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Climate change effects on the hydrological regime of small non-perennial river basins

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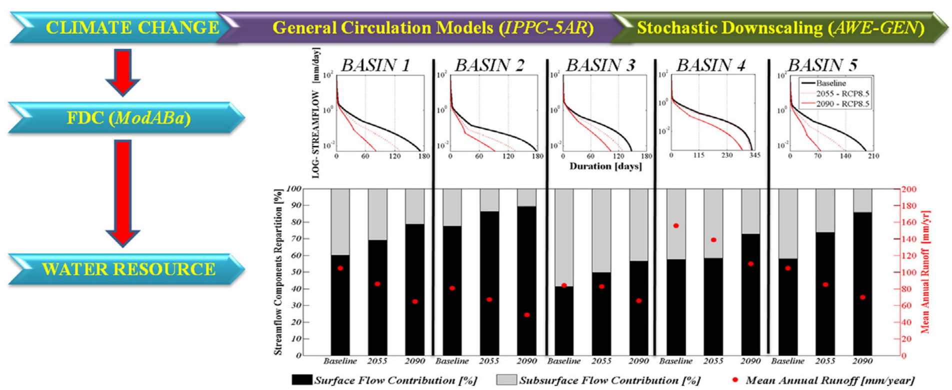
HIGHLIGHTS

- Climate Change (CC) is projected to have important fallout upon streamflow regimes.
- Mediterranean ephemeral river basins are particularly vulnerable to CC.
- CC effects on the hydrological regime of different ephemeral basins are explored.
- Streamflow rate, seasonality and composition could change relevantly in the future.
- Different soil–vegetation basins' composition may mitigate/exacerbate CC effects.

GRAPHICAL ABSTRACT



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ABSTRACT

Recent years have been witnessing an increasing interest on global climate change and, although we are only at the first stage of the projected trends, some signals of climate alteration are already visible. Climate change encompasses modifications in the characteristics of several interrelated climate variables, and unavoidably produces relevant effects on almost all the natural processes related to the hydrological cycle. This study focuses on potential impacts of climate variations on the streamflow regime of small river basins in Mediterranean, seasonally dry, regions.

The paper provides a quantitative evaluation of potential modifications in the flow duration curves (FDCs) and in the partitioning between surface and subsurface contributions to streamflow, induced by climate changes projected over the next century in different basins, also exploring the role exerted by different soil–vegetation compositions. To this aim, it is used a recent hydrological model, which is calibrated at five Sicilian (Italy) basins using a past period with available streamflow observations. The model is then forced by daily precipitation and reference evapotranspiration series representative of the current climatic conditions and two future temporal horizons, referring to the time windows 2045–2065 and 2081–2100. Future climatic series are generated by a weather generator, based on a stochastic downscaling of an ensemble of General Circulation Models.

The results show how the projected climatic modifications are differently reflected in the hydrological response of the selected basins, implying, in general, a sensible downshift of the FDCs, with a significant reduction in the mean annual streamflow, and substantial alterations in streamflow seasonality and in the relative importance

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of the surface and subsurface components. The projected climate change impact on the hydrological regime of ephemeral rivers could have important implications for the water resource management and for the sustainability of many riparian Mediterranean ecosystems.

1. Introduction

Knowledge about flow regime in river basins has a capital importance for a variety of practical applications, especially for watershed management and water sustainable use. The hydrological regime plays a crucial role in determining the biotic composition, structure and function of river basins. A full understanding of surface water availability and seasonality should drive us towards a rational use of the water resource, aimed to satisfy anthropogenic needs, warranting, at the same time, sufficient resources to support ecosystems services.

Streamflow regime in a river is highly dependent on different climatic factors, among which the most important is surely the precipitation, in terms of frequency, intensity and seasonal distribution of rainfall events. The cause–effect relationship between precipitation and discharge becomes more noticeable in non-perennial rivers, where streamflow mainly relies on surface runoff. Thus, the study of the hydrological regime under transient climate conditions results particularly relevant in ephemeral river basins, where the variations in streamflow characteristics strongly depend on the underlying precipitation patterns.

Climate change is projected to have significant fallout upon streamflow regimes worldwide. Since the beginning of climate change literature, researchers investigated on potential impacts on streamflow regimes, which, in turns, could affect water resources availability and riparian ecosystems existence in some vulnerable areas. Great attention has been recently paid on this theme, as demonstrated by the huge number of investigations over the last decade (e.g., Beyene et al., 2010; Stahl et al., 2010; Bocchiola et al., 2011; Morán-Tejeda et al., 2011; Hannaford and Buys, 2012; Liuzzo et al., 2015; Santos et al., 2014, 2015; Sellami et al., 2015), even if there are few studies on this specific topic with regard to ephemeral rivers (e.g., Ying and Zhang, 1996; Schulze, 1997; Batisani, 2011), where water scarcity frequently occur and the effects of changes in the climate forcings could imply eco-hydrological alterations heavier than for perennial streams. Most of the ephemeral basins are small in size and, in many cases, ungauged in terms of discharge observations. Defining appropriate models, therefore, represents a critical task for hydrologists and often leads to the adoption of continuous frameworks, consisting in generating a long synthetic rainfall series and using it to force continue rainfall-runoff models (e.g., Calver et al., 2009; Grimaldi et al., 2012, 2013).

Future climatic projections, according to the *fifth assessment report* of the *Intergovernmental Panel on Climate Change* — IPCC-5AR (IPCC, 2013), depict a changing global water cycle, with increases in disparity between dry and wet regions. The Mediterranean region, where future projections seem to lead towards an increase in aridity, can be considered as a "hot spot" for climate change, with marked modifications of precipitation in terms of both total amount and seasonal variability (e.g. Ulbrich et al., 2006; Sheffield and Wood, 2008). In particular, in many warm Mediterranean areas, which are already characterized by a limited water resource, the continue rise in greenhouse gases emission is likely to induce a further reduction in water availability, also in the order of 20% (Mariotti et al., 2008) or more, mainly due to the combined effect of a reduction in precipitation and a simultaneous increment of temperature, with a consequent increment in the evaporation and transpiration rates.

Starting from this premise, the primary objective of the present study is to explore the climate change impact on the hydrological regime of different ephemeral Mediterranean river basins. The soil–vegetation composition of the basins may have an important role in mitigating/exacerbating climate change fallouts (Pumo et al., 2010). Thus, differently from the few studies present in literature on this topic, the here proposed analysis is focused on a limited area of interest, i.e. the north-western Sicily (Italy), in order to investigate the different effects that similar trends in the main climate forcings may have on small basins characterized by different vegetation and soil.

A recent hydrological model for the probabilistic characterization of the daily streamflow, i.e. the ModABa — *MODel for Annual flow duration curves assessment in ephemeral small BAsins* (Pumo et al., 2014), is used. The model provides, for a given basin and climate forcings, the corresponding flow duration curve (FDC), also giving useful indications about the repartition between the slow and the fast components of streamflow. The FDC, which displays streamflow values against their relative exceedance time (Vogel and Fennessey, 1994, 1995), probably represents the most efficient method for summarizing the hydrological signatures of a river, since it describes its ability in providing flows of various magnitudes (Viola et al., 2011). Here, an opportunely designed module of the ModABa is used to infer the principal characteristics of the hydrological regime from the FDCs. The present paper also represents a first attempt to apply the ModABa to basins different from that used for its preliminary design and validation (Pumo et al., 2014), further testing its reliability and generality. Moreover, the analysis of potential future changes in the streamflow components repartition represents another challenging and innovative aspect of this work.

Five different river basins are selected within the study area; at each site, the model is first calibrated and validated against historical streamflow observations, and then forced by reliable stochastic current and future climatic scenarios. These last are generated starting from precipitation and temperature realizations obtained by General Circulation Models (GCMs). The considered GCM realizations correspond to two different greenhouse gas concentration trajectories adopted by the IPCC-5AR (Moss et al., 2010; IPCC, 2013). An opportune stochastic downscaling technique is adopted using the Advanced WEather GENerator — AWE-GEN (Ivanov et al., 2007; Fatichi et al., 2011), a numerical tool for climate time-series generation.

For each considered river basin, a *Baseline* scenario representative of the current climate (i.e., 2003–2013) is created, as well as two future climate scenarios for each emission scenarios investigated, namely the climate projections at *2055* and *2090*, based on an ensemble of GCMs projections over the periods 2045–2065 and 2081–2100, respectively. In particular, rainfall, temperature, solar radiation, relative humidity and wind speed are simulated by the AWE-GEN in order to obtain stationary 50 years long time series. Starting from such series and taking also into account the possible effect of CO_2 increase on stomatal resistance, the FAO-56 Penman–Monteith method (Allen et al., 1998) is used to estimate reference evapotranspiration series for each scenario. Finally, the ModABa, forced by the generated precipitation and reference evapotranspiration series, is applied at each examined basin, deriving the corresponding FDC and inferring some potential climate change effects on the hydrological regime for each considered future scenario.

The results achieved for the five cases could be thought as representative of the majority of Sicilian basins and, thus, they may have important implications that could interest a wide range of sectors at the regional level, from hydropower generation to agriculture, from industry to domestic water use. This study may also provide a template for