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Drought analyses using CORDEX simulations over the Mediterranean Climate Regions of Turkey

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Introduction

Drought has been a significant result of climate change that impacts the variability and the long term mean of precipitation regimes. It is a bit latent phenomenon comparing to other extreme weather events since it is not instantaneous like floods that emerges in hours -even in an hour- or heatwaves that evokes itself immediately. However, it is such an event that has widespread and long-termed effects to nature and society.

Mediterranean region is one of the hotspot regions in the world that will be significantly impacted from the expected change (Giorgi, 2006). Hence, it is important to monitor drought considering the increasing population and intensive agricultural and touristic facilities in the Mediterranean climate regions of Turkey.

This region presents several aspects of interest, such as its important inter-annual variability in precipitation and temperature, and the severe economic damages and losses of life due to droughts, flooding events or heat or cold waves happened in the last decades, together with an increase in population and infrastructure (Easterling et al., 2000). In this study, the climatic conditions were mainly taken into consideration at determination of study area rather than other identifiers like regional or provincial borders.

Figure 1 Distribution of climate types in Turkey (eba.gov.tr)

Research Objective

The main goal of this study is to investigate the drought conditions from past to the end of century in Mediterranean climate regions of Turkey. The drought analyses are performed by calculating the well-known SPI values for drought at 1, 3, 6, and 12 months timescales, assessing the impact of drought at different levels, i.e. meteorological, hydrological and agricultural droughts. Ensemble modeling approach releases 12 GCM/RCM pairs from CORDEX (the Coordinated Regional Climate Downscaling Experiment) project is used to make drought analysis not only for the past but also future period till the end of century (Table 1).

Table 1 CORDEX model couplings that are used in the study. The numerical annotations are given to prevent confusion in plots.

Model No	GCM	Institute	RCM
1-1	ICHEC-EC-EARTH	DMI	HIRHAM5
1-2		CLMcom	CCLM4-8-17
1-3		KNMI	RACMO22E
1-4		SMHI	RCA4
2-1	CNRM-CERFACS-CNRM-CM5	CNRM	ALADIN53
2-2		CLMcom	CCLM4-8-17
2-3		SMHI	RCA4
3-1	MOHC-HadGEM2-ES	CLMcom	CCLM4-8-17
3-2		KNMI	RACMO22E
3-3		SMHI	RCA4
4-1	IPSL-IPSL-CM5A-MR	SMHI	RCA4
4-2		IPSL-INERIS	WRF331F

- First, in reaching the main goal of this study, the performance analyses of the GCM/RCMs pairs in estimating monthly precipitation that are used to derive SPI indices are made at 60 grid locations corresponding to meteorological stations distributed to the study area.
- Second, the Mann Kendall trend test is applied to SPI values calculated through the period from 1972 to 2100 for each model pair.
- Finally, the assessment of drought at various magnitudes is performed at locations where drought is statistically significant from multi-model system over entire study area. As a result, the consistency of drought that appears within the region by the end of century is documented with the support of ensemble model approach.

Standardized Precipitation Index

The Standardized Precipitation Index is a meteorological drought index that was developed by Mckee et al. (1993). It interprets observed precipitation as a standardized departure with respect to a rainfall distribution function. The calculation of SPI value for desired period is based on the long-term precipitation record. McKee and others used a classification system based on SPI values to define drought intensities as shown in Table 2.

Table 2 SPI value interpretation

SPI	Classification
2.0 and higher	extremely wet
1.5 to 1.99	very wet
1.to 1.49	moderately wet
0.99 to -0.99	near normal
-1 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2.0 and less	extremely dry

Modified Mann-Kendall Test

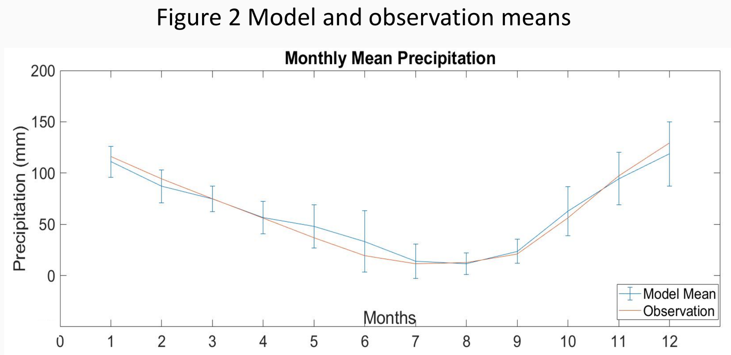
Mann Kendall test is one of the widely used non-parametric tests for detecting trends in time series (Mann, 1945; Kendall, 1975). Since SPI values are being detected in this study, a modified Mann– Kendall test that introduced by Hamed & Rao (1998) has been implied in order to avoid problems with autocorrelation.

Results

Performance of the Models

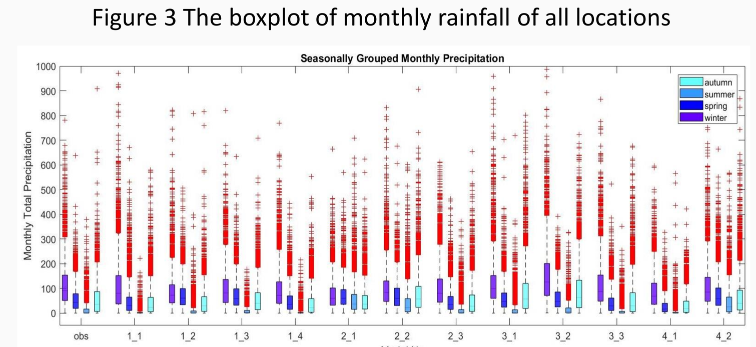
In the first step of analysis, the observed and model precipitation data was compared for the reference period 1971-2005. The mean of models for monthly precipitation values including whole stations were shown in Figure 2. The bars around model mean line denotes the standard deviations of 12 model pairs.

Figure 2 Model and observation means



The mean of monthly precipitation values are very near to observation for most of the months (Figure 2). Model means give fitting values for autumn months. However, the difference of model monthly rainfall values causes a significant divergence of model means from observation mean for May, June and December.

Figure 3 The boxplot of monthly rainfall of all locations



It can be distinguished which models cause such a divergence at model means through the instrument of Figure 3. Model 2-1, 2-2 and 4-2 overestimates summer rainfalls while 2-1 underestimates winter rainfalls. 3-2 overestimates autumn and winter rainfalls as well.

Trend Analysis

The plots in Figure 4 show the SPI values for 5 timescales and trendlines obtained by linear regression for model 1-1 predictions between the years 1972-2100 on Muğla location. The negative slope in SPI signifies increase in drought as negative SPI values mean dry conditions. Thus, it is clear that this figure points increasing drought condition for Muğla. Further, the slope of trendline increases in negative direction as timescale goes up. This location has been considered at this step since modified Mann-Kendall tests results point a significant change in trends for all timescales.

Figure 4 SPI plots for Muğla location. The equation of linear regression line is on top-right hand corner

Table 3 demonstrates the trend analysis results for 5 stations from different parts of Mediterranean climate region of Turkey. This table enables us to see the consistency and divergency of model predictions.

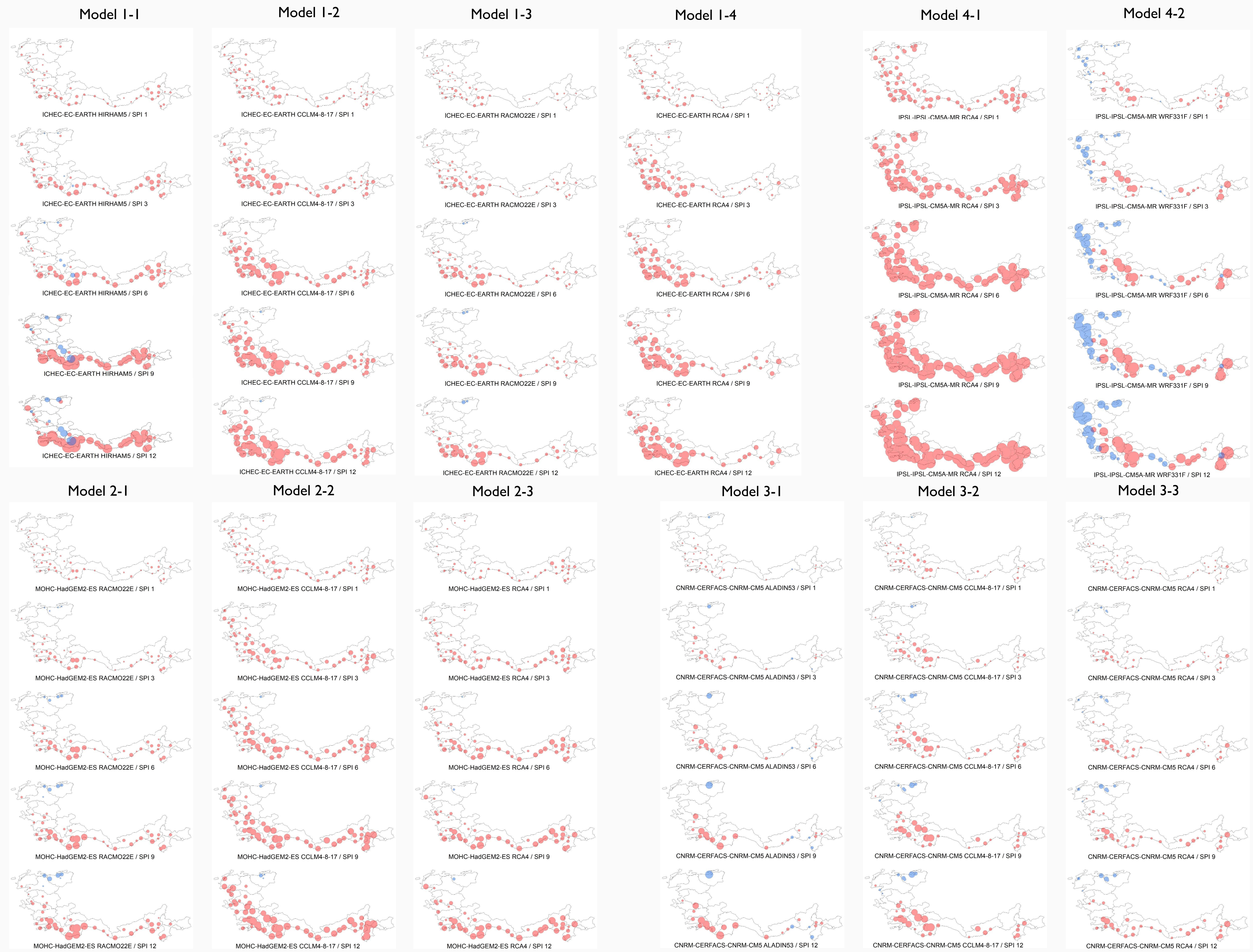
- Almost all models predict an increase in drought and decrease in annual rainfall for Muğla and Antalya locations while the analysis results are divergent for other three locations.
- The increase in drought at İzmir location is limited at 3 monthly scale for model 1-1, 1-3 and 2-2. However, model 1-2, 1-4, 2-3, 3-1, 3-2, 3-3 and 4-1 predict a negative slope at SPI trendline for not only 3-monthly but also 12-monthly scale. Lastly, a decreasing annual rainfall accompany the increasing drought according to half of the models. Model 4-2 predicts wetter conditions unlike the other 11 models.
- Balıkesir is the location on which the most optimistic trend results are obtained. This can be distinguished from the result maps in the following part. The models do not predict an increasing drought for both 3-monthly and 12-monthly scales except 3 of them (1-2, 3-1, 4-1).
- There is no significant trend in drought and annual rainfall according to four of the models for Adana. The forcing effect of Global Climate Models can be inferred since three of these four models (2-1, 2-2, 2-3) are forced by same GCM (CNRM-CERFACS-CNRM-CM5). Model 4-2 predicts no significant change at trend for this location.

Table 3 Trend results for 5 locations. ↘ denotes negative slope, ↔ denotes no significant trend, ↗ denotes positive slope.

Location	Analyzed trendlines	1-1	1-2	1-3	1-4	2-1	2-2	2-3	3-1	3-2	3-3	4-1	4-2
Adana	SPI 3	↘	↘	↘	↘	↔	↔	↘	↘	↘	↘	↘	↔
	SPI 12	↘	↘	↘	↔	↔	↔	↔	↘	↘	↘	↘	↔
	Annual	↘	↘	↘	↘	↔	↔	↔	↘	↘	↘	↘	↔
Antalya	SPI 3	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘
	SPI 12	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘
	Annual	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘
Balıkesir	SPI 3	↔	↘	↔	↘	↔	↔	↔	↘	↔	↔	↘	↔
	SPI 12	↔	↘	↔	↔	↔	↔	↔	↘	↗	↔	↘	↔
	Annual	↔	↘	↔	↔	↔	↔	↔	↔	↔	↔	↘	↔
İzmir	SPI 3	↘	↘	↘	↘	↔	↘	↘	↘	↘	↘	↘	↗
	SPI 12	↔	↘	↔	↘	↔	↔	↘	↘	↘	↘	↘	↗
	Annual	↔	↘	↔	↘	↔	↔	↘	↘	↔	↘	↘	↗
Muğla	SPI 3	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↔
	SPI 12	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↔
	Annual	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↘	↔

Table 3 also enables us to detect the forcing effect of Regional Climate models. In particular, Balıkesir and İzmir locations are proper to detect this phenomenon. Model 1-2 (forced by CCLM4-8-17 RCM) predicts drier conditions for Balıkesir in contrast to other three models which are forced by same GCM (ICHEC-EC-EARTH). IPSL-IPSL-CM5A-MR GCM is also open to RCM effect. The results are totally different for 2 models (4-1 and 4-2) which are forced by different RCMs on 4 of 5 locations.

Figure 6 Maps based on trend slopes of SPI



Legend notes

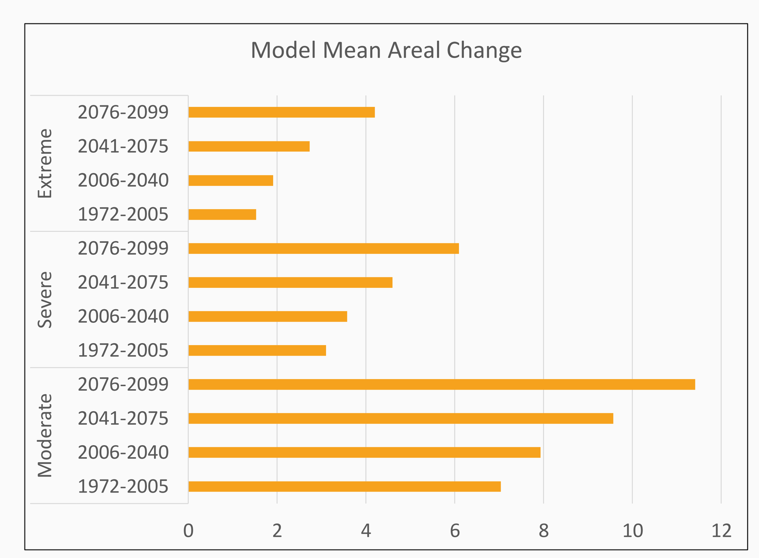
*The magnitudes of slopes are classified into 16 with 0,0001 interval

*Blue filled circles denote a decreasing trend in drought (positive slope in SPI trendline) as red filled circles denote an increasing trend in drought (negative slope in SPI trendline)

The plots in Figure 5 were constituted in order to see the areal change of drought for each severity. The percentage of the locations which affected from drought was calculated for 12 models and for 4 periods: 1971-2005, 2006-2040, 2041-2075, 2076-2099. Afterwards the averages of these percentages have been obtained for each period.

The most important outcome of this analysis is the varying ratio of areal change according to drought class.

Figure 5 Areal change of drought affected areas



Conclusions

The maps in Figure 6 show the distribution of drought trends depending on location. Muğla and western Antalya are the regions that are the most sensitive to drought in future according to most of the model predictions. The closeness of the results for these regions indicates the consistency of the models. On the other hand, the variation of the trend results of models for the rest of the area - especially Adana and Hatay regions- emerges the necessity for evaluating the RCM projections more detailly on this area.

Another significant result that can be inferred from both result tables and maps is the drought increase tends to occur for larger timescales. This means that the drier conditions may not be limited to meteorological or agricultural scale. Increase in hydrological drought is pretty probable for most of the study area. Additionally, the unstable water demand that is related to touristic facilities which intensify in summer season makes this region more vulnerable to increasing drought trends. Therefore, the measurements that will be held to manage the effects of climate change should be designed considering all demand types (agricultural, industrial, domestic use) at this region.

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