Global and Planetary Change 111 (2013) 127–132

Contents lists available at ScienceDirect

Global and Planetary Change

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

Recent changes in reference evapotranspiration in Romania

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ARTICLE INFO

Article history:
Received 7 February 2013
Received in revised form 6 September 2013
Accepted 11 September 2013
Available online 18 September 2013

Keywords:
reference evapotranspiration
climatic change
Mann–Kendall test and Sen's slope
trend
Romania

ABSTRACT

In the last few decades, climate changes have become the most important topic in the field of climatology. Reference evapotranspiration (*ET_0*) is often used to identify regions prone to drought or aridity. In this paper, we used monthly data recorded in 57 weather stations in Romania over the period 1961–2007. The FAO Penman–Monteith method, based on air temperature, sunshine duration, relative humidity and wind speed, was employed in order to calculate *ET_0*. Seasonal, annual, winter wheat and maize growing seasons data sets of ET_0 were generated. The trends were detected using the Mann–Kendall test and Sen's slope, while an ArcGIS software was employed for mapping the results. The main findings of the study are: positive slopes were found in 71% of the data series considered and almost 30% of the total number of series were found significant at $\alpha = 0.05$; the highest frequency of the increasing trends as well as their absolute maximum magnitude were detected during summer and maize growing season; in winter, significant increasing changes are specific mainly to the extra-Carpathians regions; in autumn decreasing *ET_0* is specific to more than 80% of the locations, but the significant decrease characterizes mainly the southern half of the country; during the growing seasons of maize and winter wheat, the increase of the *ET_0* is dominant for the entire country. The relative change decreases with the increase of the length of the period considered: the most intense changes were detected for climatic seasons, followed by crop growing seasons and annual values. Among the climatic seasons, the highest relative increase is specific to winter followed by summer, spring and autumn, while for the crop growing seasons the values detected are similar.

1. Introduction

In the last few decades, climate changes have become the most important topic in the field of climatology. They were detected not only in isolated temperature or precipitation, but also on complex parameters, like evapotranspiration (*ET_0*). Whereas temperature and precipitation, as individual parameters, are very useful in studying climatic change, the overall expression and significance of climatic change in bioclimatic terms is better expressed by complex parameters computed from a different combination of simple parameters (Kafle and Bruins, 2009; NCDC, 2012). *ET* is the most important parameter for revealing the climate change and the temporal–spatial patterns of parameters influencing the eco-hydrological processes, which control the evolution of the surface ecosystem. Moreover, assessment of climate change impacts on *ET* variability can be helpful in determining appropriate adaptation strategies for mitigating the probable damage from these impacts (Shadmani et al., 2012).

ET is a complex parameter that controls energy and mass exchange between terrestrial ecosystems and atmosphere. It plays a crucial role in the heat and mass fluxes of the global atmospheric system and should provide a sensitive tool to monitor the changes of energy and moisture transfer from the ground to the atmosphere, because it is governed by a variety of climatic variables such as sunshine, temperature, wind speed and atmospheric humidity and due to its related effects on soil moisture and surface albedo (Chen et al., 2006; Kousari and Ahani, 2012).

Reference evapotranspiration (*ET_0*) is very frequently used to assess the drought intensity through drought indices in a large variety of geographical regions. The moisture condition is a limiting factor affecting plant growth and distribution when associated with a certain temperature (Zheng, 2000). As one of the important parameters of the hydrologic cycle, *ET_0* plays a key role in estimating and predicting crop evapotranspiration, water management, establishing irrigation scheme and other practices of agricultural production. It also reflects the impact of atmosphere evaporation capacity on the crop water requirement in different regions and periods, and it is related only to local weather conditions. Thus, it is clear that any changes in *ET_0* would affect agricultural production and also water resource programming (Allen et al., 1998;

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0921-8181/$ – see front matter
http://dx.doi.org/10.1016/j.gloplacha.2013.09.004

Francone et al., 2010; Wang et al., 2012). Increasing ET_0 can especially affect irrigated agriculture mainly in two ways: (i) increasing the crop water needs (water demand), and (ii) modifying crop patterns and growing seasons (Döll, 2002; Espadafor et al., 2011).

Under the present global warming and climatic changes conditions, the survey of ET_0 trend in different regions of the world is very important. Most of the recent studies consider aridity indices based on *ET* (UNESCO aridity index, Thornthwaite aridity index) to assess the drought and aridity for different regions (Allen et al., 1998; Paltineanu et al., 2007a,b; Ahani et al., 2012; Shifteh Some'e et al., 2012). This is one of the main reasons why researchers have become increasingly concerned about this parameter and numerous related research projects have been conducted in many regions of the world.

Studies that investigated changes in climate variables have yielded a mixture of results and conclusions about their trends, especially about ET_0, for specific locations. In the Yellow River basin, Liu et al. (2010) reported increasing trend in ET_0, whereas both statistically significant increasing and decreasing trends were found over different sites in Iran (Tabari et al., 2011, 2012; Kousari and Ahani, 2012). Mainly increasing trends in ET_0 were found in the Mediterranean areas (Cohen et al., 2002; Chaouche et al., 2010; Domenico Palumbo et al., 2011; Espadafor et al., 2011) or in the Middle East (Tabari et al., 2011, 2012; Tabari and Aghajanloo, 2013).

Contrary to the general expectations that temperature increase would lead to an increase in evapotranspiration, some previous studies conducted in Asia and North-America concluded that pan evaporation and potential evapotranspiration have diminished in the last decades (Lawrimore and Peterson, 2000; Thomas, 2000; Golubev et al., 2001; Hobbins et al., 2004; Roderick and Farquhar, 2004; Chen et al., 2005; Xu et al., 2006a,b; Wang et al., 2007, 2012; Irmak et al., 2012; Jhajharia et al., 2012; Fan and Thomas, 2013).

One of the reasons for inconsistent findings in ET_0 trends is due to the fact that in some studies temperature or radiation-based empirical equations were employed which do not account for other critical climatic parameters such as incoming shortwave or net radiation, wind speed and vapor pressure deficit. Thus, they potentially provide incomplete or artificial trends and magnitudes in ET_0 (Irmak et al., 2012). However, some authors have predicted that little or no change in ET_0 is likely due to increasing temperature, and this would be caused by increasing air humidity and higher CO_2 concentrations, which both tend to reduce transpiration and counteract the higher temperature effects on ET_0 (Snyder et al., 2011; Paltineanu et al., 2012).

In Romania, few studies on ET_0 have been undertaken so far (Paltineanu et al., 2007a,b, 2012; Lungu et al., 2011). Most of them have been focused on the spatial distribution of different aridity indices computed based on ET_0 (Paltineanu et al., 2009; Lungu et al., 2011). One single study on changes in ET_0 has been performed before, but it considered only three locations in the southern part of the country (Paltineanu et al., 2012).

The present paper is part of a larger project focusing on aridity indices in Romania and its main objectives are to evaluate the spatial distribution of the mean annual and seasonal ET_0 and to detect its changes in the recent decades in Romania.

2. Materials and methods

2.1. Studied area

The study focuses on the entire Romanian territory, which is almost equally divided into plains, hills, tablelands and mountains (Fig. 1). Agriculture is the main economic field in plain and hilly areas as well as in mountain depressions, whereas forests and alpine vegetation cover the mountains.

The Romanian territory is separated by the Carpathian Mountains into two groups of regions: intra-Carpathian regions and extra-Carpathian regions. The extra-Carpathian regions cover the southern, eastern and southeastern parts of the country while areas located inside the mountain chain and those located westward are considered intra-Carpathian regions. The main reason for such a division was the difference in the climatic features induced by the presence of the mountain chain: the first group is more often under the influence of southern tropical or eastern continental air masses generating drier and more extreme climate, whereas the second group is more dominated by western moist air masses developing a more humid or moderate climate (Badea et al., 1983; Sandu el al., 2008). In the mountains, climate and vegetation are influenced by altitude and slope exposure to solar radiation and to air masses advection.

The area under study lies from 43°40′N to 48°11′N and from 20°19′E to 29°66′E. The altitude ranges from 0 to 2544 m. However, some variations in the climatic regime within the area can be pointed out: in the East and the South of Romania, continental conditions prevail, with mean annual temperature varying from 8 to 11 °C, while precipitation ranges from 300 (on the Black Sea Coast) to 700 mm/yr in hills. The central and western regions (intra-Carpathian) are characterized by similar temperatures, but by higher precipitations, generally above 500 mm/yr. In the mountains, temperatures decrease and precipitation rate increases with altitude reaching negative mean annual temperatures and precipitation of more than 1000 mm/yr on the highest summits (Sandu el al., 2008). In the Carpathian depressions, frequent thermal inversions are specific.

As agriculture development is one of the main priorities within the general economic development strategy of the country, investigations on changes in the ET_0 are needed as one of the most important climatic parameter for agriculture managers and stakeholders.

In Romania, agricultural lands cover 65% of the territory. Maize and winter wheat are the dominant crops. They are planted on more than one third of the total territory of the country (38%) and share more than half (55%) of the total crop cultivated areas (INS, 2011). This is the main reason that stirred us in calculating ET_0 not only for the climatic seasons (winter, spring, summer and autumn), but also for the growing seasons of maize and winter wheat (April–October and October–June, respectively).

2.2. Data description

The changes in ET_0 and its triggering factors (air temperature, relative humidity, wind speed and sunshine duration) were calculated for 57 weather stations data sets. The chosen weather stations have a good spatial coverage for all types of topography and for all considered regions: 31 are located in extra-Carpathian regions (stations 1–31), 13 in intra-Carpathian regions (stations 45–57) and 13 in the Carpathian mountains area, covering summits, slopes and depressions (stations 32–44). Their territorial distribution is shown in Fig. 1.

The most weather stations are located in the extra-Carpathians regions, which are mainly plain (Romanian or Danube Plain) and low hills areas (Getic Hills) in the South and low tableland in the East (Moldavian Tableland). The general climate conditions with no important restriction to maize and winter wheat crop, mild slopes of the terrain and good quality soils induced the increase of extensive agricultural land use in those regions. The natural vegetation cover low surfaces, as the agriculture became the main economic income source of the rural and small cities population. The exposure to drier air masses coming from the East, South or Southeast of those areas makes them very sensitive to dryness, especially during the warm period of the year. Because this study is part of a larger project dedicated to dryness and aridity indices in Romania (DARDDAI), the main reason we have chosen such a high number of weather stations in those regions is to identify with a greater spatial accuracy the most dryness prone regions.

Intra-Carpathians regions, more dominated by the tableland and the hills (Transylvanian Plateau, Western Hills), are more industrialized, while the agriculture became the second economic branch. More, the agricultural land use is mainly based on orchards, especially in central