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Climate change, water supply and environmental problems of headwaters: The paradigmatic case of the Tiber, Savio and Marecchia rivers (Central Italy)

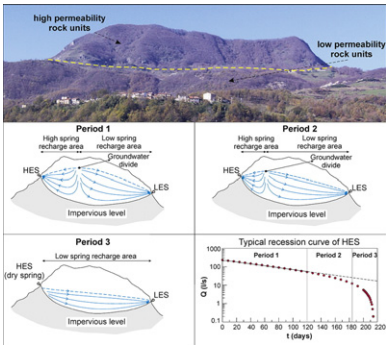
Lucio Di Matteo [a], Walter Dragoni [b,*], David Maccari [c], Simone Maria Piacentini [d]

[a] Department of Physics and Geology, University of Perugia, Via A. Pascoli snc, 06123 Perugia, Italy
[b] Department of Physics and Geology, University of Perugia, Via A. Pascoli snc, 06123 Perugia, Italy
[c] Consultant Geologist, Pieve Santo Stefano, Arezzo, Italy
[d] Department of Physics and Geology, University of Perugia, Via A. Pascoli snc, 06123 Perugia, Italy

HIGHLIGHTS

- The paper discusses the resilience to drought of springs in river headwaters.
- Effects of climate change on mountain water resources vary from place to place.
- Recession curves give information useful to water and habitat management.
- Suggestions to manage water supply in a data scarce system are proposed.

GRAPHICAL ABSTRACT



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ABSTRACT

River headwaters, in spite of their importance for habitats and water supply, are often inadequately studied and managed. This study discusses the effects of the hydrogeological system and climatic variations on the environment of Monte Fumaiolo (Central Italy), which corresponds to the headwaters of the rivers Tiber, Savio and Marecchia. The area is a key system for supplying drinking-water and is also the habitat of amphibians such as the endemic and endangered *Bombina pachypus* and other amphibian species. Ongoing climate change is affecting the area: during the last 30 years, five prolonged droughts have occurred, against only one in the preceding 40 years. On all time-scales, there is a decrease in rainfall during the recharge period and an increase of temperature: these trends correspond to a decrease in water yield of about 12% over the last 30 years. The hydrologic system of the study area is composed of one basic aquifer and a few perched aquifers feeding springs. Their resilience to drought depends on their geological setting: study of some depletion curves helped us to understand the geological setting of the various types, and two promising sites for the habitat preservation of amphibians were identified. Study results indicate new approaches to the study and management of the environment and its water supply, which could be useful in similar areas.

* Corresponding author.
E-mail addresses: lucio.dimatteo@unipg.it (L. Di Matteo), walter.dragoni@unipg.it (W. Dragoni), maccaridavid@tiscali.it (D. Maccari), simonemaria.piacentini@studenti.unipg.it (S.M. Piacentini).

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1. Introduction

Springs feeding small watercourses in river headwaters areas represent the main source of downstream waters during dry seasons and periods of drought. Interactions among groundwater, springs and streams produce often substantial habitats and are responsible for the chemical and biological characteristics of streams (Alexander et al., 2007; Winter, 2007; Bae et al., 2016; Merriam and Petty, 2016). Although such watercourses are often small, their importance is great but, despite this, they often do not appear on official maps and only a few of them are mapped (Meyer et al., 2007; Rasmussen et al., 2013). According to Gomi et al. (2002), the roles played by headwater systems are typically underestimated and inadequately managed, in comparison with larger downstream systems. Knowledge of headwater areas, even if small in extent, requires specific conceptual and field studies, which are important in identifying emerging problems at an early stage of their development (Grip, 2000).

The main problems of headwater areas may be summarised as follows:

- As headwater regions are often among the last natural or poorly anthropised areas, they have high environmental value, which is in conflict with the increasing demand of land for agriculture, industry and tourism, etc.; headwater regions generally provide the environment with high-quality waters. They can partly satisfy the increasing demand for drinking-water, which is a worldwide phenomenon. This may clash with the maintenance of wet habitats.
- Climate change, which severely affects the water cycle, increases all the problems of these fragile environments.
- Due to their marginal geographical position and consequent low economic and political status, headwater regions have received little attention, and research is hampered by proper lack of information and data (cfr. Haigh and Křeček, 1991).

Sadly enough, in spite of the importance of these environmental problems, the scarcity of hydro-meteorological data means that these spring areas have little appeal to hydrologists and hydrogeologists, and this often prevents even attempts at defining and solving problems. We believe that, if the problems are important, they should be investigated and solved as promptly as possible with available data and knowledge. Within this framework, the present work describes the problems of the Monte Fumaiolo Plateau (MFP), a typical small Mediterranean mountain headwater system, the problems of which, as well as the solutions, may be applied to other systems.

MFP is the headwaters of three important watercourses: the Savio, Marecchia and Tiber, the last being the river which flows through Rome. As the Tiber basin, including the area of Rome, is subject to frequent droughts and floods, there have been many studies focusing on droughts, floods, and the largest groundwater systems (e.g., Calenda et al., 2005; Di Matteo and Dragoni, 2006; Di Matteo et al., 2006; Romano and Preziosi, 2013; Bencivenga and Bersani, 2014; Barbetta and Moramarco, 2014; Maccioni et al., 2015; Behulu et al., 2016). However, the headwaters of all three of these rivers are much less well-known. As regards other mountainous areas of Central Italy, climate change, together with the increasing demand for water and anthropic pressures, is preparing a problematic future, from both environmental and water supply points of view (Dragoni, 1998; Bates et al., 2008; Dragoni et al., 2013; IPCC, 2014; Di Matteo et al., 2016a, 2016b). This is particularly important for the MFP, because it is a key hydrogeological system for drinking-water supply and habitat conservation. Four springs feed the main aqueducts serving a few towns in the North Apennines and along the Adriatic coast (Fig. 1): in addition, many small springs feed streams and ponds which are habitats of vital importance for amphibians and fish along the upper part of local watercourses (Lorenzoni et al., 2010; Franchi et al., 2014). Both in Europe and in Italy, the habitats and survival of endemic amphibians are in danger (Stagni et al., 2004; IUCN, 2013). Regarding this last point, the problem of maintaining wet habitats for the survival of peculiar and rare species is well-known worldwide, from humid mountain areas to arid or semi-arid ones (Enge, 1997; Ruiz et al., 2008; Surasinghe, 2009; Baker et al., 2011; D'Amen et al., 2011; Cole and North, 2014; Levison et al., 2014; EDGE, 2016). Throughout the Apennines, water withdrawal and interception of spring waters are the main threats for amphibian populations (Scoccianti, 1999; Stagni et al., 2004).

During the last few decades, increasing numbers of drought events have been documented, in general in the Mediterranean area and in particular for the Italian region, in the period 1991–2010 (e.g., Spinoni et al., 2015). Increases in the length and frequency of drought periods in the Central-Northern Apennines have affected the discharge of mountain springs, exacerbating the overall situation of both water supply and habitats (Di Matteo et al., 2013; Di Matteo et al., 2016a, 2016b). Within this framework, and on the basis of hydrogeological field investigations, new measurements and analysis of available hydro-meteorological data, the main aims of the present work are the following:

- to investigate climatic variations in the MFP area, within the framework of on-going events in the Mediterranean basin;
- to hypothesize what might happen to the water resources of the MFP in the next few decades;
- to study the hydrogeological system and the effects of climatic variations on the regime of springs, to define management strategies to minimise the impact of climate change on drinking-water resources and the environment;
- to develop investigative approaches based on the depletion curves of springs, with possibly can be applied to other areas.

The overall results should be useful to approach similar problems in other small headwater areas with similar geological features. To improve the readability and significance of this work, the acronyms and symbols used in the text are listed in Table 1.

2. Study area

2.1. Geographical characterisation

The Mount Fumaiolo Plateau is located in Central Italy and covers an area of about 11 km^2 (43°47′21.12″ N, 12°4′17.76″ E). It is forested, with a maximum elevation of 1407 m a.s.l., and is located on the Apennine watershed divide between the Tyrrhenian and Adriatic seas (Fig. 1). Three important catchment areas are comprised in the MFP: Savio, Marecchia, and Tiber (Fig. 1). The first two drain towards the Adriatic and the Tiber towards the Tyrrhenian. The Tiber basin, the second largest in Italy (about 17,340 km^2), has a rather irregular hydrological regime, due to the hydrogeological features of its basin: in its upper part, rocks of low permeability (flysch) outcrop over most of the area. This characteristic is responsible for high, fast discharges during rainy periods (autumn and winter) and, more relevant to the aims of this paper, low or negligible flows during summer, which is the local dry season (Fig. 2). Although the area of the MFP is very small when compared with the Tiber catchment, its importance for water supply (springs exploited for drinking-water) and habitat preservation is very high: the MFP is a Site of Community Importance (SCI), i.e., the European Commission has declared it to be a protected area (code IT4080008) for the survival of endemic amphibians (e.g., *Bombina pachypus;* Fig. 3).

2.2. Geological and hydrogeological setting

The geological setup of MFP is characterised by outcrops of Epi-Ligurian units (Conti et al., 2016): the Monte Fumaiolo Formation (MFU: calcareous sandstone, marly sandstone) and the San Marino