Environmental Modelling & Software 60 (2014) 202–218

Contents lists available at ScienceDirect

Environmental Modelling & Software

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

Water resources of Cyprus under changing climatic conditions: Modelling approach, validation and limitations

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ARTICLE INFO

Article history:
Received 31 March 2014
Received in revised form
6 June 2014
Accepted 9 June 2014
Available online

Keywords:
Water resources
Climate change
Catchment
Rainfall-runoff
Potential evaporation

ABSTRACT

We examine trends in the water resources of Cyprus by focussing on water flux changes in the important Kouris catchment. Our modelling approach is general and is a synthesis of an adapted conceptual daily rainfall-runoff model, radiation transfer models that use high resolution MODIS satellite climatological data and GCM scenarios for future climatic change. We used climatic data as input to our models, downscaled to the catchment resolution from two climate scenarios: the mild RCP2.6 and the extreme RCP8.5, to estimate water resources by the end of the 21st century. The models show that the present mean annual rainfall resource of 174 Mm^3 will be reduced to 162 Mm^3 and 132 Mm^3, for the mild and extreme scenario, respectively. The present mean discharge of 21.5 Mm^3 into the Kouris dam from the catchment will decrease to 16.6 Mm^3 and 6.9 Mm^3 under the mild and extreme scenario, respectively.
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1. Introduction

The depletion of water resources in many parts of the world is a major environmental problem of this century (e.g. Hoekstra et al., 2012). Cyprus, an island in the East Mediterranean (Fig. 1), has a semi-arid climate and limited water resources, entirely dependent on precipitation. The frequent droughts of the last decades together with the increase in water demand have reduced water resources considerably and Cyprus is already confronted with severe water deficit problems. In 2008, after four consecutive years of low rainfall, the available water reached a critical level and the government resorted to importing water from Greece using ship tankers. Almost all aquifers show a depleting trend and coastal aquifers have been degraded by sea water intrusion. Surface water also shows a declining trend. The government, realizing the water deficit problem early, constructed dams at the outlet of all major rivers in an effort to increase water supply. The total dam capacity increased from 6 Mm^3 in 1960 to 332 Mm^3 to date including three desalination units which have been constructed since 1997.

The impacts of climate change are one important consideration for integrated assessment of water resources (Croke et al., 2007). Worldwide, many studies have assessed the impact of climate change on water resources (Bergstrom et al., 2001; Menzel and Bürger, 2002; Christensen et al., 2004; Chiew et al., 2009; Vaze and Teng, 2011; Vaze et al., 2011b), including studies that integrate the biophysical response with an economic model (e.g. Qureshi et al., 2013). One approach for carrying out such assessments is through coupling generalized circulation models (GCMs) with hydrological models. Goodall et al. (2013) describe a method for achieving this using web services, with the GCM (running on a high performance computer) communicating with the hydrological model (running on a personal computer). Such an approach looks at the feedbacks between the climate and hydrological systems in an attempt at a more complete consideration of the total system. The penalty is the need for much more computing power, as well as increased complexity in the final model. A simpler method is to use a predicted future climate time series as an input to the model using a scenario-based approach (e.g. Cobb and Thompson, 2012; Leenhardt et al., 2012). This approach ignores the impact of the hydrological system on the climate, assuming that this is small compared to the other drivers of climate. The result is a decrease in predictive uncertainty, as well as avoiding the need for significantly more computational power.

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http://dx.doi.org/10.1016/j.envsoft.2014.06.008
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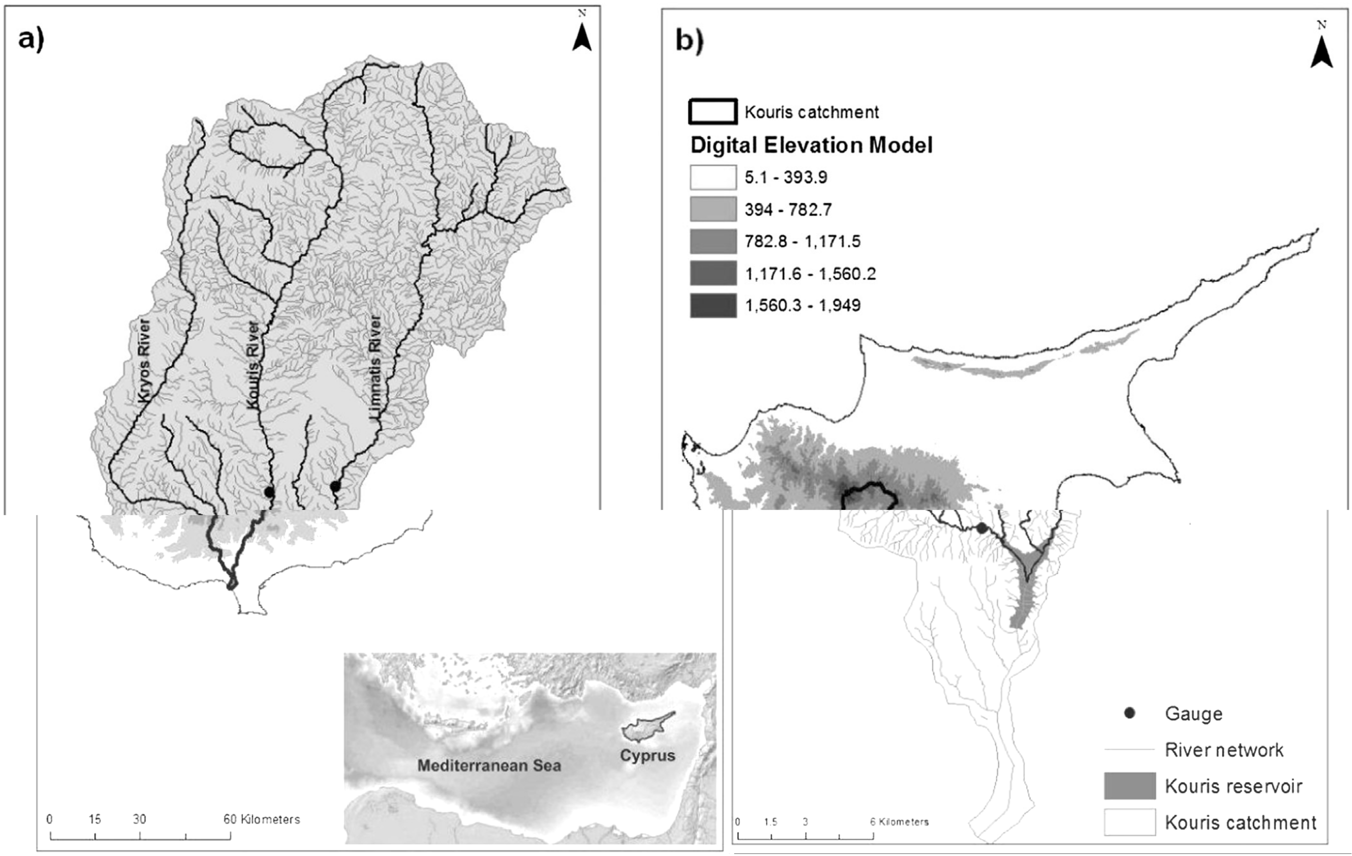

Fig. 1. The Kouris catchment with the river network and a map of Cyprus with an outline of the catchment boundary. Also shown is the location of Cyprus in the Eastern Mediterranean region.

According to the latest IPCC (2013) report, by the end of this century, the planet's climate will change in such a way that some regions will experience greater amounts of precipitation, whilst others, such as the Mediterranean region will experience lower amounts of precipitation. Mediterranean countries have already experienced the consequences of decreased precipitation and increased temperatures on their water resources (EEA Report, 2012) and these consequences are expected to worsen as the climate continues to change to a drier one.

Several studies have looked at the impact of a drier climate on the water resources of Mediterranean countries, such as those of Sanchez et al. (2009), Dubois et al. (2012), Estrela et al. (2012), but few attempts have been made to describe the potential impact of climate change on the Cyprus water resources. The interest focused on the future trends of certain climatic parameters, such as precipitation and temperature. Giannakopoulos et al. (2010) investigated the impact of climate change on precipitation and temperature over Cyprus. Lelieveld et al. (2012) used a regional climatic model to predict precipitation and temperature changes by the end of the 21st century in the Eastern Mediterranean and the Middle East, with a reference to Cyprus. Ragab et al. (2010) used simple climate change scenarios such as the per cent change in precipitation and temperature to predict the change in the water resources of two catchments (one being the Kouris) in Cyprus by 2050.

In the present work, we calculate future water fluxes for the most important catchment in Cyprus, that of Kouris. We employ a general modelling approach that combines a daily conceptual daily rainfall-runoff model (CREEK, Vardavas, 1988; Croke et al., 2000) adapted to the Kouris catchment, radiation transfer models (Vardavas and Taylor, 2011) using high resolution MODIS satellite climatic data, and GCM scenarios for climate change downscaled to the catchment resolution. We focus on the estimation of seasonal and annual values of rainfall, surface runoff, actual evaporation and recharge of the catchment in order to first understand its hydrology and secondly to predict the potential impact of climatic changes on the water cycle of the catchment and thus on the future water resources of Cyprus. In order to assess the climatic impact on the catchment's hydrology we compare water fluxes of the catchment using both historical model input data and future GCM climatic data. For this purpose, we chose the middle range GCM ECHAM6 predictions for two emission scenarios for greenhouse gases, which cover the range of the expected climate change.

Modelling catchment hydrology and the climatic parameters that affect it, is a process that involves inevitably uncertainties, especially when modelling future catchment hydrology. First, there is the uncertainty in the hydrological model due to its structure and its calibrated parameters (Wilby, 2005; Vaze et al., 2010; Bastola et al., 2011; Merz et al., 2011; Coron et al., 2012). Secondly, there is the uncertainty in downscaling climate parameters, such as the rainfall and the potential evaporation (Chiew et al., 2009; Chen et al., 2011), from a coarser GCM resolution to the catchment scale. Thirdly, there is the uncertainty associated with the GCM models and the scenarios of future emissions of greenhouse gases and other forcing agents, and this is the largest uncertainty according to many scientists (Prudhomme et al., 2003; Minville et al., 2008; Kay et al., 2009; Teng et al., 2012). GCMs are the best tools we have so far to describe the evolving climate system and even though a big improvement has been made in climate modelling (IPCC, 2013) there is still the question of how well the climate

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