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Trend and fluctuation of long karst spring discharge series

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ABSTRACT

Long karst spring discharge series have been analysed to find trends and fluctuations and relations to climate variables. In some cases hydrological data cover more than one hundred years of records. Data come from aquifers of southern Italy, where karst springs constitute the main water resource and supply millions of peoples.

As the spring discharge expresses the output of the aquifer, it is connected to recharge processes, which depend mainly on the rainfall and temperature catchment distribution. For these reasons, spring discharge "mediates" the climate parameter records on long term, and can be considered an important indicator of the climate.

KEY WORDS: *Karst springs, discharge time series, Southern Italy.*

INTRODUCTION

Karst aquifers provide about 25% of the world's drinking water (Ford & Williams, 2007). In Italy this contribute is considerable higher in many areas of the peninsula, and reaches values near 100% in many regions (Umbria, Marche, Lazio, Abruzzo, Molise, Campania), supplying millions of peoples. In these areas, karst springs were tapped by aqueduct since Roman age, and have had an important role in the historical development. The regime of these springs depends on the rainfall and temperature distribution, and it is controlled by the morphological and hydrogeological setting of the basins.

The climate change observed worldwide, has suggested to investigate on the possible consequences of the regime of these springs.

Fiorillo *et al.* (2007) analysed the long spring discharge series of Serino spring (Campania), and highlighted the discharge drop after 1986. Fiorillo (2009), based on historical series of some spring discharge series of the Campania region, focused the analyses on the drought periods, evaluating the hydrological conditions leading to droughts in karst environments.

In this study we have collected discharge measurements of powerful karst springs located in Southern Italy. On the basis of these measurements, analyses to find trends and fluctuations have been carried out and comparison between series has been also considered. To investigate on the relation with climate variables, some rain gauges located inside the hydrogeological basins of the karst springs have been selected; their annual rainfall time series have been compared with that of annual mean spring discharge.

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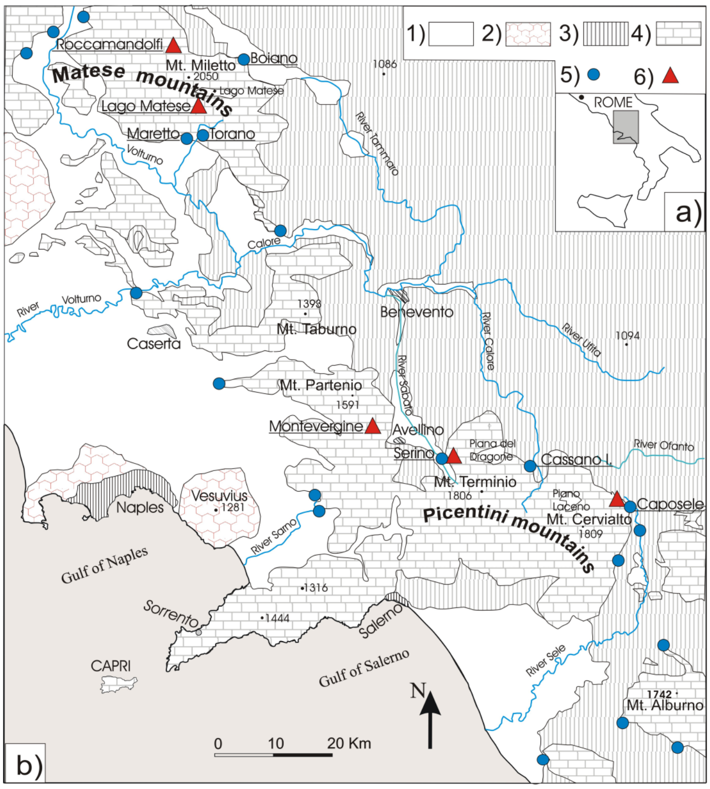

Fig. 1 – a) Southern Italian peninsula. b) Geological sketch of the Western Campania; 1) Slope breccias and debris, pyroclastic, alluvial and lacustrine deposits (Quaternary); 2) Lavas and tuffs of volcano complex; 3) argillaceous complex and Flysch sequences (Paleogene–Pliocene); 4) limestone sequences of platform (Triassic–Miocene); 5) main karst spring; 6) rain gauges considered in this study (modified from Fiorillo and Guadagno, 2012).

GEOLOGICAL AND HYDROGEOLOGICAL FEATURES

The investigated karst springs belong to the two main karst systems of Campania: the Matese massif, and the Picentini mountains. These mountains are primarily characterized by high slopes and elevations up to 2050 m a.s.l. for Matese massif and 1809 m a.s.l. for Picentini mountains (Figure 1). Flat zones are limited to endorheic areas and induced a higher and concentrated infiltration. In particular, the polje of Lago Matese and Piano Laceno are the most important respectively for the Cervialto and Matese massif. Both the karst massifs are constituted by calcareous and calcareous-dolomite series (Late Triassic-Miocene), characterized by a thickness ranging between 2500 and 3000 m, which are heavily fractured and faulted. Along the northern and eastern sectors, these massifs are tectonically overlapped on the terrigenous and impermeable deposits, constituting complex argillaceous (Paleocene) and flysch sequences (Miocene). Along the southern and western sectors, these massifs are limited by normal faults and are covered by recent quaternary deposits. More specific geological insight of the outcropping areas can be found in Parotto and Praturlon (2004) and related literature, and recent Geological Map of Italy, 1:50.000 scale (ISPRA, 2009).

Pyroclastic deposits of Somma-Vesuvius activity cover the Picentini mountains, with thickness of few decimeters along steep slopes and entire area of Mount Cervialto. These deposits, almost absent on the Matese massif, play an important role in the infiltration of water into the karst substratum.

These karst massifs feed many karst springs with discharge up to thousands liters/second, and constitute the main water resource in Southern Italy, and their main hydrological characteristics are shown in Table 1.

Hydrogeological details of these springs can be found in Civita (1969a-b), Celico & Civita (1976), Celico (1978); Budetta *et al.* (1994); Fiorillo & Doglioni (2010); Fiorillo & Guadagno (2012).

DATA ANALYSIS AND FINAL CONSIDERATION

To compare the different time series of the spring discharge, the annual mean values (November-October), Q_i, have been standardized, Q_s, by the following (1):

$$Q_s = \frac{Q_i - \mu}{\sigma} \qquad (1)$$

with μ and σ, the mean and the standard deviation of the series, respectively (Figure 2a). In general, it is possible to distinguish periods characterized by consecutive values above the mean (*High flow period)*, during which isolated value below the mean can be present, and period characterized by consecutive values below the mean (*Low flow period*), during which isolated value above the mean can be present. The lowest values of 1949 and 2002, coincident with the most intense droughts, are well marked in all series, as other intense droughts (1943, 1946, 1975 and the recent period 2007-2008). Fiorillo *et al.* (2007) analysed the trend of the Serino spring discharge and provide a methods to forecast droughts. Fiorillo (2009) extends the previous hydrological analyses and compared Caposele and Serino spring discharge, defining the hydrological threshold below which drought occurs. The highest discharge values of the Picentini springs were induced by the 23 November 1980 Irpinia earthquake (Ms=6.9). After 1986 all series clearly show a decrease in discharge values, which appears interrupted only during 2006 and 2009.

To compare the spring discharge and rainfall, the series of the mean standardised annual values has been considered. For each year, the mean standardised of spring discharge, Q_{s-m}, is computed as the mean of the Q_s values available; thus, it coincides with Q_s of Serino spring discharge up to 1919; it is the mean between Q_s of Serino and Caposele spring discharge in the period 1920-1950; and so on. The same has been done for the mean standardized annual rainfall, P_{s-m}, using the rain gauges of table 2.

Figure 2b shows the time series of the mean standardized values, Q_{s-m} and P_{s-m}, where the high linear correlation indicate the important control of the annual rainfall on the annual mean spring discharge. However, the relation appears weaker before 1918, probably because only one rainfall series (Montevergine) and one discharge series (Serino) are available. Later the relation is stronger, with exception of the period 1980-1982, because spring discharge were influenced by the November 1980 earthquakes.

After 1986 spring discharge exceeds the mean value only during 2006 and 2009 (Figure 2b), whereas the rainfall exceeds more times the mean value in the same period.

The two main characters of the spring discharge series are the cyclicity and the drop of the discharge after 1986. The cyclicity can be observed for the longer time series (Serino and Caposele), but probably it is common to all series. This cyclicity has to be connected to tendency of wet years to bunch together, as well as dry years (Fiorillo, 2009). The drop of discharge after 1986 has been prolonged up to recent wet years 2009 and 2010 and has to be connected to the changing of the climatic conditions.

All discharge series are strictly controlled by the annual rainfall time series, providing that the cyclicity of the series is an effect of the hydrological cycle control. After 1986, also annual rainfall present a clear decreasing; however, it doesn't fully explain the drop of the spring discharge. This seems indicate that temperature increasing observed since the eighteens has a contribute in the spring discharge lowering after 1986. Temperature data from worldwide (MOHC, 2010) and Italy (Brunetti *et. al*., 2006) confirm that the beginning of the general warming has been recorded worldwide mainly since the eighties. Thus, spring discharge time series reflect two important modification in the climate records: the drop of the annual rainfall and the increasing of the temperature, both occurred since the eighties.

The drop of the groundwater level has been also found in many other regions of southern Italy (Polemio and Casarano, 2008; Simeone, 2001) and of central Italy (Cambi & Dragoni, 2000), providing that the phenomenon is common in a wide area of the Mediterranean basin, and depends on the global climate control. These climate changing seem indicate a modification of the hydrological cycle, which needs specific investigations and monitoring on the effect on the groundwater.

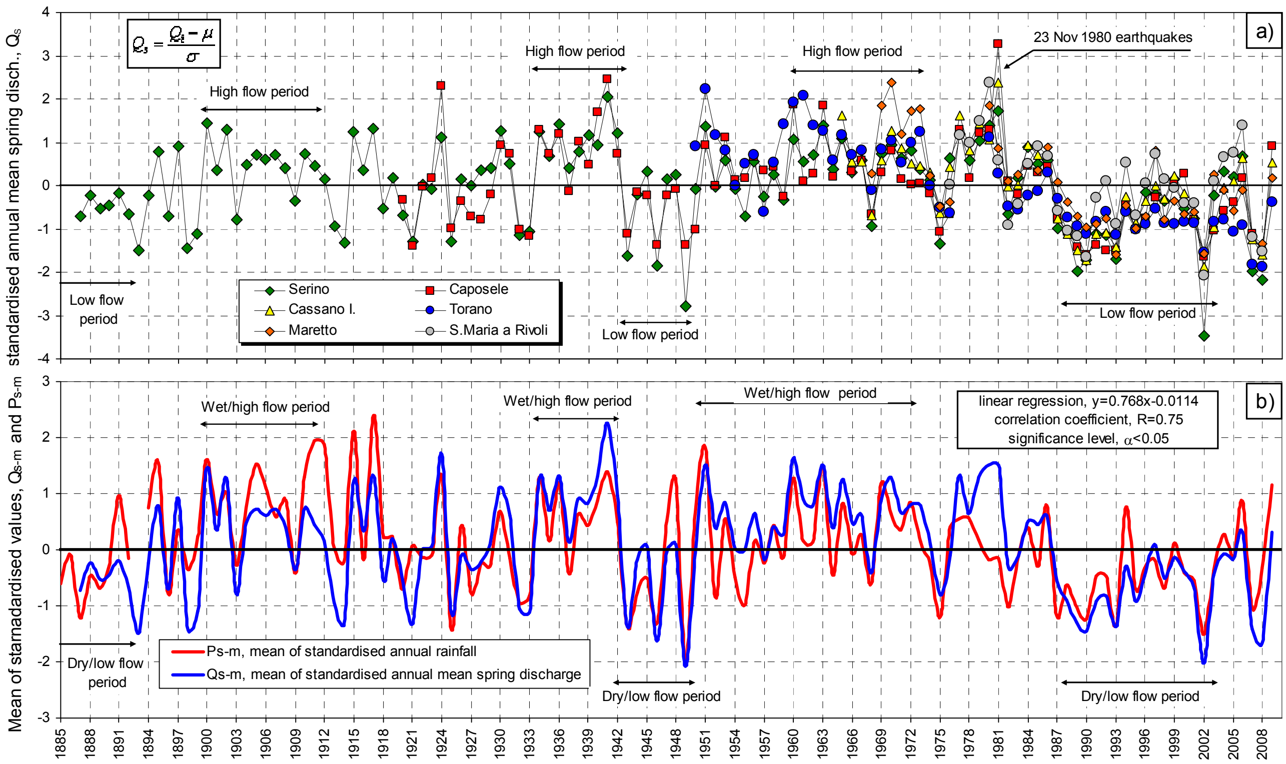

Fig. 2 – a) Standardised annual mean (November-October) karst spring discharge series, Q_s (modified from Fiorillo and Guadagno, 2012). b) Mean of standardised annual mean karst spring discharge, $Q_{s\text{-}m}$, and mean of standardised annual rainfall (September-August), $P_{s\text{-}m}$.

Table 1. Statistics of karst springs analysed. μ, mean; σ, standard deviation; Q_{90}, 90th percentile; Q_{10}, 10th percentile.

Location	Matese Massif			Picentini Mountains		
Spring	Torano	Maretto	S.Maria a Rivoli	Caposele	Cassano I.	Serino
Elevation (m a.s.l.)	201	175	485-505	420	473-476	330-380
Time interval of data series	1 Jan 1950 to 31 Aug 2009	1 Jan 1968 to 31 Aug 2009	1 Jan 1976 to 31 Dec 2008	1 Jan 1920 to 31 Dec 2009	1 Jan 1965 to 31 Dec 2009	1 Jan 1887 to 31 Dec 2008
μ *(mm)*	2.04	0.99	1.04	3.96	2.73	2.24
σ *(mm)*	0.64	0.30	0.46	0.59	0.68	0.33
Q_{90} (m^3/s)	2.90	1.35	1.65	4.89	3.55	2.64
Q_{10} (m^3/s)	1.35	0.62	0.51	3.14	1.79	1.81

Table 2. Characteristics of the rain gauges analysed. μ, annual mean rainfall (September-August); σ, standard deviation; P_{90}, 90th percentile; P_{10}, 10th percentile (modified from Fiorillo and Guadagno, 2012).

Location	Matese massif		Partenio massif	Picentini Mountains	
Rain gauge	Lago Matese	Roccamandolfi	Montevergine	Serino	Caposele
Elevation (m a.s.l.)	1050	810	1270	351	426
Time interval of data series	1 Jan 1920 to 31 Dec 2009	1 Sep 1919 to 31 Dec 2009	1 Aug 1884 to 31 Dec 2009	1 Aug 1920 to 31 Dec 2009	1 Sep 1917 to 31 Dec 2009
μ *(mm)*	1948	1830	2172	1334	1245
σ *(mm)*	414	370	630	283	267
P_{90} *(mm)*	2463	2297	2978	1663	1618
P_{10} *(mm)*	1446	1377	1455	969	927

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