the daily runoff data for the sum of Adda and Adige river basin, showing the annual, 6-monthly and 3-monthly period, but also a secondary energy peaks corresponding to a 12-year period.

The Fourier spectrum of the 150-year time series of the sum of daily runoff of Adda and Adige basins is shown in Figure 3, pointing out the 1-year, 6-month and 3-month period harmonics needed to reconstruct the asymmetric annual runoff cycle. But also a secondary peak with an, approximately, 12-year period is observed. A similar spectrum is exhibited by the wavelet spectral analysis shown in Figure 4.

Worth noticing is the gap in energy of the runoff wavelet spectrum in correspondence with the drought at the beginning of the 21st century, much more evident that that in the 1940s, 1970s and 1990s. A general decreasing trend in the energy for the entire 1862-2011 period at annual scale is observable and confirms the results of the trend analysis of annual runoff. Additionally, a secondary peak at the 12-year period in the wavelet spectrum is noted as well, although it is not significant at 5% level, as shown by the comparison with the red dotted line in Figure 4. This observation suggests a possible link with the solar activity period or with other climatic teleconnections. Following a conjecture by Zanchettin et al. (2008), who pointed out a possible link of runoff with solar activity in the 200-year time series of the Po river, we estimated a wavelet coherence spectrum of runoff with sunspot numbers for the Adige and Adda river basin. No significant coherence was found, however, between these two signals. A more significant one, was found, instead, for the wavelet coherence spectrum between monthly North Atlantic Oscillation (NAO) indices and the sum of runoff of Adda and Adige which revealed a region of significant phase coherence at a period of around 12 years, starting from 1875 and ending in 1960 (see Figure 5). A negative correlation between NAO and precipitation is indeed reported in the literature for this region (Steirou et al., 2017; Wrzesiński and Paluszkiewicz, 2011; López-Moreno et al., 2011; Shorthouse and Arnell, 1999). However, questions can be raised regarding the significance of its influence on alpine regions, where precipitation variability can be considered as endogenous and whose driving force is a combination of climate but also, and maybe more importantly, topography (Bartolini et al., 2009). In any case, it should be noted that this 12-year cycle remains of secondary importance in terms of amplitude in respect with the 1-year cycle which is the only one significant at 5% level. Other teleconnection indexes relevant for the Alpine region, as the AMO-Atlantic Multidecadal Oscillation of the Western Mediterranean Oscillation could show a possible link with runoff even at different scales.

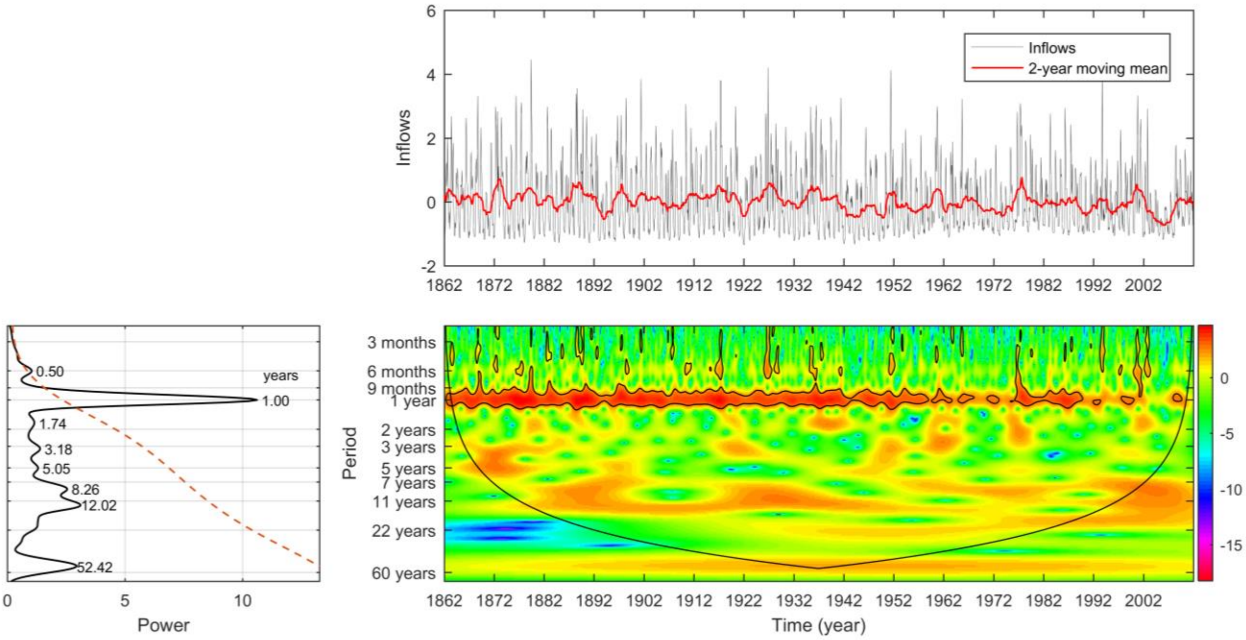

Figure 4. Standardized time series, wavelet spectrum and global wavelet spectrum of the sum of the monthly inflow runoff of Adda and Adige river for the common period of 1862-2011; 5% significance levels are marked with black contour lines in wavelet spectrum and COI; in global wavelet spectrum 5% significance levels are marked with a dotted red line.

We started to investigate the possible reasons of the runoff decline which seems not to be induced by the slight decrease of precipitation only. A mean areal temperature index for the two basins was computed and plotted in Figure 6. Since temperature has increased during the entire observation period, a plausible explanation of the decrease in runoff could be the increased evapotranspiration losses. However, in both basins potential evapotranspiration, calculated with a simple Thorthwaite-Mather method for reference crops, and plotted also in Figure 6, cannot justify this increase. In fact the observed hydrological losses estimated as the difference between precipitation and runoff in the hydrological years, from September to October, exhibit an increasing trend more marked than that of potential evapotranspiration.

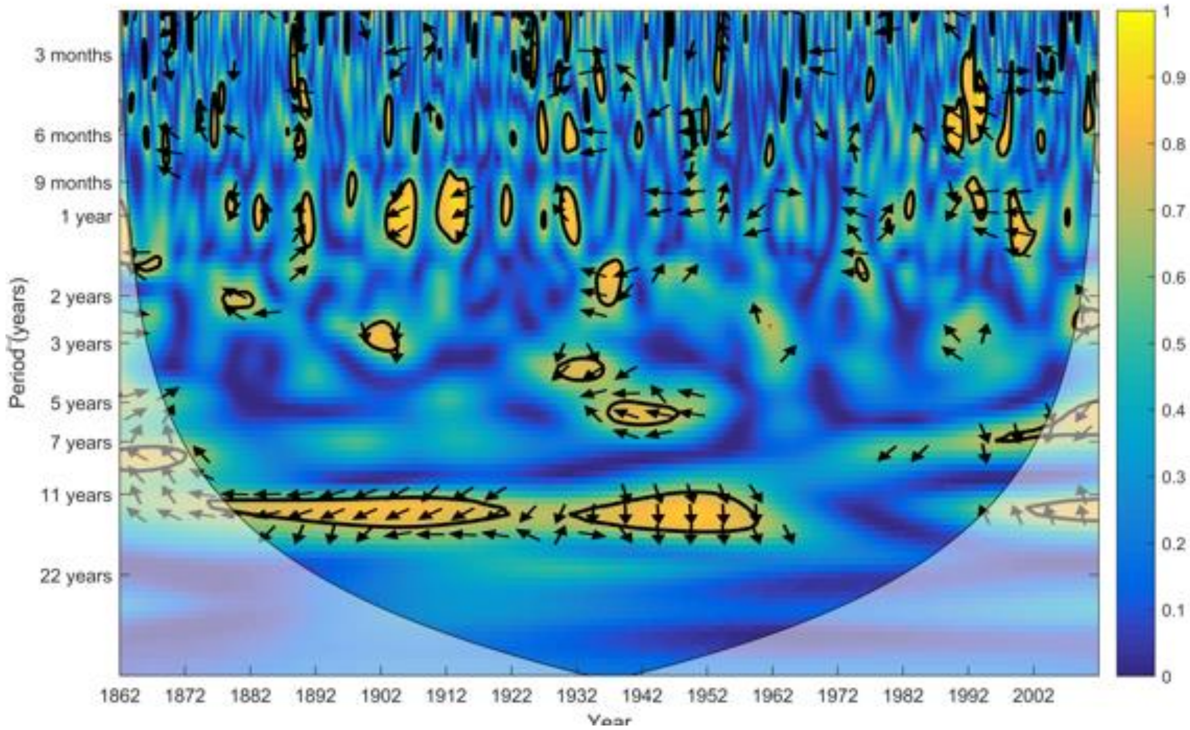

Figure 5. Wavelet coherence spectrum of NAO monthly index and monthly runoff of Adda and Adige river, 5% significance levels are marked with black contour lines and COI; arrows pointing to the right indicate in-phase between the two variables, arrows pointing down a lead of the first variable by 90° and left-pointing arrows indicate anti-phase.

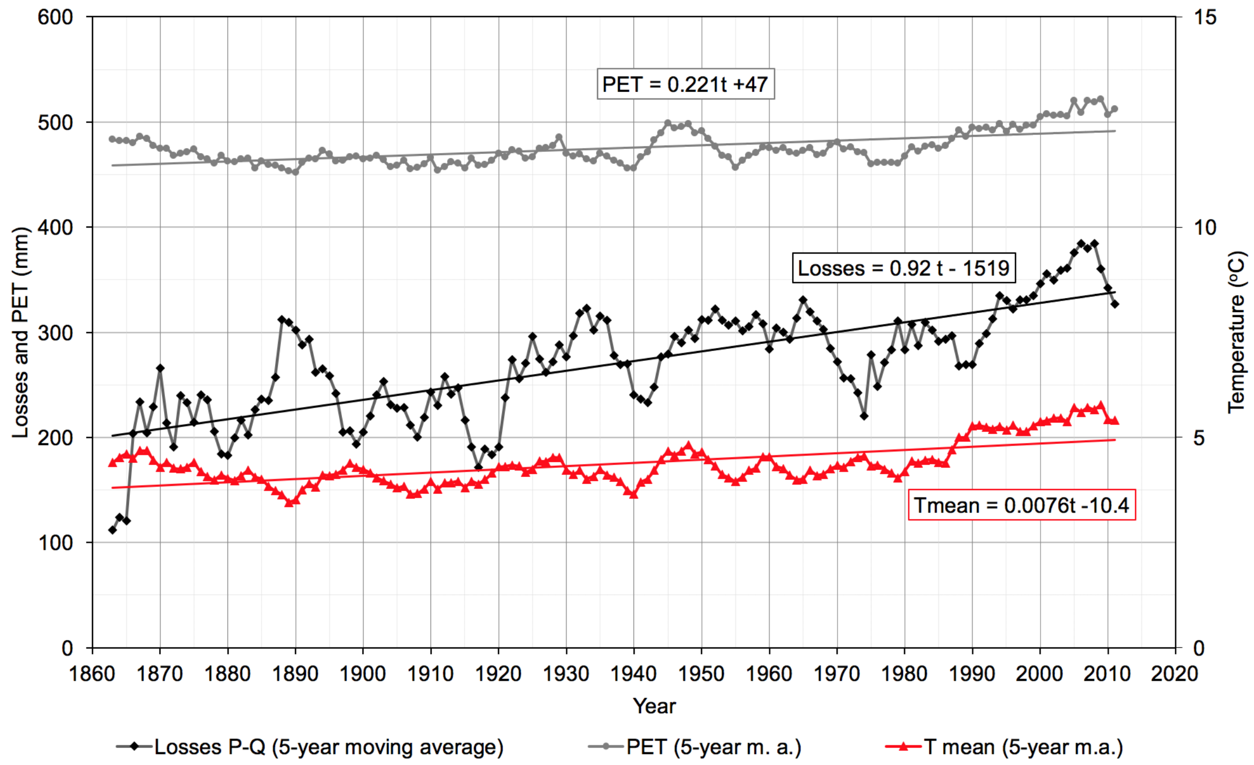

Figure 6. Actual losses, mean areal temperature, and potential evapotranspiration in the Adige + Adda riverbasins in the 1862-2011 monitoring period

The 2.2 mm decade^{-1} trend observed for potential evapotranspiration results from the 0.76 °C century^{-1} temperature increase only, as land use and soil properties are assumed constant over the monitoring period. Instead the 9.2 mm decade^{-1} observed losses are a result also of anthropogenic factors, as land use changes or water consumptive uses mainly for irrigation or water supply. Worth to notice is the gap between estimated potential evapotranspiration and the observed losses which can be ascribed in part to an underestimation of areal precipitation because of the systematic measurement errors of snow precipitation and orographic precipitation effects which cannot properly detected by raingauge networks.

Land-use changes could have influenced runoff since in the Alps and Europe forested areas continue to expand their extent (FAO, 2016) as noted also by Ranzi et al. (2017) for the Adige basin. Detailed quantitative measures of these changes are in progress and first analyses confirm this tendency also for the Adda river basin.

Regarding consumptive uses for irrigation or water supply, an estimate was conducted for the Adda river basin, where water needs for irrigation and anti-frost sprinklers for the 2 200 hectares of crops (mainly fruit trees, vineyards and corn), upstream the Como Lake, and the uptakes from the lake for a civil and industrial aqueduct amount to about 20 mm year^{-1}, out of the 1102 mm of runoff observed in the last decades in the Adda river basin.

3 CONCLUSIONS

The primary driving forces of precipitation and runoff were investigated in the two alpine basins of Adda and Adige in Northern Italy. Trend tests were carried out in order to detect changes in the runoff regime spanning the common 150 years of observations for the Adda and Adige river basins. In both basins similar patterns were seen, namely a non-significant decrease in precipitation and a significant decrease in runoff through the entire period.

Wavelet spectra analysis highlighted this decrease in runoff energy in the entire observation period, intensifying around 2005 during a severe drought. A secondary energy peak was observed, as well, around the 12-year scale, present also in sunspot number and NAO spectra. Wavelet coherence spectra between the hydrological variables and the sunspot numbers failed to indicate areas of phase coherence and thus, a cause-effect relationship between the variables. A more probable but time- and scale-localized correlation was observed in the wavelet coherence spectrum of monthly NAO indices and the sum of runoff of Adda and Adige. Significant and slightly intermittent phase coherence areas were present in the coherence spectrum around the 12-year scale in the period 1875-1960, however since the amplitude of a 12-year cycle is much weaker than the one of the 1-year cycle anthropic factors were investigated also to explain the decrease of runoff.

Since the temperature increase only and the resulting enhanced potential evapotranspiration are not sufficient to explain the increasing observed water losses anthropic factors are a very likely reason of the runoff coefficient decrease. Consumptive uses of irrigation, civil and industrial needs are assessed as 20 mm yr^{-1} out of 1102 mm yr^{-1} of observed runoff in the Adda basin. In addition, a general increase in forested areas is observed in some test sites in the two basins over the last decades and they could have induced an increase of actual evapotranspiration losses and a runoff decrease. Therefore, a more extensive land-use change detection and quantitative assessment are necessary in order to draw safe conclusions about the changes in runoff regime in these vast river basins, in addition to climatic and hydrometeorological analyses.

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