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Global change and river flow in Italy

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ABSTRACT

The hydrological data of 23 flow gauges, evenly distributed across the Italian territory and covering almost 40% of it, have been analyzed in order to verify the occurrence of temporal trends and their rates of change. A total of 102 time series diagrams of the parameters considered, i.e. precipitation, runoff, maximum discharge, discharge exceed 10 days a year, were obtained. The results indicate that all the parameters considered show a decreasing trend. Also the comparison of bankfull discharge calculated for three periods, prior to 1951, 1951–1980 and 1981–2007, indicate a substantial decrease. The general decrease in river flow is accounted for in terms of global change (namely precipitation, land use change and water consumption increase). In the aim to summarize the pattern of change of the parameters considered, the data have been standardized and mean time series of Z score for a few representative rivers have been obtained. All these results depict for Italy a framework of substantial decrease of water resources (average precipitation and runoff decreasing rates are − 2.11 and − 2.65 mmyr-1, respectively) and sediment transport capacity with evident consequences on the river ecosystems and beach stability. The countertrending behavior of medium to high discharge of the Po River are analyzed and explained in terms of temperature increase. In order to investigate the role of the upstream catchment area in determining the variability of a few of the parameters considered in this study, simple regression analyses have been performed which demonstrate a high degree of accuracy in predicting specific discharges also for rivers without flow records or insufficient flow data.

1. Introduction

Nowadays, not only scientists, but also the general public is well aware of the effects that global change may have on the hydrological cycle (Doll et al., 2009; EEA, 2017). Several studies (e.g., Oki and Kanae, 2006; Feng et al., 2011; Tao et al., 2011; Kundzewicz et al., 2013; Kundzewicz et al., 2014) and international organizations reports (e.g., Hadley Centre, 2005; Kim et al., 2008; Walling, 2009; UNFCCC, 2011; EEA, 2017) have emphasized the climate change and human impact effects on seasonal and annual river flows and on the increased frequency and intensity of floods observed during the last decades. Such hydrological variations have so many negative implications on water resources and related economic issues to rise the interest of scientists and the concern of people involved in land planning and management (Binder, 2006). For this reason, many studies have been carried out to analyze the time variability of river flow and its connections with climate change and the general atmospheric circulation (Chiew and McMahon, 2002; Barnett et al., 2005; Nohara et al., 2006; Dai et al., 2009; Fu et al., 2009; Gosling et al., 2011) or with human activities which imply the exploitation of water resources (Doll et al., 2009; Vogl and Lopes, 2009). In this regard, Hannah et al. (2011) clearly pointed out the crucial role of flow discharge historical records and archives to conduct appropriate and reliable analyses of hydrological variability in the recent past, to develop predictive models of the future situation and to solve operational and engineering design problems (Marsh, 2002).

Many models to predict global hydrological changes have been developed, calibrated and validated on large data sets. As emphasized by Bordi et al. (2009) and by EEA (2017), the availability of updated observations is a key factor in increasing the performance of these models, especially for large scale investigations within a framework of global reduction in the number of recording stations (Hannah et al., 2011).

In the EEA (2012) report, which is essentially based on a study by Stahl et al. (2010), the monthly flow variations of many European rivers in the 1962–2004 interval are analyzed. The report includes also the results of a study by Rojas et al. (2012) that quantifies, in terms of percentage, the river flow variations predicted for the 2071–2100 interval. These authors used precipitation-runoff models that were validated by the hydrological data of several rivers, among which only one Italian river was considered, i.e. the Po River at the flow gauge of

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Pontelagoscuro (the most downstream one and very close to the mouth). In the work of Stahl et al. (2010), no data of any Italian river was used.

In The EEA (2017) report, it's confirmed that river flows in Europe have increased in winter and decreased in summer since the 1960s, but with substantial regional and seasonal variation. Climate change is an important factor in these observed changes, but other factors, such as river engineering, also have a strong influence. The number of very severe floods in Europe has increased since 1980, but with large inter-annual variability. River flow is influenced by rainfall/runoff and by hydromorphological changes of the river bed, e.g. through river engineering or bed material excavation. Furthermore, homogeneous river flow time series are generally shorter than those for meteorological data and substantially more time may be required before statistically significant changes in hydrological variables can be observed, especially with respect to extreme and exceptional events. Recently, the EEA (2016) has compiled a European Flood Impact Database that combines information on past floods with significant observed impacts from global sources with the reporting by EU Member States for the Preliminary Flood Risk Assessment (PFRA) (EC, 2007). This database has been collecting information on flood hazards and their impacts since 1980, but it does not include any data about floods in Italy, though the frequency of flash floods has substantially increased, especially during the last two decades. Guidance for recording and sharing disaster damage and loss data is under development for Europe (De Groeve et al., 2014; JRC, 2015), coherent with the Sendai Framework for Disaster Risk Reduction (UN, 2015).

The Global Runoff Data Centre (GRDC) of the World Meteorological Organization (WMO) and the FRIEND European Water Archive of UNESCO-IHP are the most important archives in the world with hydrological data of several thousands of rivers (9000 flow recording stations at the GRDC) from all the continents. The GRDC archives include data of about 20 flow gauges on 15 Italian rivers but, for the most of them, the monthly series are very short as they consist only of the last 10–15 year records or end up in the 1990s, also for important rivers such as Po, Adige and Tevere. The daily data time series are even shorter and in many cases encompass only a few years. Moreover, the number of years of monitoring of longest series do not correspond to the actual one as measurement interruptions (such as those due to World War II) are not considered. These data gaps are commonly of different length (even a few years), as in the case of the transfer of the hydrological measurements duty from the National Hydrographic Service to the regional offices.

A large number of Italian rivers flow gauges are listed in the UNESCO-IHP European Water Archive, but the interactive index map is more a catalog of the operating stations rather than a veritable source of information as no data is present, but for a few exceptions and for very short intervals.

Notwithstanding the substantial lack of data for the Italian rives, these archives remarkably contributed to expand our knowledge on past water resources and on the current global hydrology trends though a few scientists (e.g., Bordi et al., 2009; Hannah et al., 2011) highlighted the need to widen and, above all, to update the database.

Though in a global perspective the relevance of Italian rivers within projections of future hydrological scenarios may be limited, it is worth noticing that, since the onset of official instrumental observations in the early 1920s, no study on flow variations in Italian rivers has ever been made up to date. Within a framework of global change that is affecting many industrialized countries, such a lack of information is a substantial constraint to any attempt to make a reliable assessment of water resources and flood hazard in Italy for the coming years.

Aim of this paper is, therefore, to fill such a gap of knowledge through the analysis of the variations of a few hydrological parameters of the Italian rivers with the longest and most continuous data series throughout the last eight decades.

Table 1
Study rivers and flow gauges.

No.	River	Flow gauge	Area[a] (km^2)	Data (yr)
1	Arno	Subbiano	738	79
2	Arno	Nave di Rosano	4083	72
3	Arno	S. Giovanni alla Vena	8186	92
4	Sieve	Fornacina	831	79
5	Chiana	P.te FS FI-Roma	1272	66
6	Elsa	Castelfiorentino	806	48
7	Cecina	Monterufoli	634	47
8	Farma	P.te di Torniella	70	36
9	Cornia	P.te SS Aurelia	356	42
10	Ombrone	Sasso d'Ombrone	2657	82
11	Reno	Casalecchio	1051	70
12	Reno	Bastia	3410	49
13	Samoggia	Calcara	175	37
14	Ofanto	Monteverede	1028	52
15	Ofanto	S·Samuele di Cafiero	2716	64
16	Salsola	P.te SS FG-S·Severo	463	58
17	Po	Pontelagoscuro	70,091	68
18	Adige	Boara Pisani	11,954	63
19	Brenta	Barziza	1567	47
20	Tevere	Roma (Ripetta)	16,545	58
21	Oreto	Parco	76	74
22	Eleuterio	Lupo	10	56
23	Imera Meridionale	Capodarso	631	48

[a] Catchment area actually undertaken by the flow gauge.

2. Study rivers

Flow discharge observations started in Italy at the late 1800s with sporadic measurements on a few rivers. It was after the establishment of the National Hydrographic Service in 1917 that the hydrological measurements were carried out on a regular base on several rivers, starting with the Po and using scientific criteria and modern instrumentation.

Though the number of flow gauges has substantially increased since then, unfortunately on many rivers the data monitoring was not continuous. In a few cases, in fact, the measurements were stopped and, at times, resumed only after several years; some recording station was permanently dismantled, whereas new ones were installed on the same rivers but in a different site or on rivers never monitored before, with the latter situation characterizing especially the last decade. As a result of all that, with the exception of five rivers, Po, Arno, Chiana, Ombrone and Oreto (a very small stream in Sicily island), which have almost uninterrupted time series starting from the 1920s, only few other rivers have rather long time series with few data gaps. Among them, 20 rivers and 23 flow gauges were selected for this study. The list of the rivers and the flow gauges considered is reported in Table 1, whereas their location is indicated in the map of Fig. 1. The area of the catchments undertaken is widely variable, from 10 km^2 of the Eleuterio at Lupo to the 70,019 km^2 of the Po at Pontelagoscuro, and several scales of magnitude are represented within these two extremes (Table 1) for a total of 119,366 km^2, corresponding to about 40% of the Italian territory. The study catchments encompass also different climatic conditions, expressed in terms of annual precipitation, with 566.5 mm of the Imera Meridionale at Capodarso in Sicily to the 1298 mm of the Brenta at Barziza in northern Italy (Table 2 and Fig. 1).

3. Data collection and methods

The data used in this study were taken from the annals of the National Hydrographic Service (ISPRA, 2017, database, http://www.acq.isprambiente.it/annalipdf/), the publication of which ended around the mid-1990s, and from the archives of the Regional Hydro-meteorology Departments (e.g., Regione Toscana, 2017, http://www.sir.toscana.it/ricerca-dati; Regione Emilia-Romagna, 2017, https://