Catena 151 (2017) 74–86

Contents lists available at ScienceDirect

Catena

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

Variability of the aridity in the South-Eastern Europe over 1961–2050

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ARTICLE INFO

Article history:
Received 4 July 2016
Received in revised form 13 October 2016
Accepted 28 November 2016
Available online 23 December 2016

Keywords:
Climate change
Aridity
Potential and actual evapotranspiration
South-Eastern Europe

ABSTRACT

Past and projected variability of the air temperature, precipitation, evapotranspiration and aridity in the South-Eastern Europe are evaluated throughout 1961–2050. Changes in aridity are estimated by means of five indices: de Martonne Aridity Index, UNEP Aridity Index, Pinna Combinative Index, Johansson Continentality Index and Kerner Oceanity Index. The data were aggregated from three regional climate models (RCMs) – RegCM3, ALADIN-Climate and PROMES, at 25-km spatial resolution. Our study confirms that the South-Eastern Europe is warming, while the precipitation amounts are increasing in the northern part of the domain and decreasing in the southern areas. The potential and actual evapotranspiration perform accordingly, with obvious effects on aridity. The general aridity spatial pattern remains steady along 1961–2050, but significant shifts towards more arid categories will occur in the Pannonian Plain, in the proximity of the Black Sea, and in the eastern part of the Balkan Peninsula. Increases in both potential and actual evapotranspiration can be expected over the entire region, except for some coastal areas in southern Italy, Greece and Turkey, where the actual evapotranspiration may decrease, as a result of significantly less projected precipitation available for evaporation.

1. Introduction

Climate is a transnational environmental feature, which permanently controls the ecosystems and influences the human society, triggering the constant interest of large public, policy makers and scientists. While the temporal and spatial variability is a common feature of the climate, climate change has become a topic of major concern in the recent decades. Climate variability and change occur over any region and the impact on water resources may be severe, mainly when the result is a long-term or intense deficit. South-Eastern Europe (SEE) contains a great natural diversity, subjected to dramatic political, social and economic convulsions along its history, making the region quite sensitive to environmental issues, including climate change.

In this context, numerous initiatives addressed the harmonization of the social-economic progress of the SEE with the larger European context, considering the environmental realities and long-term forecast. The South-East Europe Transnational Cooperation Programme, commonly referred to as SEE Programme, was implemented through 2007–2014, pledging for transnational cooperation and sustainability of the European development, pointing out that the (a) protection and improvement of the environment and (b) the transnational synergies for sustainable growth areas are among the top regional priorities.[1] More than 120 projects were successfully implemented in the framework of the SEE Programme, and climate change and the derived impacts were tackled extensively. For instance, *Climate Change and Impacts on Water Supply* (CC-WaterS), and *Integrated Transnational Strategy for Water Protection and Mitigating Water Resources Vulnerability* (CC-WARE) were approached in two homonym projects performed through 2009–2012 and 2012–2014, respectively, generating useful knowledge about the future climate variability.

Numerous publications documented aspects regarding the aridity and its main triggering factors in the SEE, focusing on different past or future periods, mainly at sub-regional, country or local scale. Based on different quantitative indices, Baltas (2007) and Nastos et al. (2013) described the spatial distribution and variability of the aridity in Greece. Colantoni et al. (2015) found out that the climate aridity increased in Italy during 1951–2010, while Gao and Giorgi (2008) claimed an increasing aridity over the extended Mediterranean area would happen by the end of the 21st century. Hrnjak et al. (2014) concluded that no significant changes occurred in the decadal observed aridity from Vojvodina (Serbia). Cheval et al. (2014), and Spinoni et al. (2015)tackled the observed variability of relevant climate parameters (e.g., temperature, precipitation, humidity) in the Carpathian Mountains region along 1961–2010. Boroneant and

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[1] www.southeast-europe.net/en/about_see/programme_presentation/

http://dx.doi.org/10.1016/j.catena.2016.11.029
0341-8162/

Nikolova (2011) reported on the observed changes in precipitation, while Păltineanu et al. (2007) and Croitoru et al. (2013) tackled spatiotemporal variations of the aridity in Romania. The climate projections for the 21st century and various applications in the upper Danube were analysed by Dankers et al. (2007), Dobler et al. (2011) Kling et al. (2012), and Szépszó et al. (2014). Lucarini et al. (2007) analysed the performances of 20 Global Circulation Models in representation of hydrological cycle of the whole Danube basin, while ICDPR (2013) briefly presents the climatic perspective for the next decades under the A1B scenario at country scale, and refers more consistently to the adaptation options. The report mentions that drought and low flow frequencies are expected to increase, especially in the summer, so that the scientific and practical interest in studies tackling such phenomena is very high. Moreover, Connor et al. (2013) claimed that aridity from the SE Balkans could have delayed the spread of agriculture into Europe during the Last Glacial Maximum, thus pledging for the practical meaning of the aridity along the evolution of the humankind.

The scarce water input may trigger both drought and aridity, and the two terms are often misunderstood. While drought means a temporary lack or insufficient water resources, aridity commonly refers to a permanent water deficit in an area. Drought means the negative deviation from the mean precipitation and it may occur in any type of climate, while aridity defines the climate with low multiannual average precipitation amounts. Aridity is a function of a continuum of environmental factors like temperature, precipitation, evaporation, and land cover (Vaughn, 2005). This study aims at providing information about temporal and spatial variability of the aridity in the SEE over the period 1961–2050 based on a set of indicators computed at annual resolution derived from the outputs of the projects CC-WaterS and CC-WARE. We approach the differences between the present and past aridity, on one hand, and between future and present aridity, on the other hand, as reflected by meteorological factors (temperature, precipitation, and evapotranspiration), aridity indicators, continentality and oceanity.

2. Geographical background and climate characteristics of the study area

This study approaches the area of the SEE Programme, approximately between 37° and 49°N, and from 7° to 29°E (*Online resource* 1). The elevations range from sea level to above 4000 m, and the geographical background includes three major mountain chains (the Alps, Carpathians and Balkans) and complex marine basins (Black Sea, Mediterranean Sea), with coastlines highly unregulated. Danube is the largest river, crossing the SEE area from west to east, while the most extended flat areas lie in the East (Romanian Plain), centre (Panonnian Plain), and West (Po Plain).

The climate is temperate, and the Köppen–Geiger classification system indicates that the humid continental types (Dfa, Dfb) prevail in the northern half, while Mediterranean climate (Csa, Csb) dominates the southern areas of the SEE (Peel et al., 2007). From the climate change perspective, the SEE lies at the contact between divergent precipitation trends, slightly increasing in the north, and decreasing in the south, and it is generally subjected to warming at different rates (van der Linden and Mitchell, 2009).

3. Methodology

This study exploits the outputs of the SEE projects CC-WaterS and CC-WARE. CC-WaterS (2009–2012) applied the outputs of Regional Climate Models (RCMs) from the ENSEMBLES project (van der Linden and Mitchell, 2009), and produced temperature and precipitation data sets based on observations and simulations resulted from statistical downscaling derived from canonical correlation analysis, weather classification and artificial networks (CC-WaterS, 2010). The downscaling was performed for the A1B SRES IPCC scenario, which presumes balanced energy sources within a consistent economic growth, into the context of increasing population until the mid-21st century, and rapid introduction of more efficient technologies (IPCC TAR WG1, 2001). Within the project CC-WaterS, the RCMs-based temperature and precipitation data sets were bias corrected using the gridded time series of the E-OBS database (Haylock et al., 2008), leading to a substantial enhancement of the overall picture (CC-WaterS, 2010). CC-WARE (2012–2014) was the follow-up project, and delivered quantitative indices aggregated from three RCMs, relevant for analysing the vulnerability of the water resources in the SEE.

3.1. Regional climate models

The CC-WaterS data base comprises daily and monthly temperature and precipitations derived from three RCMs, namely RegCM3, ALADIN-Climate and PROMES, extended from 1961 to 2050, at 25-km spatial resolution. RegCM3 is the third generation of the RCM originally developed at the National Center for Atmospheric Research during the late 1980s and early 1990s. The model is driven by the GCM ECHAM5-r3, it uses a dynamical downscaling, and it is nowadays supported by the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy (Elguindi et al., 2007). ALADIN-Climate was developed at Centre National de Recherche Meteorologique (CNRM), and it is downscaled from the ARPEGE-Climate as a driver for the IPCC climate scenarios over the European domain (Spiridonov et al., 2005; Farda et al., 2010). PROMES is a mesoscale atmospheric model developed by MOMAC (MOdelizacion para el Medio Ambiente y el Clima) research group at the Complutense University of Madrid (UCM) and the University of Castilla-La Mancha (UCLM) (Castro et al., 1993; Gaertner et al., 2010), and it is driven from the GCM HADCM3Q0. The initial simulation results of RegCM3, ADALDIN-Climate and PROMES were available from the ENSEMBLES project (Hewitt and Griggs, 2004), and they were selected because (1) their spatial extent covers the full study area of CCWaterS, (2) they provided good performance in the simulation of historic climate conditions, and (3) each of them uses a different driving GCM. The RCMs outputs were bias corrected using E-OBS data sets and the quintile mapping technique (Déqué, 2007; Formayer and Haas, 2010) based on daily observations (CC-WaterS, 2010), and their ability to reproduce the temperature and precipitation in various areas was tested with good results (Busuioc et al., 2010). The comparison between the gridded E-OBS and each projection revealed very small differences for the mean annual temperatures (<1 °C), and reasonable for precipitation amounts (*Online resource* 2). The assessment of the differences between the model-based values and seven meteorological stations in the study area is consistent with the known uncertainties of the RCMs (Soares et al., 2012; Wilcke et al., 2013). Generally, the RMSE is lower than 1 °C for temperature, and around 100–150 mm for precipitation, with higher deviations in the mountain areas (*Online resource* 2).

3.2. Data sets and indices

Aridity and drought phenomenon can be defined from various perspectives (e.g. meteorology, hydrology, ecology, economy), and numerous assessment methodologies have been developed accordingly. It has to be stressed that there is a fundamental distinction between aridity – a long-term climatic phenomenon – and droughts, which refers to a temporary state (water deficit) (Maliva and Missimer, 2012; Mainguet, 2013). While drought can occur in any geographical conditions and at temporal scales usually extended from months to years (van Dijk et al., 2013), aridity is an environmental feature that defines a certain area and it can be changed only over climatologic scale (e.g. >30 years). In this study, we analysed the air temperature, precipitation, potential and actual evapotranspiration as triggering factors; de Martonne, UNEP and Pinna Combinative indices are used to assess the aridity, and Johansson and Kerner indices to explore the continentality/oceanity.