Hydrol. Earth Syst. Sci. Discuss., 9, 6689–6713, 2012
www.hydrol-earth-syst-sci-discuss.net/9/6689/2012/
doi:10.5194/hessd-9-6689-2012

Hydrology and
Earth System
Sciences
Discussions

Hydrology of the Po River: looking for changing patterns in river discharge

A. Montanari

Department DICAM, University of Bologna, Bologna, Italy

Received: 13 May 2012 – Accepted: 19 May 2012 – Published: 30 May 2012

Correspondence to: A. Montanari (alberto.montanari@unibo.it)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

Scientists and public administrators are devoting increasing attention to the Po River, in Italy, in view of concerns related to the impact of increasing urbanisation and exploitation of water resources. A better understanding of the hydrological regime of the river is necessary to improve water resources management and flood protection. In particular, the analysis of the effects of hydrological and climatic change is crucial for planning sustainable development and economic growth. An extremely interesting issue is to inspect to what extent river flows can be naturally affected by the occurrence of long periods of water abundance or scarcity, which can be erroneously interpreted as irreversible changes due to human impact. In fact, drought and flood periods alternatively occurred in the recent past in the form of long term cycles. This paper presents advanced graphical and analytical methods to gain a better understanding of the temporal distribution of the Po River discharge. In particular, we present an analysis of river flow variability and memory properties to better understand natural patterns and in particular long term changes, which may affect the future flood risk and availability of water resources.

1 Introduction

The Po River is known to the public as the longest river entirely flowing in the Italian peninsula, being its main stream about 652 km long. It is also the Italian river with the most extended catchment, whose area is about 71 000 km^2 at the delta. Its observed discharge time series at the closure river cross section, which is conventionally located at Pontelagoscuro (44°53′19.34′′ N and 11°36′29.60′′ E), includes the top observed values in Italy of minimum, average and maximum daily river flow, that are 275 m^3 s^{-1}, 1470 m^3 s^{-1} and 10 300 m^3 s^{-1}, respectively. The Po River has 141 main tributaries and the related river network has a total length of about 6750 km and 31 000 km for natural and artificial channels, respectively. The average volume of annual precipitation is

$78 \times 10^9\,\mathrm{m}^3$, of which 60 % is converted in outflow volume at the closure section. About 450 lakes are located in the Po River basin. The water level of the larger south-alpine lakes of glacial origin is regulated according to given management policies, therefore obtaining a regulation volume of $1.3 \times 10^9\,\mathrm{m}^3$ approximately. It is interesting to mention that 9 hydro-ecoregions are identified within the Po River (Po River Basin Authority, 2006), which are defined as geographic areas where freshwater ecosystems have a limited variability in terms of chemical, physical and biological characteristics.

The above synthetic description clearly highlights the complexity of Po River basin, where significantly different hydrological behaviours and ecosystems coexist and co-evolve. In fact, it is interesting to note that the Po River Basin Authority (2006) has identified 12 different fluvial regimes in the Po catchment. Figure 1 presents a schematic map of the Po River basin, while Fig. 2 shows the spatial distribution of rainfall over the catchment.

The story of the Po River floods is well known. Historical information enables us to assess that 22, 14 and 18 floods occurred in the XVIth, XVIIth and XVIIIth century, respectively. The 1705 flood is remembered as a particularly destructive event. In the XIXth century there were 19 floods, with the severest ones occurring in 1801, 1839, 1846, 1857, 1868 and 1872. The most important floods in the XXth century occurred in 1926, 1928, 1937, 1945, 1949, 1951, 1953, 1957, 1959, 1966, 1968, 1976, 1977, 1986, 1993, 1994 and 2000. The 1951 flood was particularly severe, with inundations due to broken embankments occurring at Gualtieri (close to Reggio Emilia) and Occhiobello (close to Ferrara).

The hydrological behaviours of the Po River has been extensively studied, especially for what refers to the flood regime (see, for example, Marchi, 1994; Visentini, 1953; Piccoli, 1976; Zanchettini et al., 2008). However, many relevant questions are still open on the hydrology of the Po river, and in particular regarding the impact of the intense human activity that has developed in the catchment during the XXth century and the impact of climate change. In fact, the occurrence of long periods characterised by abundance or scarcity of river flows led to the development of scientific questions that are largely unexplored.

In a more general context, the analysis of the memory properties of complex river systems is attracting a renewed interest today, in view of the related implications on natural hydrological variability in the face of environmental change. Within this respect, a relevant role is played by long term persistence, which means that river flows may remember their past for a very extended period (Mudelsee, 2007; Koutsoyiannis, 2003, 2010). As a matter of fact, long term persistence implies the presence of cycles that may behave as irreversible tendencies in the short term and therefore have important consequences on flood mitigation and water resources management.

This paper makes use of advanced graphical and analytical techniques to inspect the variability of the Po River flows and their memory properties, to gain a better understanding of the behaviours of the river regime, the possible presence of footprints of human impact and the occurrence of the above anomalous periods of water abundance and scarcity.

2 Anthropisation and sustainability

The downstream reach of the Po River flows across the Padana Plain, a flat and fertile area that is very attractive for human settlement. In fact, it experienced an intensive agricultural and industrial development during the XXth century, in particular after the Second World War. Currently, about 17 million people live in the Po River basin, where 40 % of the gross domestic product of Italy is produced (Po River Basin Authority, 2006). Employment, agricultural production and energy consumption in the Po River basin amount to 46 %, 35 % and 48 %, respectively, of the Italian total. In fact, water resources are intensely exploited in the catchment for irrigation, hydro-power production, civil and industrial use. The mean annual hydrological balance for the Po River basin is summarised in Fig. 3. In detail, in addition to the aforementioned average volumes of annual precipitation and river discharge at the outlet, the annual inflow to the underground aquifer is approximately 9×10^9 m^3, while the withdrawal is 6.5×10^9 m^3. These latter values reveal that groundwater resources are close to overexploitation and therefore the margins to ensure future sustainability are limited, especially during years with lower than average rainfall. The annual water withdrawal for irrigation is 17×10^9 m^3, while the evapotranspiration volume is approximately 22×10^9 m^3. This latter estimate includes the evapotranspiration fluxes induced by irrigation. Water withdrawals for industrial and civil use amount to 5×10^9 m^3, 80 % of which being withdrew from groundwater.

The overall situation depicted in Fig. 3 reveals an intense exploitation of water resources that is currently sustainable on average, as we previously mentioned, but it is potentially problematic during drought periods. It is clear that efficient water resources management strategies are needed to ensure future sustainability of water uses, which need to be supported by a detailed analysis of river discharge variability. Not surprisingly, this research area is gaining an increasing attention by the international scientific community (see, for example, Bloeschl and Montanari, 2010).

3 Analysis of river discharge variability

3.1 Intra-annual analysis

River discharge variability is frequently analysed in hydrology with reference to the intra-annual period, in order to estimate the seasonal component, namely, the progress of the average river flow along the year. The seasonal component was herein estimated for the daily river flow time series observed along the Po River at Pontelagoscuro, Piacenza and Moncalieri, as well as for the tributaries Stura di Lanzo River at Lanzo, Tanaro River at Farigliano and Dora Baltea River at Tavagnasco. Table 1 reports the observation period of the series, their mean value and standard deviation along with the catchment area and synthetic information on the dominant fluvial regime. The series are complete, that is, they are not affected by missing values.

To complete the information provided by Table 1 one may note that the dominant flood season for the Po River at Pontelagoscuro and Piacenza is Autumn, while the peak discharge volumes are generally observed in late Spring. At Moncalieri the alpine fluvial regime exerts a significant influence. Accordingly, the discharge volume in Autumn is reduced and the dominant flood season is late Spring. Similar behaviours are observed for the Tanaro River, that is characterised by a mixed pluvial/alpine regime, and the Stura di Lanzo River, where the alpine regime is dominant. The Dora Baltea River is a typical example of alpine regime, with one peak flow period only that occurs during summer.

The seasonal component for the time series presented in Table 1 was estimated by computing the daily average flow, for each calendar day, across the years of the observation period. The loess smoother was applied to reduce the variability of the periodical component, with a 30-day interpolation window (Grimaldi and Montanari, 2000). Figure 4 shows the obtained seasonal components. They reflect the dominant climatic behaviours and thus confirm what was anticipated in Table 1. It is interesting to note that the seasonal components of the Po River at Piacenza and Pontelagoscuro are characterised by a minor peak in spring, that occurs around the end of March, which is likely due to melting snow from mid altitude mountains. For the Tanaro and Stura di Lanzo rivers the late spring peak is anticipated and delayed, respectively, with respect to what is observed in the lower course of the Po River. The seasonal component for the Dora Baltea River is distinctly different, being characterized by a single peak in the summer months, as expected.

3.2 Inter-annual analysis – assessment of patterns in peak and low flows

The intra-annual variability analysis carried out in the previous section provides indications about water resources availability in different periods of the year, but it does not provide any information on the possible presence of inter-annual trends. Actually, these latter are important because they may be due to human impact and imply long term variations that may affect the future efficiency of water resources management strategies. Inter-annual tendencies in time series are often studied by analysing extreme flow values. For example, Figs. 5 and 6 show the progress of the annual maximum and minimum value, respectively, of the daily river flows of the Po River at Pontelagoscuro, along with the related linear regression line estimated over the whole period. The results show that an increasing and decreasing tendency seems to affect peak and drought flows, respectively, therefore implying an exacerbation of the flood and drought risk in recent years. Similar results have been repeatedly obtained by previous analyses carried out by local administrations.

However, it should be noted that the above trends are scarcely relevant from a statistical perspective. In fact, the slope of the linear regressions differs significantly from the null value at the 89 % and 74 % confidence level for annual maxima and minima, respectively. One can see that there is a significant probability to reject the null hypothesis of no trend when it is true, especially for low flows. Indeed, the reference value traditionally adopted in statistics for the confidence level is 95 %. As a matter of fact, the uncertainty of the estimate is relevant and becomes even more clear if one performed the linear regression over 41 subsequent 50-yr time windows, starting from 1920, in order to assess the variability of the results along the observation period. The results of such analyses are presented in the supplementary material with a animated pictures (see files regression-minima.gif and regression-maxima.gif). For the case of annual minima, 19 negative slope values are obtained against 22 positive ones, while the average value is even positive, being equal to 0.18 $\text{m}^3\,\text{s}^{-1}\,\text{yr}^{-1}$. For the annual maxima the situation is seemingly more clear, with 5 negative versus 36 positive slopes, with an average value of 9.24 $\text{m}^3\,\text{s}^{-1}\,\text{yr}^{-1}$. However, even in the latter case the average confidence level that makes the regression significant is equal to 46 % only. These results show that the long term tendency of the river flow is not easy to assess, for local and opposite tendencies alternating irregularly along time.

The above results show that the analysis of peak and low river flows that is traditionally carried out to detect trends is hardly useful to predict future configurations, even when applying robust tools such the linear regression to extended data bases like the Po River one. More refined analyses should be carried out to inspect the possible presence of patterns in river flows, which should make use of all the observed values of river discharge.

3.3 Inter-annual analysis – a graphical technique to assess long term variability

Variability analysis and pattern identification for long hydrological time series is a complex task because seasonality is superimposed to long term and local behaviours which are buried in a large amount of data. Analytical techniques, like investigation of the memory properties of the process, are useful tools but sometimes the presence of uncertainty makes the physical interpretation of results cumbersome (see, for instance, Sect. 3.4). Graphical techniques are more effective in providing a perspective on local and global patterns, but it is difficult to obtain a clear picture when dealing with long series.

A careful analysis was carried out for the series of the Po River at Pontelagoscuro by depicting the yearly time series one by one. The results of such investigation are presented in the supplementary material with an animated picture (see file yearly-series.gif). They reveal the possible concentration of floods and droughts in some periods that are several years long.

In order to obtain an overall graphical representation of river discharge time series, for the purpose of detecting long and short term patterns, we devised a 3-dimensional representation where river discharge is plotted on the vertical axis as a function of the respective year and calendar day that are represented on the horizontal axes. The resulting surface needs to be smoothed to make it regular. Smoothing was obtained by applying a moving average filter followed by a Gaussian one. The width of the filter window was 25 and 10 days along the intra-annual and inter-annual direction, respectively.

Figure 7 shows the resulting surface for the Po River at Pontelagoscuro. An animated revolving version of the same figure is presented in the supplementary material with an animated picture (see file perspective-discharge.gif) that allows one to better identify local patterns. The seasonal regularity can be clearly seen, as well as singularities in the inter-annual direction that are extended well beyond the filter width. In particular, the summer drought is clearly exacerbated in the recent period, but a similar local perturbation occurred from 1940 to 1960, when a prolonged situation of water scarcity occurred that is well remembered by the elder population. The singularity arising from the occurrence of two major floods in 1994 and 2000 is visible as well. It is interesting to note the presence of other singularities. For instance, the spring peak occurring around the end of March was more pronounced in the years from 1950 to 1980 approximately, while it is less evident in recent years.

Overall, Fig. 7 shows that the discharge time series of the Po River at Pontelagoscuro is affected by long term natural cycles that significantly affect distribution and temporal variability of water resources. This situation is compatible with the presence of long-term persistence, which in hydrology is also called “Hurst-Kolmogorov behaviour”, for which a convincing physical interpretation was not yet provided (see, for example, Hurst, 1951; Montanari et al., 1997; Koutsoyiannis, 2003; Montanari, 2003; Koutsoyiannis and Montanari, 2007; Koutsoyiannis et al. , 2009). In particular, the surface depicted in Fig. 7 is compatible with the presence of a 2-dimensional Hurst-Kolmogorov pattern (Koutsoyiannis et al., 2011). In order to provide a more substantial support to the above interpretation a quantitative analysis of the memory of the process has been carried out.

3.4 Inter-annual analysis – assessment of the memory properties

The literature has proposed numerous techniques to assess the memory properties of time series to provide support to the possible presence of the Hurst-Kolmogorov effect. An extended description of a selection of such techniques was provided by Taqqu et al. (1995) and Montanari et al. (1997). In the present work we preferred to focus on variability analysis and therefore applied the analysis of the variance method (Koutsoyiannis, 2003). In detail, the method investigates the variability of the time series obtained by aggregating the observed river flow over time periods of increasing extension. It can be shown that, for independent data, the variance rescales after aggregation according to the relationship (Taqqu et al., 1995)

$$\mathrm{Var}\left(\overline{X}_N\right) \approx cN^{-1}, \tag{1}$$

where $\overline{X}_N$ is the data series aggregated over N time steps and $c > 0$ is a constant. Then, by plotting the variance against the aggregation level in logarithmic scale one should obtain points displaced along a straight line with slope equal to -1. The analysis of the variance was applied to time series listed in Table 1 by using equally spaced N values in logarithmic scale and allowing blocks of aggregated data to overlap. Figure 8 shows the obtained results. By focusing on the River Po at Pontelagoscuro one notes that the variability decreases slower than expected. This result is due to the presence of correlation that violates the above assumption of independence. Its effect should become negligible when the aggregation level becomes comparable to the temporal extension of the process memory. However, Fig. 8 shows that the decreasing rate for variability that is expected for independent data is never reached, but only approached when aggregation reaches about 10 yr. This latter result is consistent with the presence of long-term persistence.

Similar results are obtained for the series of the Po River at Piacenza, while in Moncalieri, and especially for the tributaries, memory is less extended. These results seem to indicate that the superimposition of several regimes affected by short term persistence may induce the presence of long-term persistence in the receiving river reach. In fact, the same conclusion was previously reached by Mudelsee (2007).

The above described analysis of the variance was carried out by aggregating data in chronological order. A subsequent investigation was made of the variability after inter-annual aggregation. In detail, reference was made to an assigned day of the year and aggregation was performed over an increasing number of years. The analysis was repeated for the 365 calendar days and the obtained slopes of the regression line were subsequently regularised by using a 10-day wide moving average filter. Intuition suggests that the river flow observed in a given day of the year should have no memory of what occurred in the same day in previous years, and therefore we expected to obtain slopes close to −1. Figure 9 shows that the results did not confirm such preliminary expectation.

In fact, most of the slope values are lower than −1, which implies the presence of negative memory, with the exception of the March-April period for which positive correlation is found, that could be induced by the presence of the spring peak during some windows of the observation period. Overall, Figure 9 shows the presence of singularities for which a physical interpretation is not readily available, that should be investigated with more detail. In fact, they have significant practical implications for water resources management.

4 Conclusions

The analysis of the variability of mean daily flow series observed along the Po River and some tributaries highlights the presence of local cycles of water scarcity and abundance that last for several years. They seem to be originated by perturbations whose memory is maintained in the long term. Likewise, statistical analyses confirm that the river flow series seem to be affected by long term persistence, whose intensity increases for increasing catchment size. The above results show that the long term behaviours of the Po River flows are not easily decipherable. Traditional methods for trend detection could be inadequate for interpreting patterns that seem to be far more complex than monotonic tendencies.

In fact, the picture emerges of a hydrological system that is affected by local patterns that are likely to be related to natural climatic variability, even if one cannot exclude more complex interpretations that could refer to the intrinsic dynamics of the rainfall-runoff transformation. Similar phenomena were detected in other major rivers all over the world (Montanari et al., 1997; Montanari, 2003; Grimaldi, 2004). The literature has not proposed a convincing physical explanation for such behaviours so far (Mudelsee, 2007). Yet, their implications in water resources management are potentially very relevant, inasmuch they imply the above occurrence of long periods of water abundance and scarcity. These phenomena have been called “Noah Effect” and “Joseph Effect” by Mandelbrot and Wallis (1968).

The above summary puts in evidence that more research efforts are needed to improve the interpretation of such long term cycles. The links between local patterns in river flows and weather variables, like rainfall and atmospheric pressure, should be better investigated to improve our prediction capabilities of future critical situations. Such analyses are indeed complicated for the uncertainty related to the estimation of mean areal values for the above weather variables. However, they are definitely worth attempting, because a better understanding of hydrological dynamics would allow us to gain very interesting insights into natural variability and impact as compared to human induced changes. In fact, for the Po River fluvial regime the human impact is not as clearly emerging as the above temporary tendencies.

The present work highlights that the identification of optimal water resources management policies, that are needed to support sustainable development planning, must necessarily be based on the identification of the scientific priorities and a pragmatic planning of future strategies. In fact, an incomplete understanding of the natural river flow regime prevents one to gain a reliable assessment of the human impact and to devise efficient mitigation plans for natural risks. The unavoidable presence of uncertainty suggests the opportunity to give high priority to no-regret strategies of reduced environmental impact (Wilby and Dessay, 2010).

Supplementary material related to this article is available online at: http://www.hydrol-earth-syst-sci-discuss.net/9/6689/2012/ hessd-9-6689-2012-supplement.zip.

Acknowledgements. The author wishes to thank Giovanni Seminara for providing useful advice, and Silvano Pecora, Francesco Laio and Daniele Ganora for kindly providing the data series. Demetris Koutsoyiannis provided invaluable support in the interpretation of the results. This work has been partially supported by the Italian government through the grant “Uncertainty estimation for precipitation and river discharge data. Effects on water resources planning and flood risk management”.

References

Autorità di Bacino del Fiume Po: Behaviours of the Po River catchment and first investigation of the impact of human activities on water resources, 2006. 6691, 6692, 6703, 6705

Bloeschl, G. and Montanari, A.: Climate change impacts: throwing the dice?, Hydrol. Process., 24, 374–381, 2010. 6693

Grimaldi, S.: Linear parametric models applied on daily hydrological series, J. Hydrol. Eng.-ASCE, 9, 383–391, 2004. 6699

Grimaldi, S. and Montanari, A.: On techniques for estimating the seasonal components of daily hydrological data, in: Proceedings of the XXVII National Conference on Hydraulics and Hydraulic Works, Genoa, 12–15 September 2000, Vol. II, 237–244, CNR-GNDCI, Genoa, 2000. 6694

Hurst, H. E.: Long Term Storage Capacity of Reservoirs, T. Am. Soc. Civil Eng., 116, 770–799, 1951. 6697

Koutsoyiannis, D.: Climate change, the Hurst phenomenon, and hydrological statistics, Hydrolog. Sci. J., 48, 3–24, 2003. 6692, 6697

Koutsoyiannis, D.: HESS Opinions “A random walk on water”, Hydrol. Earth Syst. Sci., 14, 585–601, doi:10.5194/hess-14-585-2010, 2010. 6692

Koutsoyiannis, D. and Montanari, A.: Statistical analysis of hydroclimatic time series: uncertainty and insights, Water Resour. Res., 43, W05429, doi:10.1029/2006WR005592, 2007. 6697

Koutsoyiannis, D., Makropoulos, C., Langousis, A., Baki, S., Efstratiadis, A., Christofides, A., Karavokiros, G., and Mamassis, N.: HESS Opinions: “Climate, hydrology, energy, water: recognizing uncertainty and seeking sustainability”, Hydrol. Earth Syst. Sci., 13, 247–257, doi:10.5194/hess-13-247-2009, 2009. 6697

Koutsoyiannis, D., Paschalis, A., and Theodoratos N.: Two-dimensional Hurst-Kolmogorov process and its application to rainfall fields, J. Hydrol., 398, 91–100, 2011. 6697

Mandelbrot, B. B. and Wallis, J. R.: Noah, Joseph, and operational hydrology, Water Resour. Res., 4, 909–918, 1968. 6700

Marchi, E.: Hydraulic aspects of the Po River flood occurred in 1951, in: Proceedings of the XVII Conference on Historical Studies, Rovigo, 22–24 November 1991, Minnelliana Editions, Rovigo, 1994. 6691

Montanari, A.: Long range dependence in hydrology, in: Theory and Applications of Long-Range Dependence, edited by: Doukhan, P., Oppenheim, G., and Taqqu, M. S., Birkhauser, Boston, 461–472, 2003. 6697, 6699

Montanari, A., Rosso, R., and Taqqu, M. S.: Fractionally differenced ARIMA models applied to hydrologic time series: identification, estimation and simulation, Water Resour. Res., 33, 1035–1044, 1997. 6697, 6699

Mudelsee, M.: Long memory of rivers from spatial aggregation, Water Resour. Res., 43, W01202, doi:10.1029/2006WR005721, 2007. 6692, 6698, 6699

Piccoli, A.: The most important floods of the Po River from 1900 to 1970, Accademia Nazionale dei Lincei, Rome, 1976. 6691

Taqqu, M. S., Teverovski, V., and Willinger, W.: Estimators for longrange dependence: an empirical study, Fractals, 3, 785–798, 1995. 6697, 6698

Visentini, M.: The latest floods of the Po River, in: Proceedings of the XVIII International Conference on Navigation, Rome, 1953. 6691

Wilby, L. R. and Dessay, S.: Robust adaptation to climate change, Weather, 65, 180–185, 2010. 6700

Zanchettini, D., Traverso, P., and Tomasino, M.: Po River discharge: a preliminary analysis of a 200-yr time series, Climatic Change, 88, 411–433, doi:10.1007/s10584-008-9395-z, 2008. 6691

Table 1. Observation period, mean value μ and standard deviation σ of the observed time series, along with the catchment area A at the considered location and the dominant fluvial regime accordingly to the Po River Basin Authority (2006).

Location	Period	μ ($m^3 s^{-1}$)	σ ($m^3 s^{-1}$)	A (km^2)	Fluvial regime
Po at Pontelagoscuro	1920–2009	1470	1007	71 000	Pluvial regime with two peak periods
Po at Piacenza	1924–2009	959	773	42 030	Pluvial regime with two peak periods
Po at Moncalieri	1942–1984	80	89	4885	Pluvial regime with two peak periods
Tanaro at Farigliano	1944–1973	39	49	1522	Pluvial regime with two peak periods and high variability
Stura di Lanzo at Lanzo	1946–1981	19	27	582	Mixed alpine and pluvial regime, Autumn discharge is low
Dora Baltea at Tavagnasco	1951–1989	91	78	3314	Alpine regime with only one peak during summer

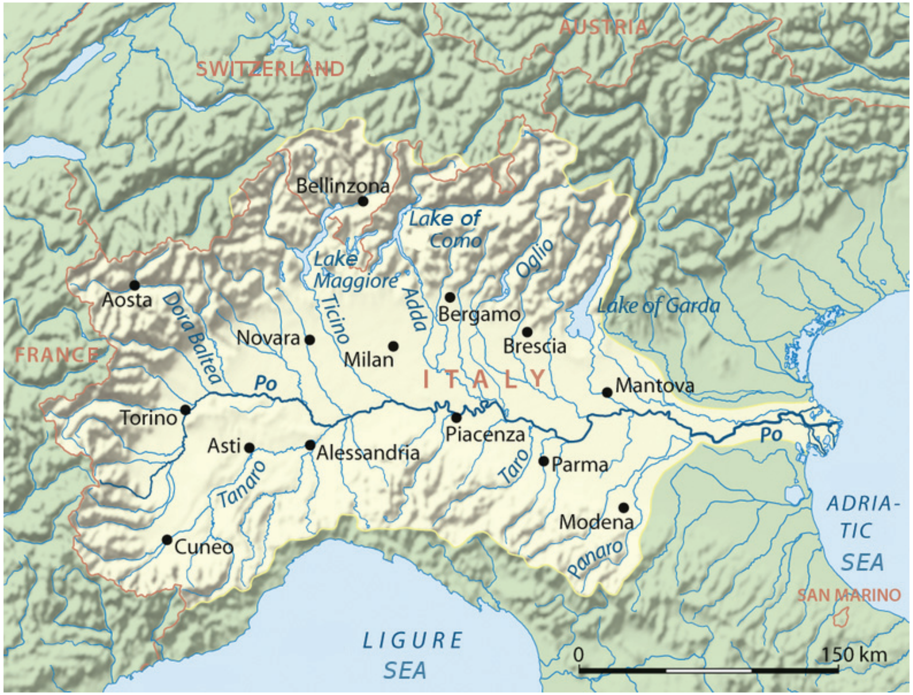


Fig. 1. Map of the Po River basin (from Wikipedia).

HESSD
9, 6689–6713, 2012

Changing patterns in Po River discharge

A. Montanari

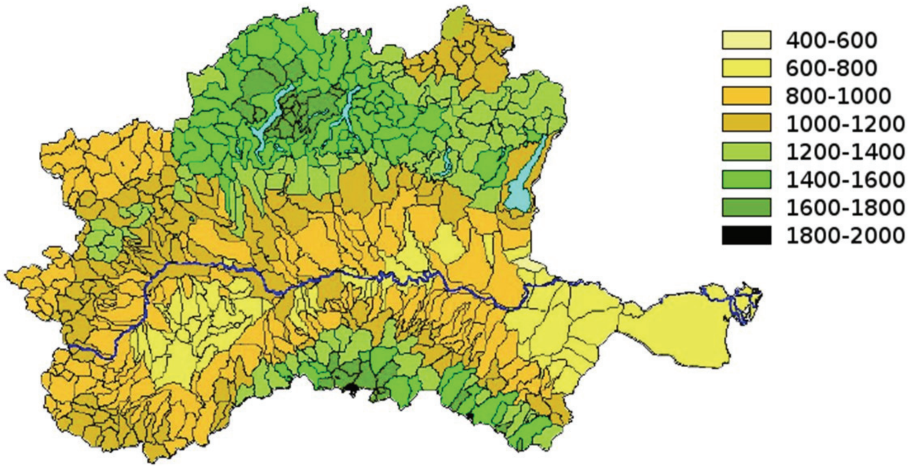


Fig. 2. Mean annual rainfall over the Po River basin (from Po River Basin Authority, 2006).

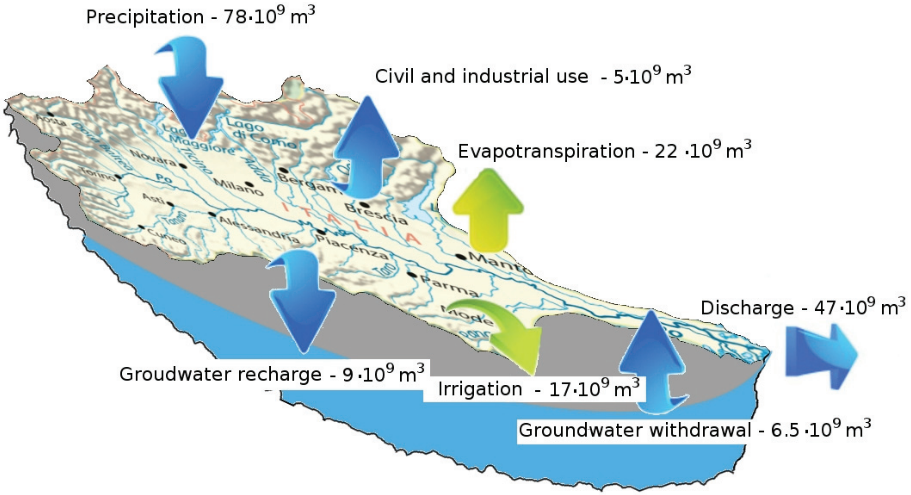
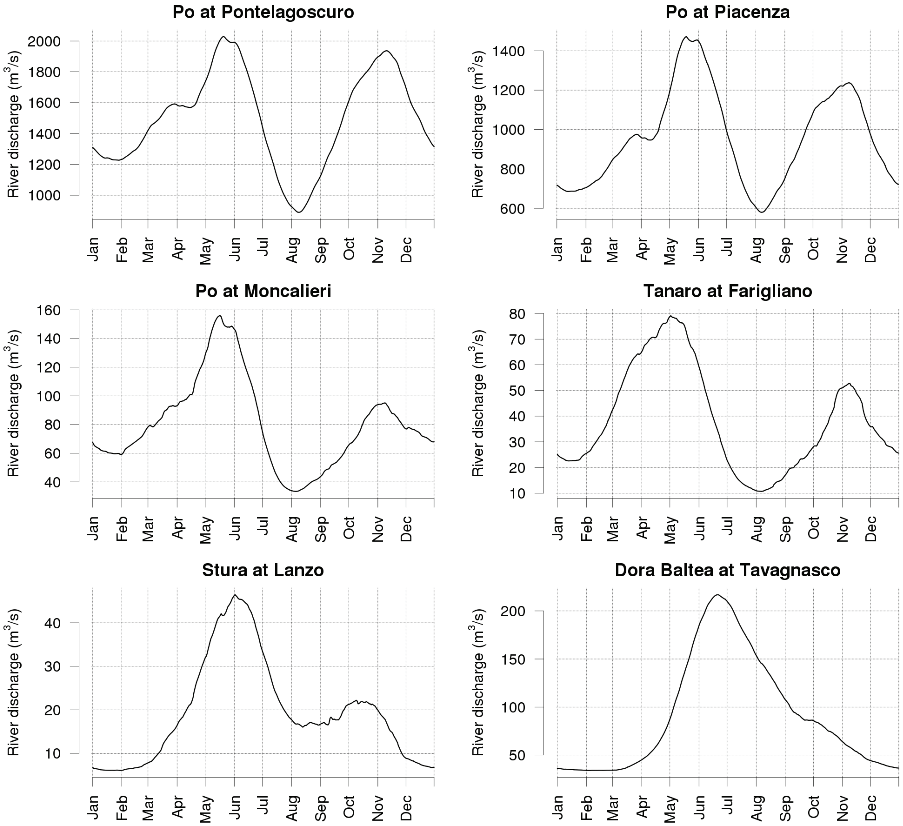


Fig. 3. Hydrological balance for the Po River basin.



Po at Pontelagoscuro

Po at Piacenza

Po at Moncalieri

Tanaro at Farigliano

Stura at Lanzo

Dora Baltea at Tavagnasco

Fig. 4. Seasonal components for the considered time series.

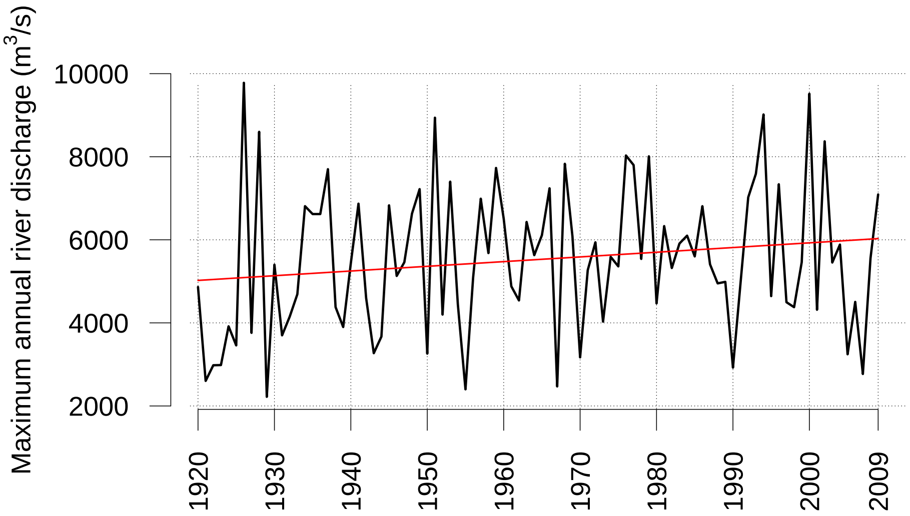


Fig. 5. Annual maxima of the Po River at Pontelagoscuro daily discharge series (1920–2009) and linear regression line.

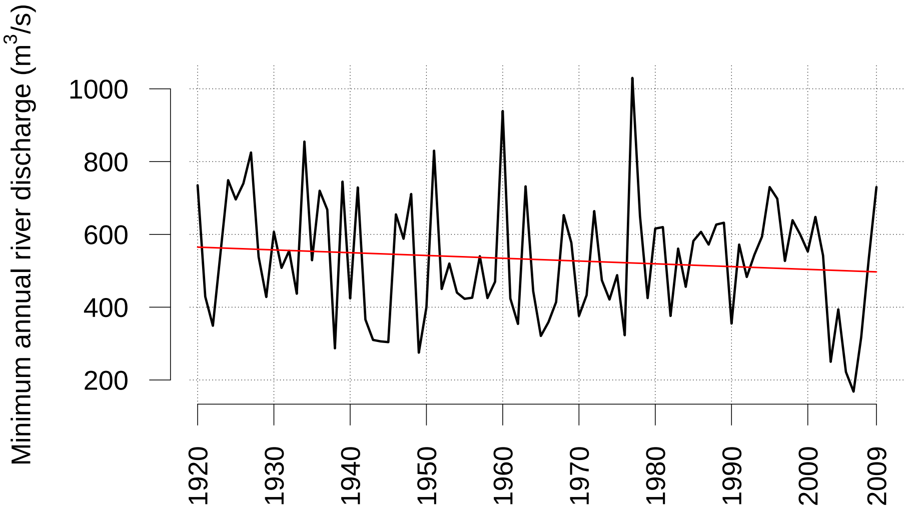


Fig. 6. Annual minima of the Po River at Pontelagoscuro daily discharge series (1920–2009) and linear regression line.

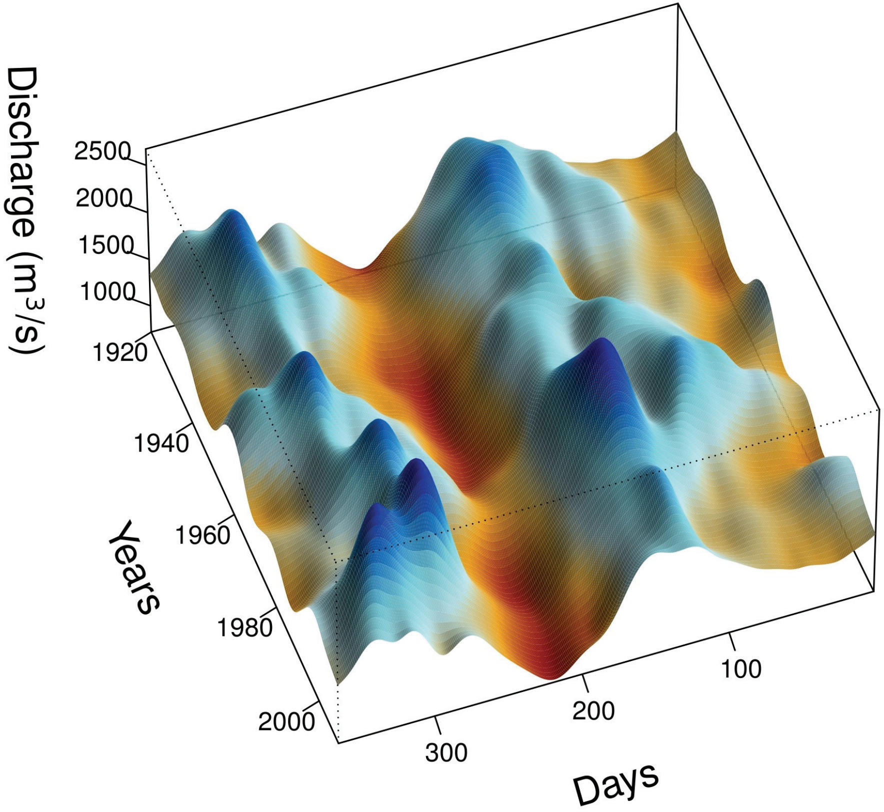


Fig. 7. 3-D representation of the Po River daily discharge time series (1920–2009). The resulting surface was smoothed by applying a moving average and a Gaussian filter.

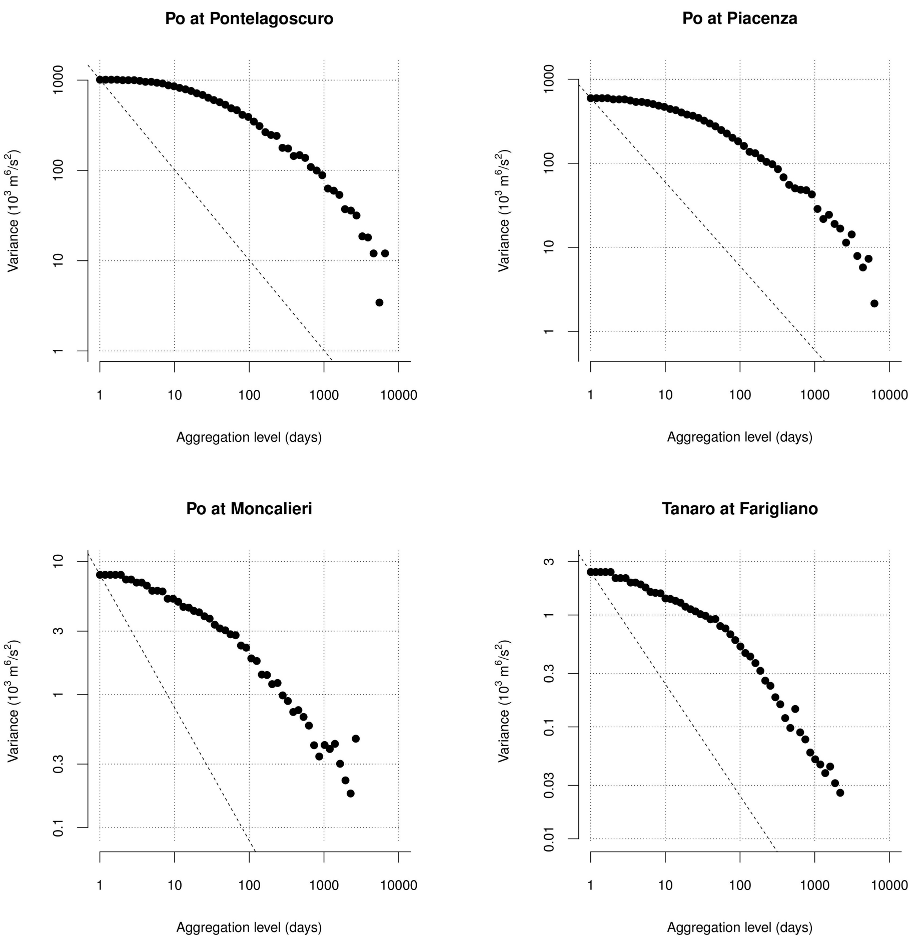


Fig. 8. See caption on next page.

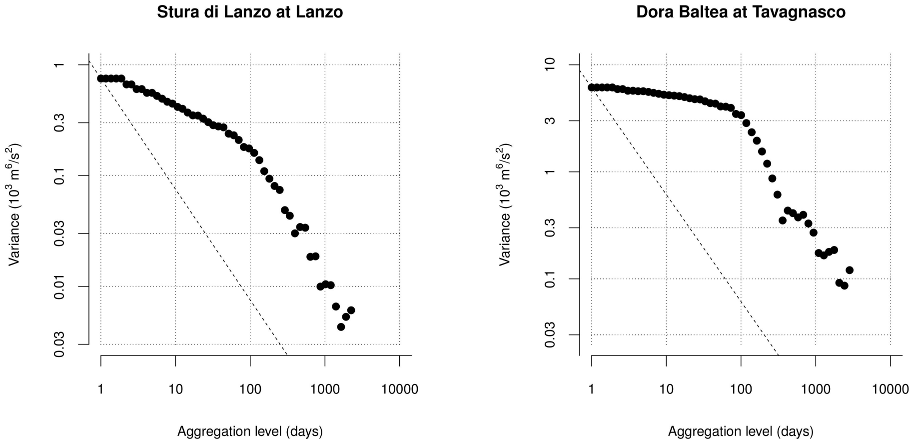


Fig. 8. Analysis of the variance for the considered time series.

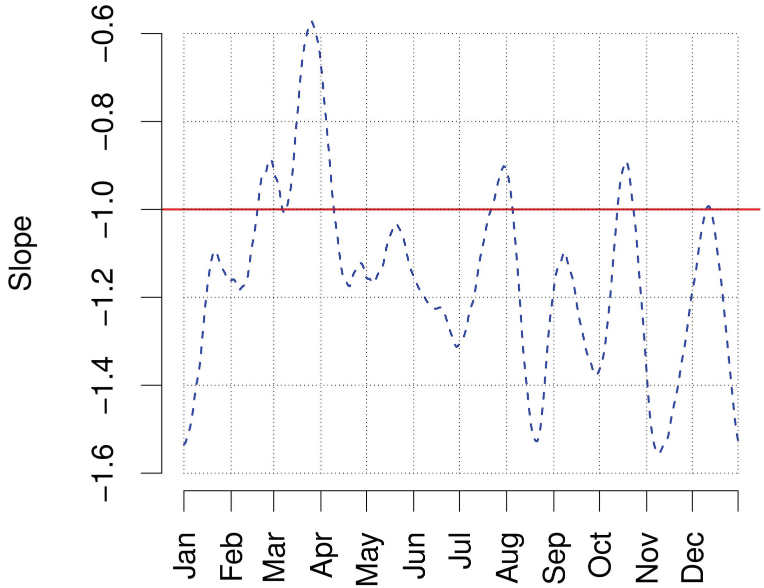


Fig. 9. Analysis of the inter-annual variance for the time series of the Po River at Pontelagoscuro (1920–2009).