EPiC Series in Engineering
Volume 3, 2018, Pages 1727–1734
HIC 2018. 13th International Conference on Hydroinformatics

Detection of rainfall and runoff trends of the Adda river in Lecco (1845-2014) at different time scales

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Abstract

A recovery of ancient records of the Como Lake water levels at the Fortilizio in Lecco hydrometric station enabled the reconstruction of a time series of daily water level and runoff from the Como Lake spanning the 1845-2014 period. In parallel, the monthly areal precipitation at the Adda river catchment scale was estimated for the same 170 years-long period. This time series, which is one of the longest available for Italian riverbasins will support analyses of the reasons of changes in the runoff regime in response to climatic and anthropogenic changes. A comparison of the two series applying the Mann-Kendall, Spearman and Theil-Sen trend tests, shows a decline, in the long term, of runoff and a more significant one of precipitation. Because some changes in the operation at the outlet of the Como Lake occurred after 1946 and also in the storage capacity of the upstream reservoirs the time series was splitted in two periods, before and after 1946. The results of the statistical tests for both precipitation and runoff in three time periods are consistent, but only for the time series of annual runoff the decline is statistically significant with 5% significance level. To analyse if changes occurred at different time scales the wavelet transform was applied to the daily runoff series. Finally the Fourier power spectrum of the 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, and its significance is under investigation.

1 Introduction

The data set of daily water level of lake Como and daily outflows from the lake are reconstructed using different sources of data coming from the Adda River Authority and from the National Hydrographic Service. With a process of digitalisation of historical hardcopy and by getting the missing data from the other stations, the complete data set from 1845 to 2014 of daily water level and outflows recorded at the station of Fortilizio at the lake's outlet is obtained. From 1845 to 1945, the daily inflows are obtained solving the continuity equation and using the data of daily outflows at Fortilizio and water level at Malpensata and Malgrate stations. From 1946 to 2014 the inflows are given by the Adda River Authority and they are obtained using the outflows referred to Lavello station, which is located downstream the dam. Statistical Mann-Kendall, Spearman and Theil-Sen slope tests are used to analyze the time series of both rainfall and runoff of the Adda river, characterized by conflicting water resources management and flood protection issues, especially during the last decades. Trend analyses of both annual amounts and extreme values of runoff have been analyzed on the basis of the unpublished second longest time series of daily runoff available for Italian basins, spanning over 170 years in total as shown in Figure 1 where the water level, runoff inflow into the lake and outflow from its outlet are shown. Another 200-year long times series of long term runoff records in Italy is available for the Po river at Pontelagoscuro (Zanchettin et al., 2008a), but the corresponding river section is less stable than the Como Lake's outlet and so, in our opinion, these data are less accurate and precise than the Adda river ones. Spectral analyses were performed for the daily runoff time series which has a mean value of 165 m^3/s and includes the largest flood ever recorded for the region of the southern Alps, the 1868 one, with a maximum value of 2520 m^3/s.

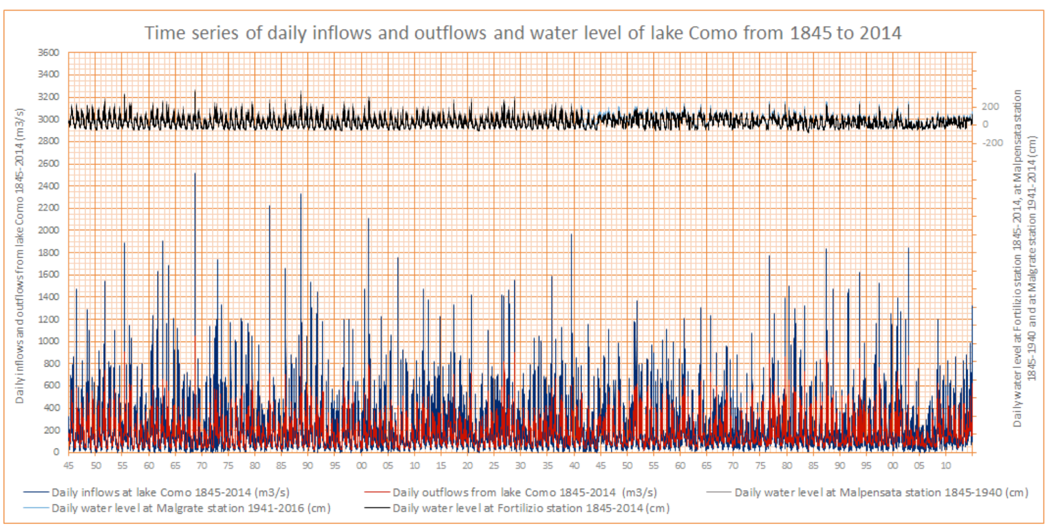


Figure 1: Time series of the daily water level at the Fortilizio in Lecco station (top), daily inflow and outflow of the Adda river from the Como Lake (bottom).

2 Materials and methods

In addition to the runoff data, reconstructed as described briefly in the introduction, 747 monthly precipitation series covering the Adda upper basin and neighbouring areas were considered. Data coverage over Adda basin is about one station per 70 km^2. Series are retrieved from the archive of the National Hydrographic Service, several regional services, MeteoSwiss and previous projects of the last three authors. All the series are subjected to quality-check and homogenisation by means of the Craddock test in order to correct not climatic signals (Ranzi et al., 2017). 1961-1990 monthly normals are then computed for each site after filling the gaps in the climatological period by means of neighbouring stations. High-resolution 1961-1990 precipitation climatologies of the study area are computed by performing a local weighted linear precipitation-elevation regression (LWLR) at each cell of a smoothed 30-arc-second-resolution Digital Elevation Model (DEM) (Figure 2). Monthly records of the longest and most homogeneous series are converted into monthly anomalies as ratio to corresponding 1961-1990 normals. 1845-2014 monthly anomalies series are computed for each point of the 30-arcsec grid by a weighed average of neighbouring stations.

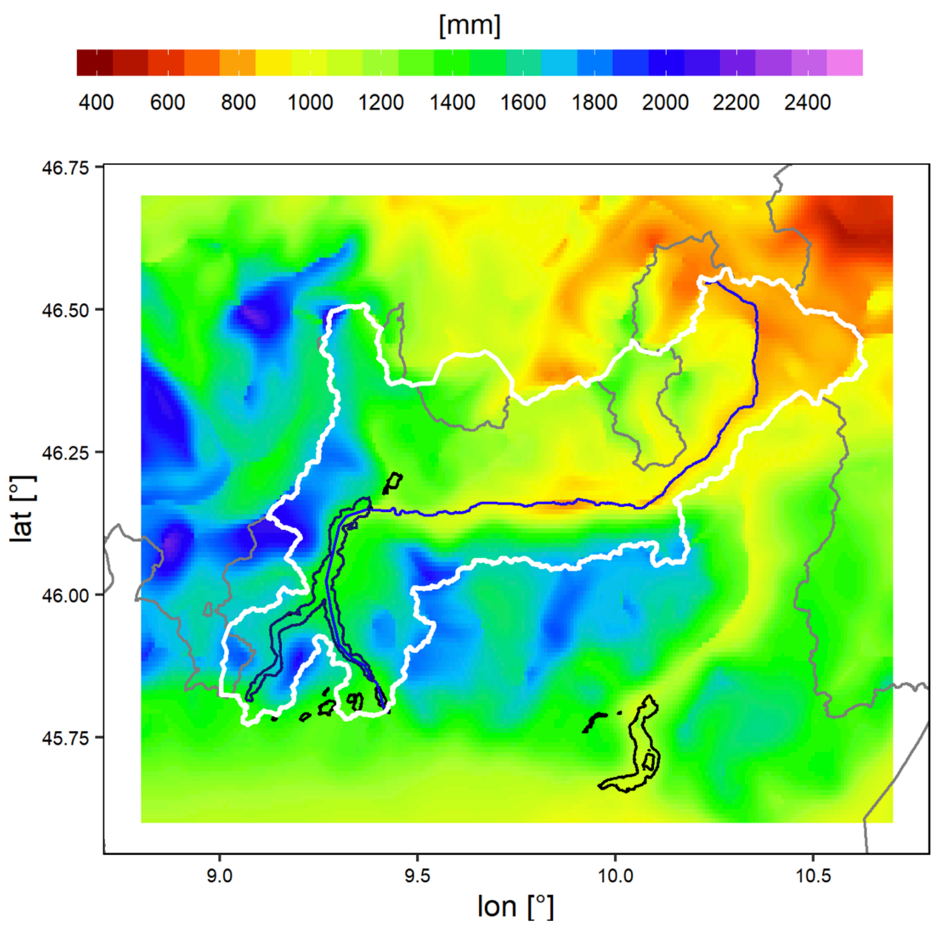
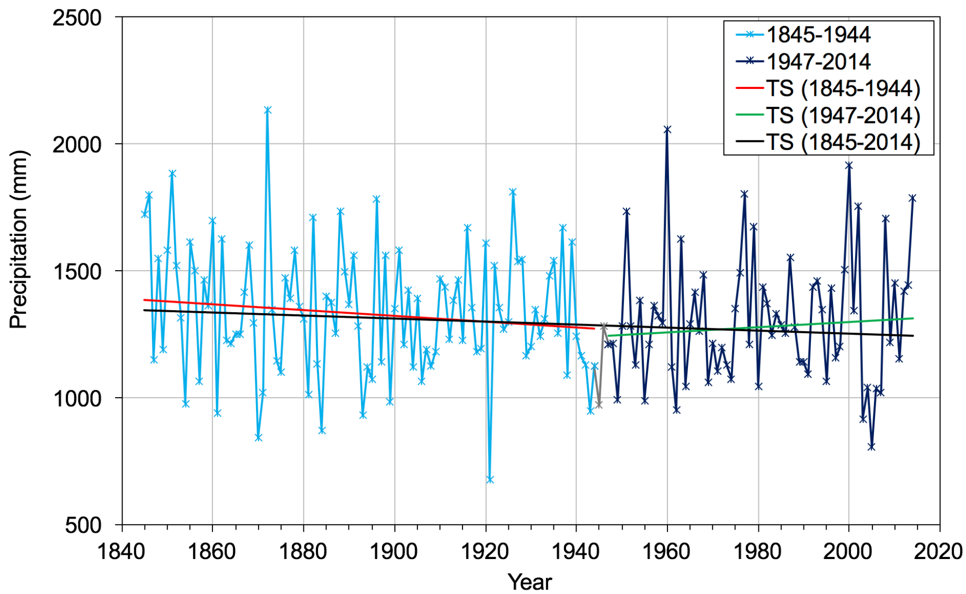


Figure 2: 1961-1990 climatology of mean annual precipitation computed for the investigated area based on 747 monthly precipitation data. The watershed divide of the Adda riverbasin gauged at the Como Lake's outlet is outlined in white. Administrative boundaries are in grey.

Mann-Kendall, Spearman rho-test, and Theil-Sen slope tests, as described in Brunetti et al. (2012), were performed on the mean annual precipitation, inflow and outflow and on annual maxima of inflow as well. The observation period was divided in two parts as after 1946 the operation at the gates at the lake's outlet and the increase of storage capacity in the upstream reservoirs introduced a non-stationarity in the series. It has to be pointed out, however, that at the annual scale this non-stationarity has negligible effects on the trend analysis.

3 Results and discussion

Table 1 shows, in summary, some key findings in the trend analysis, depicted also in Figure 3 and 4 where the annual precipitation and annual runoff series are plotted. Both precipitation and runoff series show a decline in the pre-regulation period (1845-1944) and an increase in the post-regulation period (1947-2014). Also the precipitation and runoff trends over the long term period (1845-2014) are consistent, showing a decline, but only the runoff series decrease is significant at 5% significance level. The long-term decrease of runoff can be possibly explained arguing an increase of evapotranspiration losses due to the temperature increase and the expansion of forested areas in the last decades (Brunetti et al., 2012). In addition, water uptake for irrigation purposes is a reason of this significant decline of runoff. On the other hand, the recent slight increase of runoff may be explained as a response to the increase of precipitation, but also as an effect of the 20 mm of annual specific runoff volume diverted since 1960 to the Adda river from the Spöl river, a tributary of the Inn and Danube, where an artificial reservoir was built.



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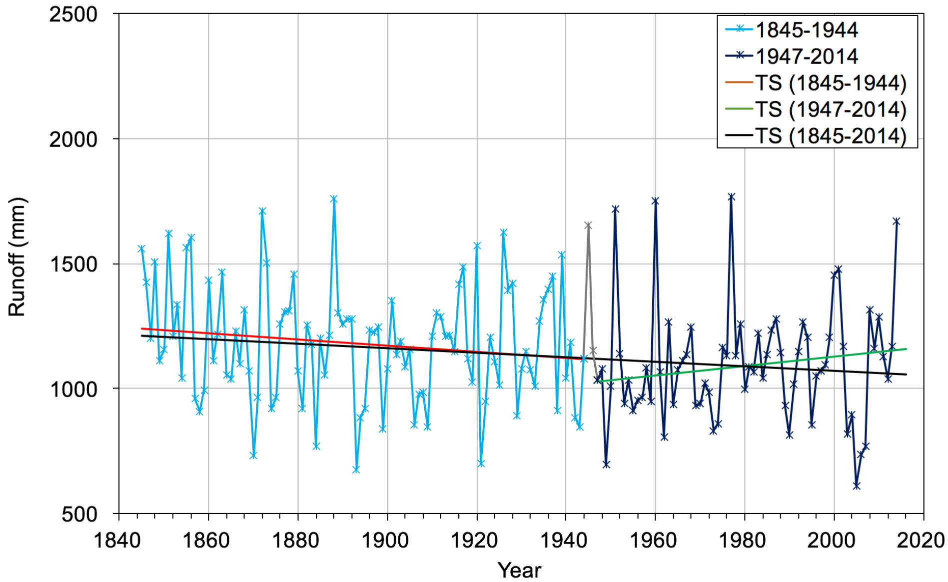

Figure 4: Time series of annual runoff outflow from the Como Lake and trend lines estimated with the Theil-Sen method for three periods, indicated in Table 1.

Series	Mean (mm)	St. dev (mm)	Z_{MK}	Z_{SR}	Trend LS (mm a^{-1})	Trend TS (mm a^{-1})	Conf. interval TS (mm a^{-1})	Period	N
Runoff	1182	232	-1.429	-1.414	-1.177±0.800	-1.217	(-2.935, 0.518)	1845-1944	100
	1096	231	1.519	1.443	0.890±1.431	1.896	(-0.602, 4.182)	1947-2014	68
	1150	**237**	**-2.471**	**-2.504**	**-0.899±0.364**	**-0.902**	**(-1.636, -0.195)**	**1845-2014**	**170**
Precipitat.	1343	252	-1.260	-1.290	-1.219±0.870	-1.130	(-2.946, 0.730)	1845-1944	100
	1307	249	0.715	0.759	0.925±1.545	1.059	(-1.932, 4.000)	1947-2014	68
	1326	251	-1.426	-1.413	-0.508±0.391	-0.593	(-1.371, 0.228)	1845-2014	170

Table 1: Trend analysis of annual outflow runoff from the Como Lake and annual precipitation (significant trends in bold).

Another source of additional runoff in the last decades is the glaciers' retreat both in term of areas (reduced from 92 km^2 in the 1960s to the actual 65 km^2) and thickness, with an average loss of about 1 m a^{-1} water equivalent in the last decades. Finally the Fourier power spectrum of the the daily runoff data after linear detrending, shows, in addition to the obvious annual cycle, with three main energy peaks, a signal of higher energy corresponding to a period of about 12 years, close to the sunspots cycle period which some authors assume may influence the hydrological cycle (Zanchettin et al., 2008b). The statistical significance of this energy peak is under further investigation because in the scientific literature about this issue a consensus is not achieved about the evidence of a significant correlation between precipitation or runoff series and sunspot numbers (Rodriguez-Iturbe & Yevjevich (1968).

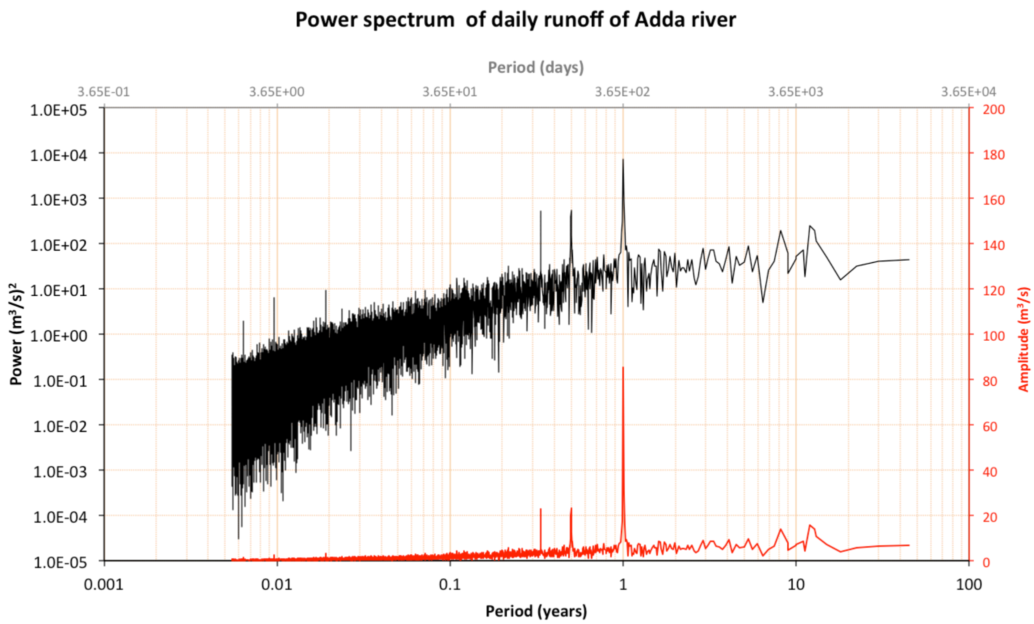

Figure 5: Fourier power and amplitude spectrum of the daily runoff data for the Adda river, showing the annual, 6-monthly and 3-monthly period, but also a secondary energy peaks corresponding to a 12-years period. The amplitude spectrum is the average amplitude of the Fourier spectrum of two series of 2^15 data obtained by splitting the 170 years data in two parts.

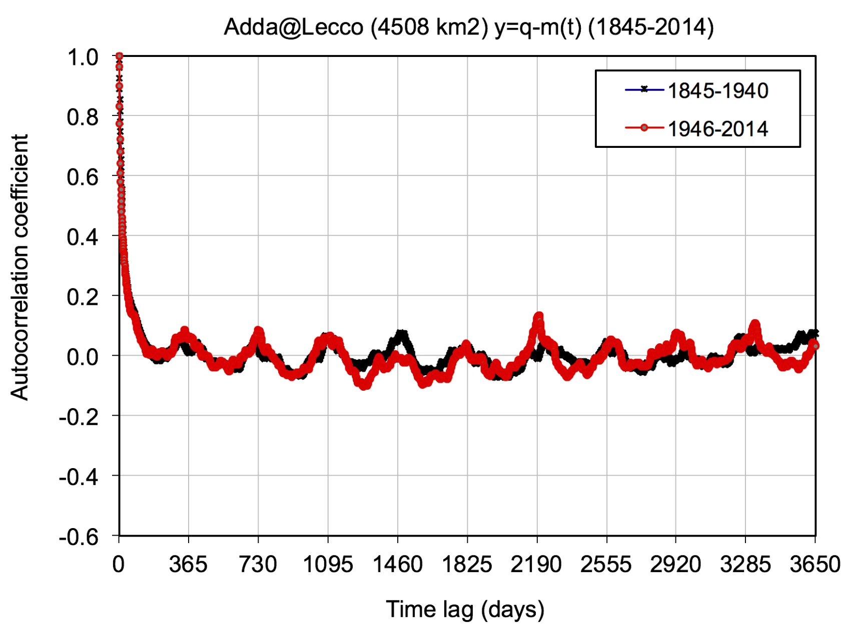

Figure 6: Time-autocorrelation function of the time series $y(t,d)=q(t)-m(d)$ of observed ouflow flow the Como Lake deseasonalised by subtracting the mean $m(d)$ in the Julian day d.

The availability, however, of such a long time series of daily runoff data (Ranzi et al., 2018) provides material for detailed analyses of hydrological data, looking for the existence of multiannual patterns and cycles in runoff data as discussed, for instance, by Blöschl et al. (2017) about floods in Europe.

Another interesting result of the time series analysis is shown in Figure 6, where the autocorrelation function of the outflow from the Como Lake $q(t)$, deseasonalised with the long-term mean $m(d)$ of runoff in the Julian day d, is plotted. The figure shows a rapid decline of the autocorrelation with time constant of about 25 days – about 60 day for the original data (Ranzi et al., 2018) – but also the vanishing of the long-term memory after one year, as the pattern of the autocorrelation is basically the same with a time lag of one or more years, up to a decade. It can also be observed that the function is very similar in the pre-regulation period (1845-1940), when no human decision modifies the outflow, and the post-regulation period (1946-2014), when the Adda water authority managed a barrage to meet the objectives of irrigation and hydropower demand downstream taking into account also flood control on the lake's shores.

4 Conclusions

The second-longest time series of daily runoff for Italy, and possibly the most reliable one, that of the Adda river inflow and outflow of the Como Lake, is analysed for detecting trends, periodic patterns and persistence. An overall decline of annual rainfall and runoff is observed, consistent in sign over three periods, but only the runoff trend over the 170 years spanning from 1845 to 2014 is statistically significant at 5% significance level. Meteorological, climatological, hydrological and anthropic factors can explain these trends, including the natural variability of precipitation, the increased evapotranspiration losses due to temperature and forest cover increase, diversion of a river for hydropower exploitation, glacier's retreat. This case study, relevant for the Mediterranean area, indicates how conclusions about the impact of climate change on runoff need a careful analysis of the development of the catchment over the monitoring period. An open question is the possible influence of solar activity on the hydrological cycle, but further investigations on these data and in other catchments are needed. Preliminary analyses of changes occurred at different time scales with the wavelet transform exhibit an increase of energy at high frequency scales, while the pattern at other scales is consistent with the overall runoff trend. The cross-wavelet spectrum exhibits no significant coherence between solar activity and runoff.

5 References

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