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WATER AVAILABILITY VARIATION UNDER CLIMATE CHANGE IN TURKEY DURING 21ST CENTURY

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Abstract: Water renewal is an essential cycle which depends directly on climate conditions, especially in the drought regions. Monthly and annual potential evapotranspiration (ET0) together with the actual evapotranspiration (AET0) have been used here to find water availability at a spatial scale in Turkey. Two climate models at a very high spatial resolution for 2011-2040 (present) and 2041-2070 (future) were considered to carry out the areas with high water availability and areas with water deficit. The maximum monthly ET0 reaches a value of 275 mm in July in the present period while in the future, the monthly ET0 reaches a value of 317 mm in July and August. Increase in the annual ET0 from 1288 mm to 1495 mm indicates a negative climate change on land-atmosphere exchanges. Even if the annual AET0 decreases between present and future from 901 mm to 896 mm, the water availability indicates an important decrease from 1446 mm $year^{-1}$ to 1263 mm $year^{-1}$ in these two periods. The most affected areas are located in central Turkey, mainly in the Anatolian Plateau where the water availability falls below 50 mm, in European Turkey, western coastal sides, and in the northwestern extremity of the country. The main implications of the spatial distribution of water availability and its amount could affect both surface and groundwater resources directly and indirectly affect agriculture and related activities in Turkey.

Keywords: climate change, water availability, high spatial resolution models, potential evapotranspiration, actual evapotranspiration, Turkey.

1. INTRODUCTION

The recent climate change has a negative impact on natural and artificial systems due to global warming (Haeberli et al., 1999). As a result, major climatic changes in the Mediterranean basin were observed which reflect in the long drought periods, changes in the extreme values of temperature and precipitation, and water availability depletion. Also, at the global scale, the mean temperature may reach variations up to +3 °C (Stocks et al., 1998; Stavig et al., 2005; The Canadian Centre for Climate Modelling, 2014). In addition, CO_2 concentration influences global warming increases (Cox et al., 2000). In addition, related to the global scale, IPCC (2001) indicated a rise in air temperature and a decrease in precipitation over the next few decades.

Regarding water quantity, river flow depletion reduced springs' discharge, and change in the water table level were reported (Jiménez Cisneros et al., 2014). Parmesan & Yohe (2003), Kløve et al., (2014), Yustres et al., (2013), Nistor (2016) indicated the negative effect of climate change on groundwater. Sea level oscillations and related problems of the quality and quantity of groundwater in the coastal areas are linked to global warming (Collins, 2008; Aguilera & Murillo, 2009; Hidalgo et al., 2009; Piao et al., 2010). The increase in groundwater temperature conducts to undesirable changes of water quality due to chemical reactions in the aquifers media (Taylor & Stefan, 2009; Figura et al., 2011; Kløve et al., 2012; Haldorsen et al., 2012; Kløve et al., 2014).

In the Northern Hemisphere, the summer periods of the Mediterranean and Eastern Europe countries induce drought for a long time, biodiversity changes, and desertification (Čenčur Curk et al., 2014; Prăvălie, 2014; Čenčur Curk et al., 2015). Many hydrogeologists and climatologists completed the calculation of the ET0 and AET0 at a spatial scale. The AET0 and water balance have been done for China over 1960-2002 by Gao et al. (2007), Gao et al. (2012), while in the Emilia-Romagna region from Italy, Nistor & Porumb-Ghiurco (2015) mapped the crop evapotranspiration using the ET0 and AET0. Using the performant methods, Ambas & Baltas (2012) evaluated the evapotranspiration sensitive parameters in the Prefecture of Florina region from Greece. The ET0 and AET0 have been used also in agriculture and to calculate water balance (Allen et al., 1998; Allen, 2000; Gowda et al., 2008; Gerrits et al., 2009).

In the current climate changes, the study of ET0 and AET0 is an indispensable issue for water availability calculation. The aim of the current study is to complete the spatial distribution of water availability based on monthly and annual ET0 and AET0 at a spatial scale in Turkey using climate models of temperature and precipitation for two periods of the 21st century (2011-2040 and 2041-2070). With a complex climate and orography, Turkey territory represent a transition land between Europe and Middle East. The geographical position between Black Sea in North and Mediterranean Sea in South, and the main mountains ranges, are the main aspects, which influence the climate and the water availability regime at spatial scale. The survey presented here, as a priority in the fight against global warming, may be of major interest to Climatology researchers and Hydrology domains, and also for decision making in environmental planning.

Figure 1. Location of Turkey and the physical map of the territory.

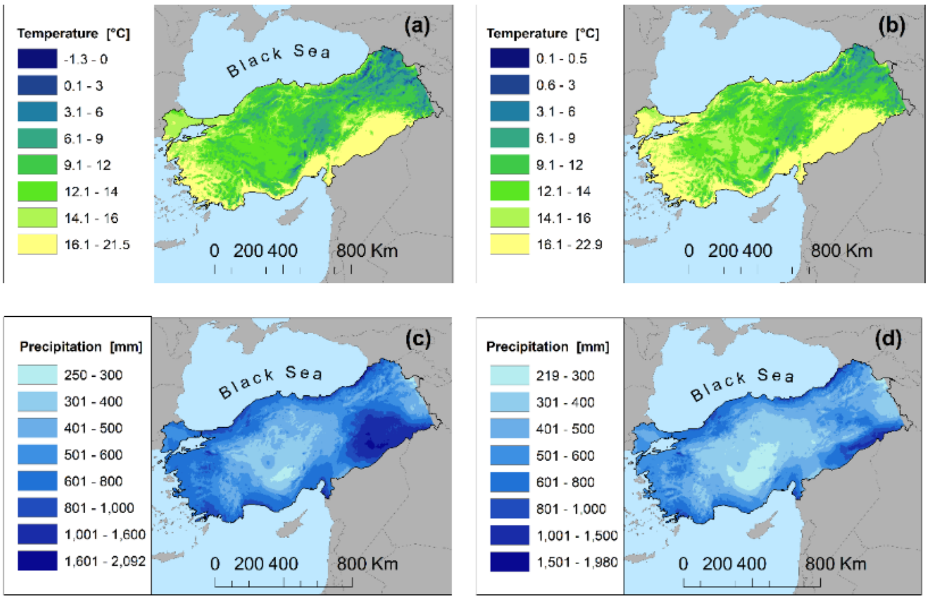

Figure 2. Spatial distribution of the mean air temperature and precipitation in Turkey. a. The average of the mean annual air temperature for the present (model of 2011-2040). b. The average of the mean annual air temperature for the future (model of 2041-2070). c. The average of the mean annual precipitation for the present (model of 2011-2040). d. The average of the mean annual precipitation for the future (model of 2041-2070).

2. STUDY AREA

The orographic characteristics of the territory and climate vary due to its geological evolution and geographical position. Turkey spreads from 25°38’ to 44°48’ East and from 35°48’ to 42°6’ North (Fig. 1). The major part of the realm is elevated land, with Armenian Highlands in the East, Pontic Mountains in the North, Taurus Mountains in the South, and the Anatolian Plateau in the center. Plains and lowlands are much present along the coastal areas and in the southeastern sides, near the Syrian border. The highest peak is Mount Ararat 5165 m, but there are numerous peaks over 3000 m. Turkey extends on two continents, Europe and Asia, and has large seaside openings. In the North, there is the Black Sea, in the South is the Mediterranean Sea, whereas in the western part, the Aegean and Marmara Seas are present.

The orography and geographical position influence the climate of the country. Variation in the mean air temperature and precipitation over 2011-2070 are shown in Figure 2. The mean air temperature registers values between -1.3 °C and 21.5 °C during the present period while in the future period the values vary from 0.1 °C to 21.5 °C. In the present period, the annual precipitation ranges from 250 mm to 2092 mm and, in the future period, the precipitation ranges from 219 mm to 1980 mm. Interestingly, in the case of the country of Turkey, the coastal areas and southeastern sides have high values of temperature and precipitation. Lower temperature could be observed in the elevated mountains. The lower values of precipitation extend to the central sides of the Turkey. Following the Koppen-Geiger classification, in the western, southern, and eastern sides of Turkey, the Csa climate was depicted, with dry and hot summers (Kottek et al., 2006). In the central part, the Csb class with warm temperate climate, characterized by dry and warm summer extends, whereas the Cfa class characterized by fully humid warm temperate climate with hot summers spreads in the northern sides (Kottek et al., 2006). Dfb and Dfc climates are present in the high-mountain areas, mainly in the northeastern parts of the country. These climates show fully humid season with warm summer period and fully humid with cool summer period.

3. MATERIALS AND METHODS

3.1. Climate data and models

We have determined the water availability based on the monthly and annual ET0 and annual AET0 calculations. The mean air temperature and mean precipitation models related to 2011-2040 (present) and 2041-2070 (future) belong to Andreas Hamann from Alberta University, Canada. He completed the models using the method proposed by Mitchell and Jones (2005). Parameter Regression of Independent Slopes Model (PRISM) served to obtain the precipitation models, while the ANUSplin interpolation method was used in the mean air temperature model. The projections follow the 15 AOGCMs of the CMIP5 multi-model dataset in line with the IPCC Assessment Report 5 (2013). To seek the global warming trend, the increase of Representative Concentration Pathway (RCP) of 4.5 by +1.4°C (±0.5) for the future was applied. The model procedure was presented in a clear way by Hamann & Wang (2005), Daly et al., (2006), Mbogga et al., (2009), and Hamann et al., (2013). In the East sides, near the border with Iran, the climate model data are not available.

3.2. Potential evapotranspiration (ET0)

Using the monthly raster data of temperature at high-resolution projections, we carried out the monthly and annual ET0. The Thornthwaite (1948) method was applied for the ET0 calculation in the present (2011-2040) and future (2041-2070). We have chosen this approach because it is easy to implement at a regional scale and it is reliable for the long-term period. Čenčur Curk et al., (2014) and Dezsi et al., (2018) have used the Thornthwaite method in climatological and hydrological studies, but the method is suitable also for agricultural investigations. Here, we have completed the heat index I and alfa complex function of heat index to obtain the monthly ET0 using the ArcGIS environment. The annual ET0 is the result of the ET0 12 months ensemble. In the areas with negative temperature, the heat index I raster grids have been completed with the ‘0’value using the ‘Mosaic’ function. We agree with this procedure because in those areas the evapotranspiration should be nil.

3.3. Actual evapotranspiration (AET0) and water availability

One of the most applicable approach to determine AET0 and water balance is the Budyko (1974) formula. The method is based on annual precipitation and annual ET0 values and indicates if energy is sufficient to sustain evaporation from precipitation (Gerrits et al., 2009). In this work, we applied the Budyko formula for the present and for the future in order to extract the water availability in Turkey. A simplified water balance equation, as difference between annual precipitation and annual actual evapotranspiration was used here, due to the long-term calculation (averages of 30 years). The storage and infiltration variables were neglected. This simplification was proposed and successfully applied by Čenčur Curk et al., (2014), in their study about groundwater vulnerability to climate change in South East Europe. Figure 3 shows the schematic diagram of the methodology.

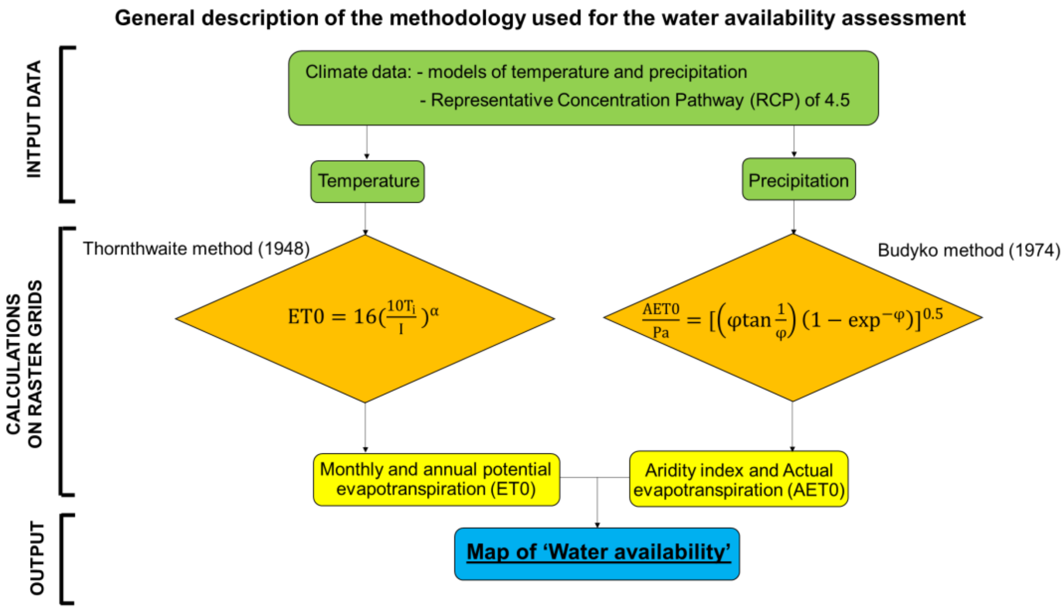

Figure 3. The overview of the applied methodology.

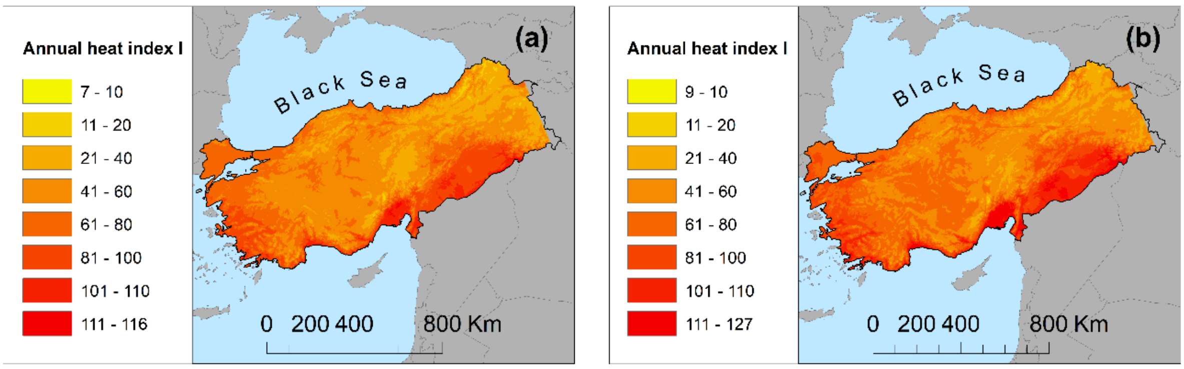

Figure 4. Spatial distribution of the annual heat index I in Turkey. a. Heat index I for the present (model of 2011-2040). b. Heat index I for the future (model of 2041-2070).

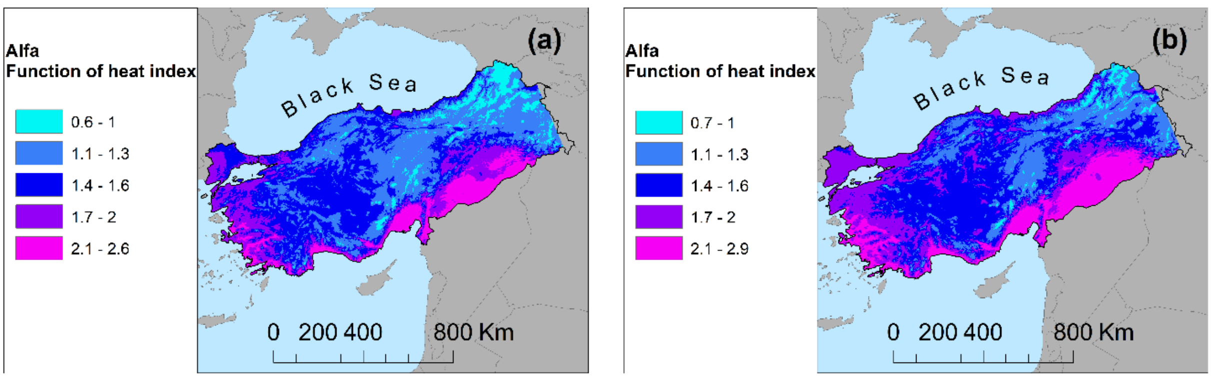

Figure 5. Spatial distribution of the annual alfa parameter in Turkey. a. Alfa parameter for the present (model of 2011-2040). b. Alfa parameter for the future (model of 2041-2070).

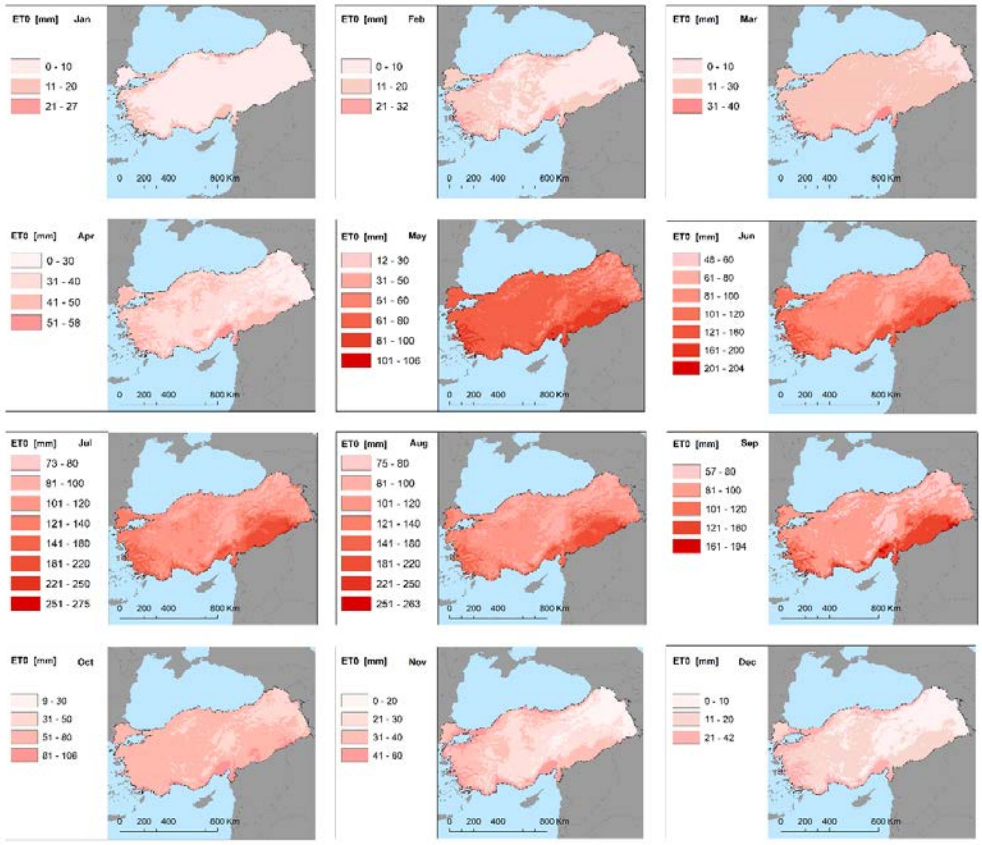

Figure 6. Spatial distribution of the monthly ET0 in Turkey for the present period (model of 2011-2040).

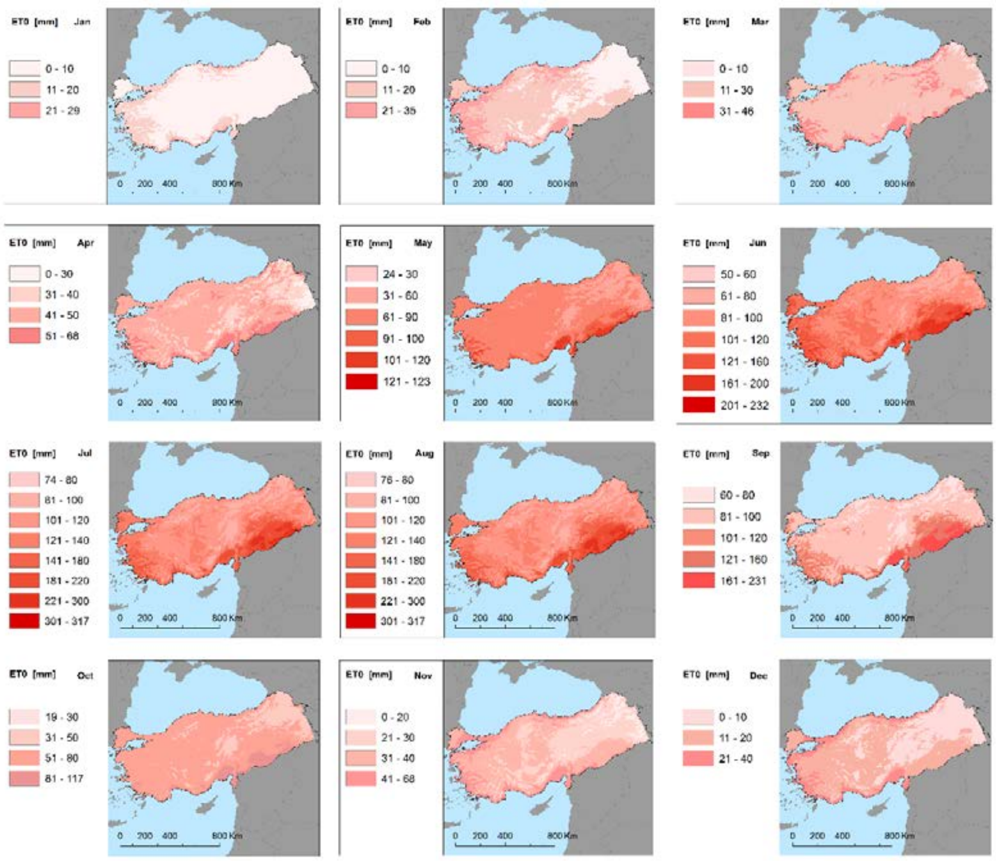

Figure 7. Spatial distribution of the monthly ET0 in Turkey for the future period (model of 2041-2070).

4. RESULTS

Climate change effect on ET0, AET0, and on water availability in Turkey during the 21st century is almost alarming on several sides. Following the methodology, the monthly heat index I varies from 0 to 116 in the present period and from 0 to 127 in the future period. The high values (over 100) of the index could be observed in the southeastern sides of Turkey and on the western coastline, near the Aegean Sea. The low values (below 20) extend mainly in the mountains and high-elevated areas, where the mean annual temperature is lower than in the plains. The high values of the heat index I extend in the future period over the central and southeastern sides. Figure 4 depicts the annual heat index I in Turkey.

The annual alfa parameter of heat index varies from 0.6 to 2.6 in the present period, whereas in the future, alfa parameter varies from 0.7 to 2.9 (Figure 5). The high values (above 2) are depicted in the South-East of Turkey and in the coastal areas, especially in the southern sides. The low values (below 1) of the alfa parameter overlap with the Taurus Mountains, northeaster sides, and few locations of eastern Turkey. In the central and western parts, the alfa parameter with values between 1.4 and 1.6 are more common. Interestingly, in the future period, high values of the alfa parameter extend over much territory than in the present period.

Analysing the monthly ET0 in the country of Turkey, the values are much diversified during one year. The maximum values during the present and future periods were depicted in the summer period. Thus, in July (2011-2040) the values of ET0 reaches 275 mm (Fig. 6), while in July and August (2041-2070), the ET0 reaches 317 mm (Fig. 7). In both periods, the high values spread over the South-East and West sides of the country. The low values of the monthly ET0 were found during the winter season (January, February, and December), but also in November, March and April. During these months, the monthly ET0 falls below 100 mm due to low-temperature values. The annual ET0 ranges from 300 mm to 1288 mm in the present period, whereas in the future period, it ranges from 321 mm to 1495 mm. The high values are localized in the South and South-East sides of Turkey, near the border with Syria and along the Mediterranean coastline. An important issue for the future period, the increase of annual ET0 values and higher territorial extension were depicted mostly in the western, central, and southeastern sides. Figure 8 illustrates the spatial distribution of the annual ET0 in Turkey.

In the AET0 assessment over the two periods, the aridity index was calculated as the ratio between ET0 and annual precipitation. Increase from 2.9 to 3.8 of the maximum aridity index has been verified between the present and future. During the present period, the low values of the index spread more in the Northern and Eastern parts of the country, but few portions could be identified in the western and southern sides also. In the future, the low values of the aridity index spread mainly in the North and North-East parts, locally in the East and West parts, but on restricted territory. Central part, especially in the Anatolian Plateau, the high values of the aridity index are (Fig. 9).

The annual AET0 varies from 239 mm to 901 mm in the present period, while in the future period, the AET0 varies from 211 mm to 896 mm. From Figure 10, it is easy to understand that in the central and eastern sides of Turkey, the AET0 is less than 400 mm. The high values (over 700 mm) were depicted in the South-East part of the country. Values over 600 mm were found also in the South, near the Mediterranean shore, and along the Black Sea coastline. These values and their distribution in the territory will influence water availability in Turkey directly.

In the present period, water availability ranges from 11 mm to 1446 mm, while in the future, water availability ranges from 5 mm to 1263 mm. The high values overlap to the southeaster and northern lands, and in the future period, the highest values have a drastic reduction in spatial distribution. The low values (below 100 mm) extend more in the central part of Turkey and in the eastern extremity. On the Black Sea coast and in few locations from the western sides, the values of water availability ranges from 200 mm to 400 mm. In European Turkey, the values fall below 200 mm and 100 mm in the present and future respectively. Figure 11 shows the spatial distribution of water availability in Turkey during the present and future periods.

5. DISCUSSION

Based on climate data models of mean air temperature and precipitation, we have completed the monthly ET0 and annual ET0 and AET0 in Turkey. Using these climate parameters, water availability was determined under the recent climate change up to 2070.

The influence of the marine climate could be observed in the coastal areas where the value of the heat index I and alfa parameter are higher than inside the country and in the eastern sides. The annual ET0 increase in the future period as a response to climate change. The difference of 207 mm in the annual ET0 between present and future is mainly influenced by

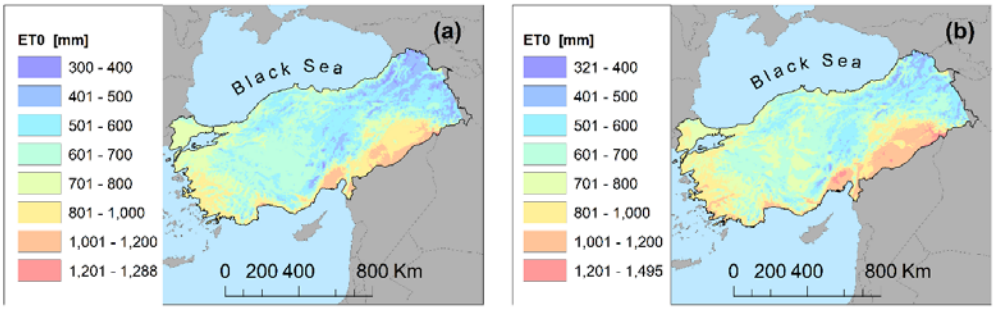

Figure 8. Spatial distribution of the annual ET0 in Turkey. a. Annual ET0 for the present period (model of 2011-2040). b. Annual ET0 for the future period (model of 2041-2070).

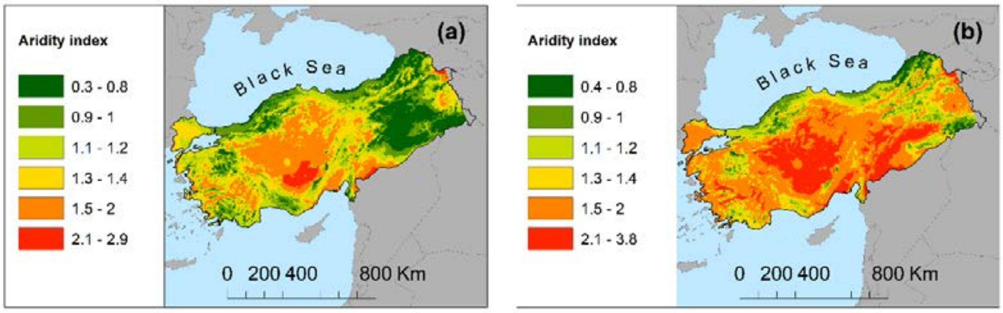

Figure 9. Spatial distribution of the Aridity index in Turkey. a. Aridity index for the present period (model of 2011-2040). b. Aridity index for the future period (model of 2041-2070).

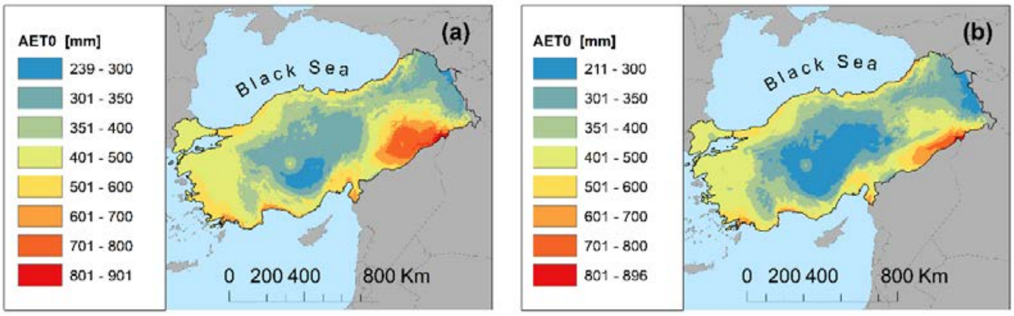

Figure 10. Spatial distribution of the annual AET0 in Turkey. a. Annual AET0 for the present period (model of 2011-2040). b. Annual AET0 for the future period (model of 2041-2070).

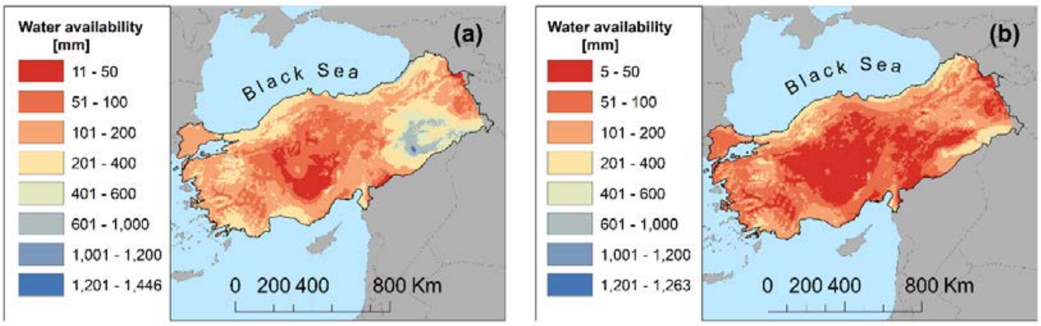

Figure 11. Spatial distribution of the water availability in Turkey. a. Water availability for the present period (model of 2011-2040). b. Water availability for the future period (model of 2041-2070).

temperature increase in the future (+1.4 °C). These results are reasonable considering the RCP projection value of 4.5. In case of the 8.5 RCP, the changes in temperature trend and ET0 could have been more accentuated. Water availability in Turkey reflects clearly the climate conditions of the territory. Despite the fact that in the southern and southeastern sides, the annual ET0 and AET0 are higher than in other sides of the country, water availability registered in these areas was up to 1446 mm in the present and up to 1263 mm in the future. The maps of the monthly and annual ET0, annual AET0, and water availability suggest the effect of climate change on water resources in Turkey. As we expected, the West and central parts have low values of water availability, due to less precipitation in the respective territories. We did not suppose that in the future, the Armenian Highlands and around the Ararat Mount, water availability will decrease considerably. As shown in Figure 10, the eastern part of Turkey is almost completely facing drought and decrease of runoff amount in the future.

In comparison with other studies, Čenčur Curk et al., (2014) reported AET0 values of 657 mm and 682 mm for the present and future respectively in South East Europe, while in the Emilia-Romagna region, Nistor & Porumb-Ghiurco (2015) called values up to 671 mm for the AET0 in the present. Regarding water availability, in South East Europe, the values reach 1717 mm during the present period and 1639 mm during the future period. Between the present study and the investigations of Čenčur Curk et al., (2014) and Nistor & Porumb-Ghiurco (2015) are some differences due to geographical position, aridization and climate conditions.

The limitations of the study could be addressed due to the empirical calculations and future climate trends. We did not include any field measurements by lysimeters or tensiometers for this study. Because of the large extension and long-term period analyses, our findings are acceptable. Moreover, the results carried out here are in line with the above mentioned literature. However, we consider that the local investigations and storage capacity of different aquifers could be measured to fill the possible gaps. These shortcomings do not affect the results on long-term period, considering the high resolution and validates climate models data.

6. CONCLUSIONS

The main goal of this paper was to calculate the ET0, AET0, and water availability in Turkey during two periods of 30 years. Mapping of the spatial distribution of these parameters allowed us to identify the drought areas in Turkey and to observe the climate change effect between the present period (2011-2040) and future period (2041-2070). From the climate data analysis and from the AET0 findings, water availability shows lower values in the central and northeastern sides of Turkey.

The northern areas, along the Black Sea coast, would seem to indicate low changes in the water availability between present and future. Between the two analyzed time shifts, major changes in the annual ET0 and aridity index were found. Even if the values of the AET0 are appropriate in the present and future, the spatial distribution is very different, due to decrease and variation in the precipitation pattern.

In aim to obtain immediately or short-term results regarding the water resources variation, we would like to recommend in-situ investigations on rivers discharge and groundwater water table level. These surveys should be completed first in the areas where the water availability falls below 200 mm $year^{-1}$, mainly in the Anatolian Plateau and eastern sides of Turkey. The European part of Turkey appears also with low values of water availability. The constructions of accumulations lakes and channels along the main rivers will play an essential role for the surface water management and agriculture.

The quality of the groundwater in the coastal aquifers may be monitored using data loggers to check the salinity variation. Due to sea level rise, the freshwaters near the coast could be affected by seawater intrusions.

Our findings represent a good input for the mitigation of the climate change and the groundwater vulnerability in the complex territory of Turkey. In addition, the results are useful to climatologists and hydrogeologists, and also for environmental strategy plans of the studied area.

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