Extremely dry and warm conditions in northern Italy during the year 2015: effects on the Po river water

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Abstract

The presented research highlights relationships between the climatic anomalies that occurred in northern Italy in 2015 and the water system of Po river. We investigated the effect of anomalous high temperature and paucity of meteoric precipitation on the Po river discharge and water geochemistry. The new geochemical data, carried out on river water sampled at Pontelagoscuro (close to the city of Ferrara) and in the delta, have been compared with an extended dataset collected since the 2009. The comparison emphasizes that water samples of 2015 were characterized by a high electrical conductivity due to high concentrations of conservative ionic species (e.g. Na, Cl, SO_4) and nutrients such as nitrate. Oxygen and hydrogen isotopes, particularly sensitive to the observed climatic changes, reveal in a $\delta^{18}O$-δD diagram evaporative trends (highlighted by displacement from the Meteoric Water Lines) with a magnitude that wasn't recorded in the last years. The monitoring is currently in progress to develop functions that relate geochemical parameters to the evolving meteo-hydrological conditions.

Keywords: Po River, northern Italy, oxygen-hydrogen isotopes, climate change

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Introduction

The Mediterranean basin is extremely vulnerable to the climate change (Ferragina et al. 2010, Hoff, 2013). The dry and warm conditions observed across northern Italy in the year 2015 have been documented by various contributions on the website of the Italian Meteorological Society (http://www.nimbus.it/). These climatic conditions influenced the hydrological behaviour of the main Italian fluvial system, the Po river, monitored at Pontelagoscuro (closing section of the river) and in its deltaic branches. This monitoring is very important because the delta provides important habitats for terrestrial and marine species, and represents a sort of filter, where continental components react and are transferred seaward (Overeem and Syvitski, 2009). In this view, it is useful to define geochemical backgrounds concomitant to this extreme warm event that in turn could have influenced the Adriatic Sea and more in general the entire Mediterranean basin (Struglia et al. 2004, Ludwig et al. 2009).

Climatic and hydrological outlines during the year 2015

The year 2015 was the warmest year since 1880 in northern Italy, exceeding the notable record observed in 2014. Noteworthy, 2015 was marked by significant anomalies both from the thermal and meteoric point of view (Ionita et al., 2016). All seasons were warmer than the average of 1961 – 2015, with an annual positive anomaly of about 2.1°C. Remarkable deviations were observed in January, June, July (up to +4.3 °C), and November and December were distinguished by the almost complete lack of rain and snow. In order to quantify such anomalies, the thermo - meteor data of approximately 40 measuring stations, located at altitudes between 0 m (Volano, FE) and 3,488 m above sea level (Cervinia - Plateau Rosa, AO), were taken into consideration. The observed thermo - pluviometric time series were provided by the national system for the collection, processing and dissemination of climatological data (www.scia.isprambiente.it). Average annual temperatures ranged from -4.6 °C (Plateau Rosa) to 14.6°C (Volano), indicating that the positive annual deviation in comparison the preceding twenty years was ca 0.8 °C throughout the entire Po river hydrological basin. The winter was the warmest, of about 1 °C, since 1991 and January was the more anomalous month in particular at medium and high altitudes with a positive deviation of about 1.5°C. The spring was characterized by temperature values moderately above the historical average (0.4 - 0.8 °C) with an early snowmelt already completed in March/April at an elevation of 2,000 m. The summer was the hottest of the last 80 years (data source ISAC – CNR). In many towns of the Po alluvial plain, the month of July was characterized by average temperature of about 28.5 °C, with daily maximum temperature constantly above 35 °C and sometimes around 41 °C. This condition was induced by a positive anomaly of geopotential (500 hPa) in northern Italy (Figure 2) that initiated early in the summer 2015; it was due to a northward shift of the Atlantic subtropical jet, leading to a northward extension of the tropical high pressure typical of the southern areas of the Mediterranean basin. This synoptic situation favoured the persistence of a continental subtropical anticyclone at sea level (the North – African anticyclone) that caused high temperature conditions. The thermal anomaly (of 0.3 - 0.7 °C) persisted in the Po basin in the subsequent autumn. In particular, November was very warm, with temperatures of about 2 - 3.5 °C higher than the average, especially at high altitude. In fact, the local authority in the upper part of the Po river basin recorded a positive thermal anomaly of 3.8 °C in November in the Piedmont region, indicating the highest temperature in the entire historical series from 1958 to today. Finally, also December 2015 was much warmer than the average and was among the warmest months since the beginning of the 1920s especially in the mountains, with an average freezing level altitude of 2,800 meters.

The total annual precipitation during 2015 was lower than the average climatic standards in the whole Italian country, in particular in the Po plain and in the Prealps, generally showing a deficit of about 200 - 400 mm (20 - 30%; Figure 3). The first months of the year were characterized by precipitation and snowfall close to the average. Subsequently, in April a continental subtropical high pressure field was formed in the whole Mediterranean area and persisted for several months.

During the summer the African derived high pressure generated an intense convective activity resulted in frequent episodes of thunderstorm. September and October were characterized by precipitation similar to the average of previous years, whereas from the beginning of November the gradual strengthening of a polar vortex at the northern latitudes, and consequently a subtropical continental anticyclone, determined a significant atmospheric blocking with a paucity of precipitation.

On the whole, the lack of polar jet waves and consequently the repeated atmospheric stability led to temperatures greatly exceeding the historical average and a deficit in precipitation up to the end of February 2016. Consequently, the snow on the mountains was almost absent up to high altitudes until February 2016 when the incursion of Arctic air masses brought abundant snowfalls. The peculiar meteo - climatic conditions described above influenced the hydrological behaviour of the main fluvial systems. Coherently, the monitoring of the Po river discharge at Pontelagoscuro revealed that the typical discharge peaks usually occurring in May and November were not recorded in this anomalous year characterized by scarce precipitations. In this framework, remarkable droughts were recorded in summer (down to 400 m^3/s at Pontelagoscuro) and in winter (down to 800 m^3/sec at Pontelagoscuro), when high flow conditions (more than 1,500 m^3/sec) were generally expected.

Sampling and analytical methods

The geochemical study includes: 1) 9 water samples collected in different months between July 2015 and February 2016 at Pontelagoscuro that is the closure river section located just upstream of the deltaic system; 2) 30 water samples collected in two different hydrological conditions (during August and December 2015, respectively) in distinct branches of the Po river delta (Figure 1).

Electrical conductivity (EC), pH, and temperature were directly measured in the field (Table 1 and Table 2), and then water samples were collected in 100 mL bottles for laboratory analyses.

Chemical analyses were carried out at the Department of Physics and Earth Sciences of the University of Ferrara. Cations were measured by inductively coupled plasma mass spectrometry (ICP-MS) using a Thermo-Scientific X Series instrument calibrated with a Merck CertiPUR-ICP multi-element standard solution. Samples were preliminarily diluted 1:10 by deionized Milli-Q water (resistivity of ca. 18.2 MΩ×cm), introducing known amount of Re and Rh as internal standard. In each analytical session the accuracy was evaluated by analysing the reference solutions ES-L1 (a natural groundwater) and EU-L-1 (a waste water) provided by SCP-Science (www.scpscience.com) and the obtained results were always within the certified confidence interval. The major anions were determined by ion chromatography using a Dionex ICS-1000 calibrated with a solutions obtained by different dilutions of the Dionex “7-ion standard.” Accuracy and precision, based on the repeated analyses of samples and standards, were better than 10% for all the considered parameters. The coherence of the geochemical data was verified by checking the ionic balance (aqueous solutions must be electrically neutral), observing for the reported data charge-balance error generally lower than 5%. Hydrogen and oxygen isotope ratios (last two columns of Tables 1 and 2) were determined using the CRDS Los Gatos LWIA 24-d isotopic analyzer. The isotopic ratios of $^2H/^1H$ and $^{18}O/^{16O}$ were expressed as δ notation [δ=(Rsample/Rstandard−1)×1000] with respect to the Vienna Standard Mean Ocean Water (V-SMOW) international standard. Four bracketing standards that cover the whole range of isotopic values of the Po river water were systematically run in the analytical sessions. These standards, obtained from the Los Gatos Research Company, were calibrated with international standards such as V-SMOW and Standard Light Antarctic Precipitation (SLAP). Analytical precision and accuracy were better than 0.3 and 1.0 ‰ for $\delta^{18}O$ and δD, respectively.

Geochemistry of Po river in summer 2015, fall 2015 and winter 2015/2016

Physico-chemical parameters and dissolved components of Po river water

The pH of Po river water in summer 2015, fall 2015 and winter 2015/2016 was between 7 and 8, similar to that measured in the previous years (Marchina et al., 2015; 2016a; 206b). Temperature recorded in water was higher than in comparable seasons of 2012 and 2013 (up to 30 °C at the end of July) thus threatening the survival of many species typical of the riverine biota. These peculiar conditions were coupled with high electrical conductivity of the Po river water (up to 520 µS/cm); that exceeded the values recorded in the previous five years (Marchina et al., 2015; 2016a, 2016b). In this framework, the reported data indicate an inverse relationship between the discharge values and the water conductivity (Table 1, Figure 4). The water sample of February appears out of trend, because relatively high discharge was coupled with high conductivity. Water conductivity was strictly related with the Total Dissolved Solids (TDS) and also with distinct dissolved chemical species. Accordingly, conservative tracers such as chloride, bromide, sulphate, sodium and potassium appeared correlated with the water conductivity. Chloride concentration at Pontelagoscuro ranged between 13 mg/L and 26 mg/L, in September and January, respectively. Sulphates concentration ranged between 24 and 43 mg/L, in September and January, respectively. Sodium concentration ranged between 11 mg/L and 24 mg/L, in September and February, respectively. Potassium concentration ranged between 2 and 8 mg/L, in September and February, respectively. Noteworthy, the highest values were observed during winter. The correlation between these tracers is shown in Figure 5. Other cations (e.g. calcium, magnesium) displayed a less coherent behaviour, possibly due to removal/enrichment by ion-exchange processes with the suspended solid particles. The increase of TDS was also coupled with relatively high concentration of nitrogen compounds of anthropogenic origin (Table 1). This evidence indicates that during anomalous meteo - climatic conditions the Po aquatic system is more vulnerable to anthropogenic impacts, recording an increase of nutrients with respect to the previous 5 years (Marchina et al. 2015, Marchina et al., 2016a, Marchina et al. 2016b). The observed high TDS caused problems to the agricultural activities because water salinity is transferred to soils, inducing various salt stress effects in cultivated plants. In fact, salinization is a major problem for agricultural productions and may induce negative ecological, social and/or economic outcomes (Ondrasek et al., 2011; Colantoni et al., 2015; Salvati and Ferrara 2015).

Differently from what of observed at Pontelagoscuro, the geochemical fingerprint of water in the Po river delta displayed resilience to the adverse climatic conditions of the year 2015. In fact, TDS in the delta didn’t show a homogeneous increase toward the sea in all the deltaic branches, without increase of salinization with respect to the survey carried out in August 2013. This is due to a) hyporheic exchanges with groundwater that mitigate the ongoing salinization, b) tide cycles and the seawater circulation. These additional processes have to be taken into consideration in order to understand the complex (variable from the temporal/spatial point of view) mixing between fluvial and marine water. On the whole, the chloride concentration in the delta recorded a wide range between 13 mg/L and 3,277 mg/L and similarly to what observed at Pontelagoscuro, the highest values were recorded in winter. Significant changes were reflected in other conservative ionic species (sulphates, bromine, sodium) that showed evaporative and mixing trends with the seawater (Figure 5), particularly in the winter (December - January). Snapshots of the described conditions are highlighted in the geochemical maps of Figure 6 that report chloride and sulphate concentration observed in the Po river delta in December 2015. From these figures it can be noted that salinization involved preferentially the peripheral branches respect to the main course represented by the Po di Venezia.

In the delta nitrate displayed a concentration between 1.5 mg/L and 8.5 mg/L (lower than at Pontelagoscuro), and phosphate displayed a variation between 0.03 and 0.2 mg/L. These values are comparable with those of the previous investigation carried out in the same area (Marchina et al., 2015; 2016a; 2016b), indicating that the delta system is a reactor and a filter, in which part of the nutrients (e.g. nitrates) are consumed and metabolized before the marine confluence.

Isotopic composition ($\delta^{18}O$ and δD) of the Po river water

The isotopic variability measured at Pontelagoscuro and along the Po river delta is presented in Tables 1 and 2. At Pontelagoscuro values were varying between -8.6‰ and -7‰ for $\delta^{18}O$, and -62.7‰ and -55.1‰ for δD. These isotopic compositions, and in particular the $\delta^{18}O$ values, were "heavier" than those recorded at Pontelagoscuro in the previous ten years (Figure 7); coherently, the $\delta^{18}O$ marked very efficiently the peak of the warmer period of the year showing the less negative values.

In the deltaic area the isotopic composition varied between -8.4‰ and -3.5‰, -69.3‰ and -53.9‰ for $\delta^{18}O$ and δD, respectively. These isotopic ranges, although overlapped with those observed in the delta in the year 2013 $\delta^{18}O$ between -10.2 and -8.4‰, δD between -66.7 and -58.5‰; Marchina et al., (2015; 2016a), are extended toward less negative compositions, confirming that the warm condition had a repercussion also in the water composition of the deltaic branches.

Isotopic data are also reported in the δD vs $\delta^{18}O$ diagram of Figure 8, together with reference lines that represent the relationships between hydrogen and oxygen isotope ratios of freshwaters at global (GMWL; Craig, 1961) and regional (LMWL defined for northern Italy; Longinelli and Selmo, 2003) scales and of groundwater (LGWL defined for the Emilia Romagna Region; Martinelli et al., 2014). Note that waters that didn't suffer significant evaporation (such as most river water) generally fall along the reference meteoric water lines (having slope approaching 8). On the other hand, water bodies affected by significant evaporation display systematic enrichment in both ^{18}O and ^{2}H, developing trends (with slopes between 4 and 6) diverging from the meteoric water lines (Gibson et al., 1993). On this basis, the significant shift of the Po river water isotopic compositions in the year 2015 (respect to the meteoric water lines, and respect to Po river water the previous years) highlights a remarkable evaporation effect (displacement on the right of the meteoric lines) at Pontelagoscuro and in the deltaic branches (in particular in the Po di Goro, Po di Maistra and Po di Tolle). This hypothesis is also supported by the d-excess values (d-exc= $\delta D - 8.01^{*}\ \delta^{18}O$, between -41.2 and 9.8‰ in the deltaic part and between -2.1 and 6.2‰ at Pontelagoscuro) that are lower than those usually observed in the Po river water of the previous years (12‰ on average; Marchina et al. 2015; 2016a; 2016b).

Considering the observed systematic changes in the oxygen-hydrogen isotopic composition of the Po river water in response to the recorded meteo - climatic anomaly, we propose that these tracers have to be carefully monitored for setting up a hydroarchive that could be useful in the evaluation of ongoing and future climatic changes.

Conclusions

Po river water recorded significant changes in response to the remarkable climatic anomaly (warm and dry conditions) that characterized the year 2015. In fact, the EC was inversely correlated with the river discharge that recorded a minimum during the summer (July and August 2015) and also during the winter (December 2015-January 2016).

As concerns the principal constituents of the TDS, conservative elements such as chlorine and sodium marked evaporative processes and recorded in the Po river water at Pontelagoscuro anomalous values in comparison with seasons of the previous years (Marchina et al., 2015; 2016a; 2016b). These characteristics were remarkable in samples collected during winter, in relation to the unusual persistence of the drought condition. The period has been characterized also by remarkable concentrations of nitrates that were systematically higher than 10 mg/L between December 2015 and February 2016. Downstream of Pontelagoscuro, the Po river water was partially freshened by groundwater inflow, and in our view localized hyporheic exchange occurred just before the delta. TDS gradually re-increased seaward, especially in the most peripheral branches, as testified by concentration of the most conservative elements. Oxygen and hydrogen isotopes were particularly sensitive to the observed climatic changes, with evaporative trends having a magnitude that wasn't recorded in the previous years.

The monitoring will continue in order to extrapolate functions relating the geochemical parameters to the meteo - hydrological conditions. On the whole, the data, if merged with databases obtained by other riverine systems of northern Italy (Donnini et al., 2016; Natali et al., 2016) could be useful in order to evaluate the magnitude of the climatic changes at regional scale. This research is important because drought periods in northern Italy (and more in general in the Mediterranean area) are no longer rare (Gouveia et al., 2016). In fact, the ongoing evolution makes the Mediterranean a climate change "hot spot" for the 21st century (Tourre et al., 2008 Lespinas et al., 2014; Collet et al., 2015). The monitoring of water resources is therefore extremely important in order to understand the potential variations and to develop technical solutions for sustainable water management.

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CAPTIONS OF TABLES

Table 1: Discharge, physico-chemical parameters and geochemical analyses of Po river water at Pontelagoscuro (close to Ferrara) that is the closure river section of the river.

Table 2: Physico-chemical parameters and geochemical analyses of water in distinct branches of the Po river delta, i.e. Po di Venezia, Po di Tolle Po di Gnocca, Po di Goro, Po di Maistra. See the Figure 1 for the sampling sites.

CAPTIONS OF FIGURES

Figure 1: Map of the Po river and its basin (evidenced in light green and blu); in the inset the part of the river (including the delta) that has been investigated. The sampling points of the studied waters are evidenced with red circles. For a better interpretation refers to the coloured web version of the paper.

Figure 2: Synoptic features of the first part of summer 2015 – source ECMWF. For a better interpretation refers to the coloured web version of the paper.

Figure 3: Percentage deviations between the total rainfall of the year 2015 and the average of thirty years (1971 – 2000; Source ISAC – CNR). For a better interpretation refers to the coloured web version of the paper.

Figure 4: Electrical conductivity of the Po River water collected at Pontelagoscuro and the related daily discharge (m^3/s). EC data are referred to Table 1, whereas daily riverine discharge has been provided by ARPA Emilia Romagna.

Figure 5: Scatter diagrams reporting compositions of the conservative elements of the Po river water collected in the investigated period. Data are referred to Tables 1 and 2: a) Cl - Na; b) Cl - Br; c) Cl-SO_4. Light grey circles represent samples collected at the Pontelagoscuro site in summer 2015, fall 2015 and winter 2015/2016; grey and empty squares represent samples collected in the deltaic branches of the Po river in August 2015 and December 2015, respectively.

Figure 6: Geochemical maps showing spatial variation of (a) sulphates and (b) chlorides dissolved in the water of Po river deltaic branches in December 2015, obtained by the Geostatistical Analysis tool ArcGis 9.3. For a better interpretation refers to the coloured web version of the paper.

Fig. 7: Temporal variation of the oxygen isotopic composition of Po river water collected at Pontelagoscuro. Note that the original isotopic data presented in this paper are compared to those from the previous literature (Martinelli et al., 2014; Marchina et al., 2015; 2016b).

Figure 8: $\delta^{18}O$ and δD of the Po river waters collected during summer 2015, fall 2015 and winter 2015/2016 at the Pontelagoscuro site (light grey circles) and in August 2015 in the delta branches (grey squares), as reported in Tables 1 and 2. The previous isotopic compositions recorded at Pontelagoscuro (between 2005 and 2014, Martinelli et al., 2014; Marchina et al., 2015; 2016a; 206b) are also reported (black circles). Data are compared to the global meteoric water line (GMWL; Craig 1961), the local meteoric water line (MWL, defined for Northern Italy by Longinelli and Selmo 2003) and LGWL defined for the Emilia Romagna Region; Martinelli et al. 2014.