Science of the Total Environment 636 (2018) 558–568

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Historical trends and the long-term changes of the hydrological cycle components in a Mediterranean river basin

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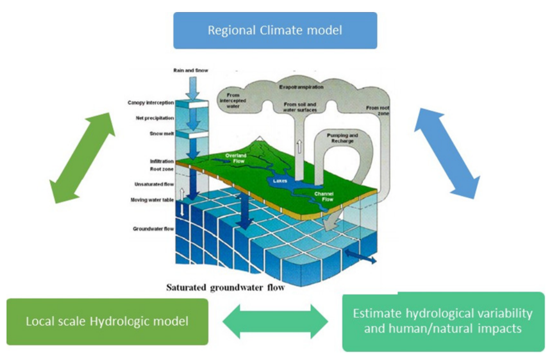
HIGHLIGHTS

- Identifying past long-term hydrologic trends in a Mediterranean river basin using regional climatic and hydrologic models
- Studying the hydrologic trends over the last 4 centuries emphasizing on human and natural forcing
- Identifying the impacts of recorded volcanic activity on the atmospheric and hydrologic conditions over the period 1660-2016

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 1 August 2017
Received in revised form 30 November 2017
Accepted 22 April 2018
Available online xxxx

Keywords:
Historical climatology
Trend analysis
Climate change
Human interventions
Spercheios River

ABSTRACT

Identifying the historical hydrometeorological trends in a river basin is necessary for understanding the dominant interactions between climate, human activities and local hydromorphological conditions. Estimating the hydrological reference conditions in a river is also crucial for estimating accurately the impacts from human water related activities and design appropriate water management schemes. In this effort, the output of a regional past climate model was used, covering the period from 1660 to 1990, in combination with a dynamic, spatially distributed, hydrologic model to estimate the past and recent trends in the main hydrologic parameters such as overland flow, water storages and evapotranspiration, in a Mediterranean river basin. The simulated past hydrologic conditions (1660–1960) were compared with the current hydrologic regime (1960–1990), to assess the magnitude of human and natural impacts on the identified hydrologic trends. The hydrological components of the recent period of 2008–2016 were also examined in relation to the impact of human activities. The estimated long-term trends of the hydrologic parameters were partially assigned to varying atmospheric forcing due to volcanic activity combined with spontaneous meteorological fluctuations.

1. Introduction

The Mediterranean region due to its morphology and geographical location is characterized by a complexity in the interactions among the various components of the hydrological cycle (Lionello et al., 2012; Peixoto et al., 1982). Located between the subtropical zone to

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https://doi.org/10.1016/j.scitotenv.2018.04.298

the south and the temperate zone to the north, the climate of the Mediterranean is affected by the arid climate of North Africa and the temperate and rainy climate of central Europe, and the interactions between mid-latitude and tropical processes (Giorgi and Lionello, 2008). This makes the specific area vulnerable to even relatively minor modifications of the general circulation and eventually climate changes, as induced by human activities and interventions, such as the increase of greenhouse gases concentrations and land use changes (Giorgi and Lionello, 2008; Mariotti et al., 2002).

Adaptation and mitigation to climate change entail the interpretation of human - environment interactions to understand the functioning of the system and the naturally imposed from the human induced changes (Dearing et al., 2006). One of the main tools for understanding climate processes prior to systematic human influence on the global atmosphere that begun with the industrial revolution, is historical climatology (Brázdil et al., 2005), which is defined as the study of the past climate before the establishment of modern networks of meteorological measurements (Mauelshagen, 2014). Research in historical climatology is mainly based on analytical techniques such as documentary evidence, corals (Evans et al., 2002), tree rings (Haines et al., 2016), ice cores (Thompson et al., 2013), speleothems, marine, lake, and other sediments (Lintern et al., 2016), soils and landforms (Brázdil et al., 2010; Brázdil et al., 2005). The study of the past alone, although important, cannot ensure the successful management of an integrated human - environment system. It is important to link the past to the present and extent this relationship to include the future, under a more holistic approach that allows an integrated, transdisciplinary synthesis and a much longer time perspective (van der Leeuw et al., 2011). Nevertheless, the limited availability of continuous, homogeneous and quantitative high-resolution observations obstructs this effort (Brázdil et al., 2005). An important tool towards this direction is the reconstruction of climate variations during the last few hundred years using climate models (Brázdil et al., 2010; Brázdil et al., 2005). Such an effort was carried out under a relevant project (SO&P - Simulations, Observations & Palaeoclimatic data), where the multiproxy reconstructions on continental and regional scales for European land areas of climate variations for the period 1500–2000 CE were performed using two state-of-the art GCM (General Circulation Model) climate models (Luterbacher et al., 2004; Pauling et al., 2006; Osborn and Briffa, 2006).

In the present effort, an integrated hydrological model, fed with the time-series reconstructions from SO&P project, has been applied in the Spercheios River Basin in Central Greece (Mediterranean) to examine the historical climatological trends since the 17th century and the associated changes of the hydrological cycle components. The main objective is to identify the magnitude of influences due to human activities (land use changes and engineering alterations in the basin river network) on the hydrological cycle of Spercheios River Basin by comparing the period before and after human interventions, over the last four centuries. The final objective of this effort is to introduce an alternative approach to the challenging field of water management, through the better understanding of how human interventions and climatic variations affect river catchments.

On a global scale, former studies also investigated changes in the hydrological cycle and their driving components for different areas and time periods. An important question is in how far changes in external forcings, such as solar, volcanic, greenhouse gases and land use might be impacting on changes in the hydrology. Specifically, for streamflow the study of Iles and Hegerl (2015) investigated the response of large river basins on strong volcanic eruptions. There are physically plausible, albeit weak signals in the relevant hydrological responses for the major river systems, for instance related to a decrease in the streamflow of the Nile River. For other river basins, the response might be different depending on the impact of the volcanic forcing on the precipitation over the study area. Moreover, in this case, the input climate data stem from reconstructions based on empirical data. This is an important aspect since Regional Climate Model (RCM) studies in the paleoclimatic context are usually related in a statistical sense (in terms of Probability Distribution Functions) to the real climate. The exact temporal evolution of an area, using RCMs driven by large scale General Circulation models, cannot be reproduced accurately due to the high complexity of land-atmospheric interactions that are not considered adequately in these models. Therefore, in this study a relatively high-resolution data set (0.5°. lat × lon) based on empirical data has been used warranting a reasonable good estimation and reconstruction of the real climate trajectory (Pauling et al., 2006).

2. Methodology

2.1. Study area

Spercheios River is located at the central part of Greece (Fig. 1a), it has a total length of approximately 91 km while its annual average discharge fluctuates from 12.9 to 21.6 m^3/s. This high intra-annual variability that can be partially assigned to the summer low flows was caused by irrigation abstractions. The Spercheios River Basin covers an area of 1661 km^2 and has a mean altitude of 641 m (Mentzafou et al., 2015).

Spercheios River's wider area, has been inhabited since the Early Neolithic period due to its strategic location as a crossroad of invaders and trade routes, the fertile soil of the riparian zone, the abundance of freshwater, the existence of the sea at the east, and the mild climate conditions (Tselika, 2006). The basin has been subjected to many hydromorphological changes mainly due to tectonic and sediment erosion-depositional processes (Kraft et al., 1987) that caused multiple alterations in the river's course during the last 2600 years. Based on old maps, historical documentation and archives, at the end of 16th and the beginning of 17th century two main rivers (Spercheios and Mavroneri rivers) run along the valley under study (Cantelli, 1684; Lucas, 1714; Mercator, 1600). Spercheios River flown into Maliakos Gulf at the north part of the basin near Lamia City, while a lake of considerable size (Eropoli) existed along a tributary of Mavroneri River (Fig. 1b).

Pococke (1745) mentioned that Spercheios River, in 1740, was located at the north part of the basin. He also witnessed an earthquake in 1758, estimated as of ML = 6.5 magnitude on the Richter scale (Papazachos and Papazachou, 1989) that could be responsible for the alteration of the river course from the northern to the southern part of the basin, near Thermopyles (Psomiadis, 2010). At the mid–end of the 18th century and beginning of 19th century, Spercheios River flows at the southern part of the basin, while three lakes are located inside the basin. Moreover, there are evidence of irrigations and artificial canals existence at that time (Arrowsmith, 1819; Gell, 1819).

At the end of the 19th century the course of Spercheios River changed route again towards the central part of the basin, which is still partially active, until today. This alteration is attributed either to the great flood of 1889 that caused the failure of the river's embankments, or to the earthquake of ML = 7.0 magnitude on the Richter scale (Papazachos and Papazachou, 1989) that occurred 30 km southeast of the study area in 1894 (Psomiadis, 2010), and/or to the land reclamation projects (Tziavos, 1977). During the late 19th–mid 20th century the main changes in Spercheios hydrography concerned the creation of a more complicated network of irrigation and flood control channels. In 1944 a large ditch close to Lamia city was constructed to drain a major stream (Xerias) and the downstream area of Spercheios River Basin. In 1957–58, Spercheios River was diverted through a flood relief channel that was constructed at the northern part of the basin while many minor projects including river bank stabilization, slope erosion control, canalisation stream dredging and drainage canals construction took place during the last 150 years in the entire hydrographic network of the basin (Mentzafou et al., 2015; Sotiropoulos, 2003). These engineering interventions are responsible for the alteration of the water and sediment balance at the coastal zone and have led to the creation of a new deltaic system at the northern part of the