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Introduction

The Southeast Anatolia Development Project (known as GAP) is a multifaceted development project for agriculture and water resources within the Turkish portions of the Euphrates and Tigris river basins. Through this project, the vulnerability of the region to drought has been investigated in both temporal and spatial terms. On completion of the project, 28% of the total water potential of Turkey will be brought under control through facilities on the Euphrates and Tigris rivers, which have a joint flow of more than 50 billion m^3 (GAP Regional Development Administration, 1997). The GAP project aims to irrigate 8.5 million hectares of land in Southeast Anatolia, which is 19% of the total economically irrigable lands in Turkey. A project of such magnitude inevitably is of major importance to the region's water resources and agricultural potential. It is therefore important to establish reasonable expectations of water use in the GAP region, since agriculture is going to be a critical component of the region's economy in coming decades. The GAP area is located in the continental Mediterranean rainfall region, and its annual precipitation varies between 400 and 800 mm. Annual precipitation decreases from north to south in the region, and the greatest portion of the annual precipitation falls in winter, December and January being the wettest months. Summers in the region are very dry, with high temperatures.

Climatic Impact Assessment

The implications of climatic change for selected soil-water parameters are evaluated in 13 major agricultural and water resources project regions (Figures 1 and 2). The scenarios include 10 hypothetical cases involving combinations of +2 and +4 degrees Celsius and -20%, -10%, 0%, +10%, and +20% precipitation changes. The precipitation scenarios compare well with precipitation changes generated from GCM data and are similar to assumptions made by previous

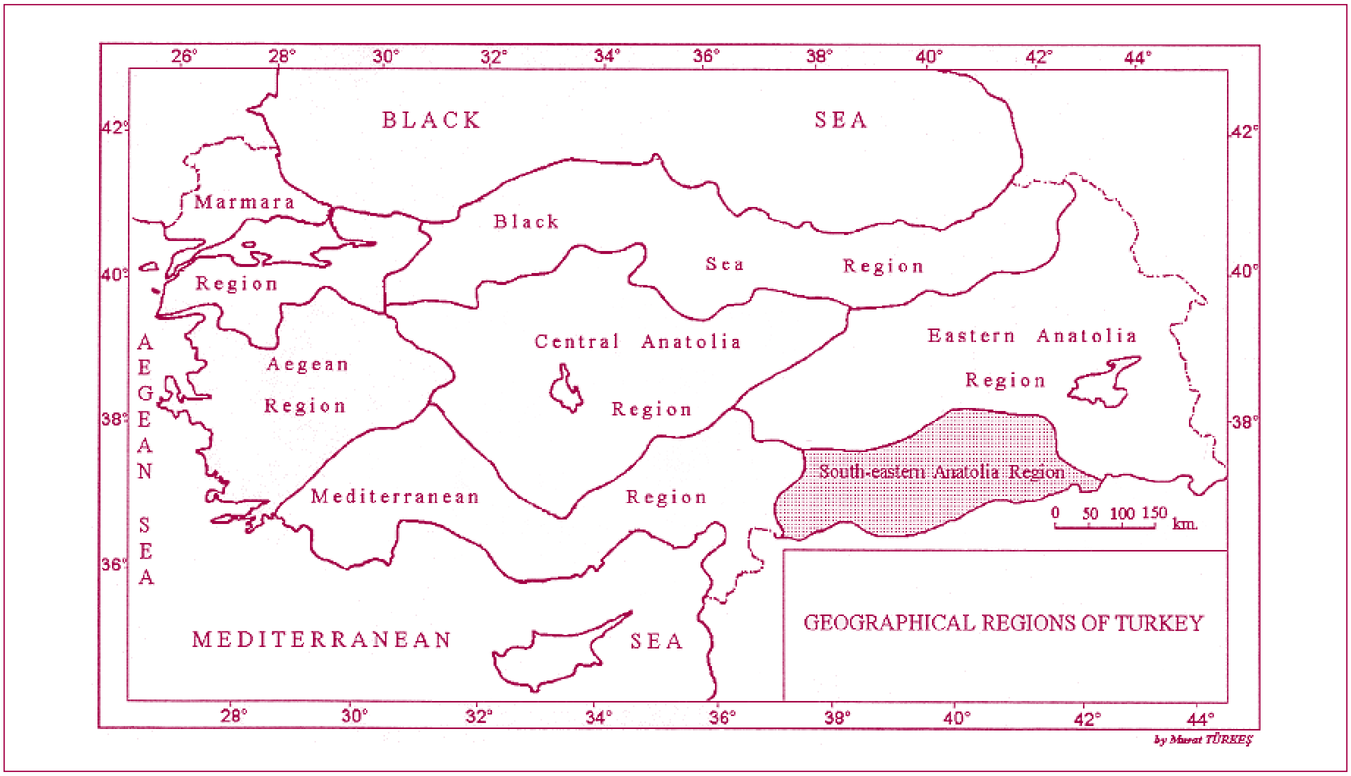


Figure 1. Location of the study area.

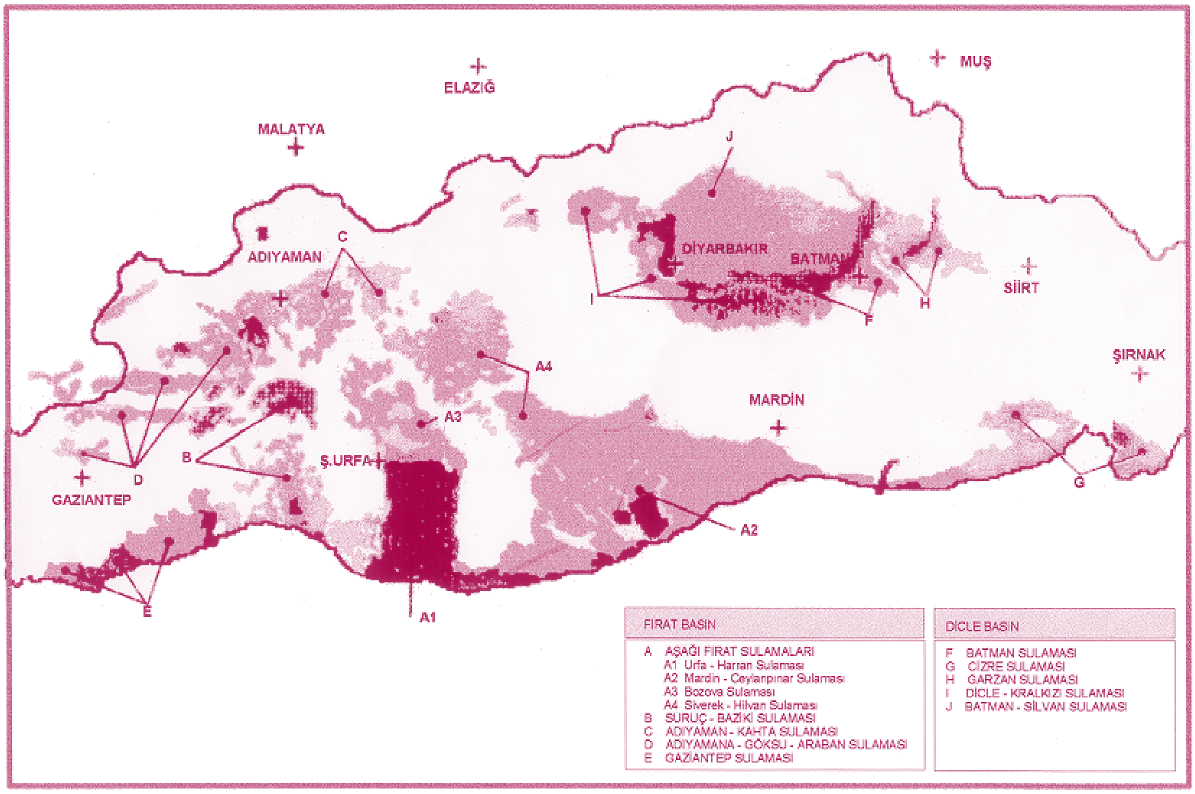


Figure 2. Major agricultural and water resources project regions of GAP.

hydrologic studies for climatic impact assessment (Gleick, 1987).

The study uses a computerized version of the original Thornthwaite water balance model, which was developed by Willmot (1997). The model requires data on precipitation, temperature, soil-water holding capacity, heat index, and latitude of a given station. It computes potential and actual evapotranspiration, soil moisture deficits, and soil moisture surplus for a predetermined time period. There are 28 climate stations within and nearby the study area. A grouping of the stations was made within each individual project area. Using the Thiessen method, representative values of precipitation, temperature, and moisture field capacity were constructed for each project area. Each project area thus was treated as a single unit of a study site.

Climate Impact Assessment Results

The results of the model runs for the hypothetical scenarios were plotted as differences from the soil moisture deficit. In Figure 3, changes in the soil moisture deficit (D) from the present are shown for a 2°C warming and prescribed precipitation changes. Groups of subregions that portray similar trends and changes are identified. A general behavior observed in all groups is that during part of spring and all of summer, the region will be affected by severe water shortages. Enhancement of the soil moisture deficit even extends to early autumn in most cases. The severity of the dryness increases during this period because the moisture demand is not satisfied by precipitation. Even with an increase in precipitation, a 2°C warming will be sufficient to cause an extended period of drought throughout the year in the region. In all the subregions, a 2°C warming coupled with a 20% decrease in precipitation will cause a major soil moisture deficit in the region. The extent of the drought also varies geographically. The effect of warming on summer deficits is most pronounced in the Cizre subregion. The timing of the deficit period shifts one month ahead in the southeastern parts of the region, starting in April. The demand for moisture peaks in all subregions in June.

Figure 4 shows the monthly changes in soil moisture deficit under a scenario of a +4°C increase in temperature. The severity of the water shortage in

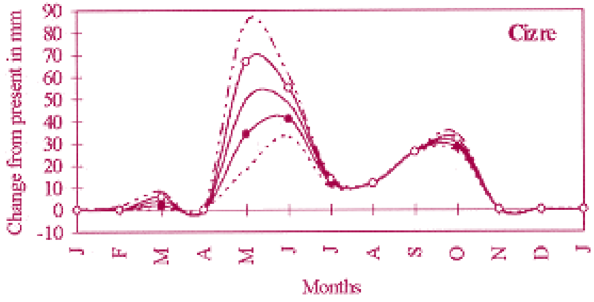
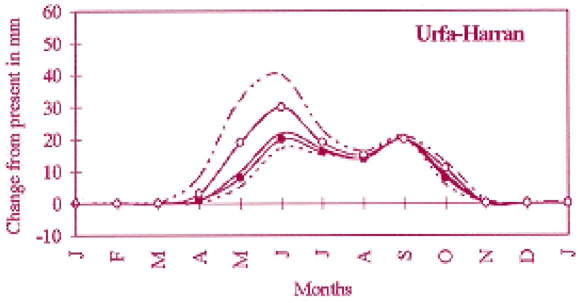
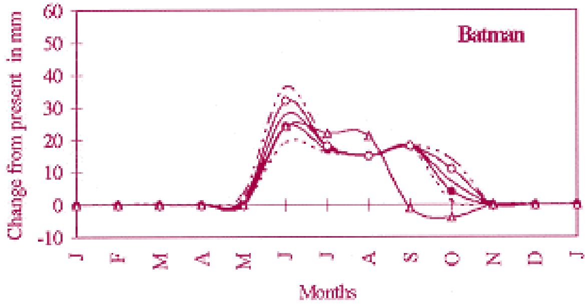
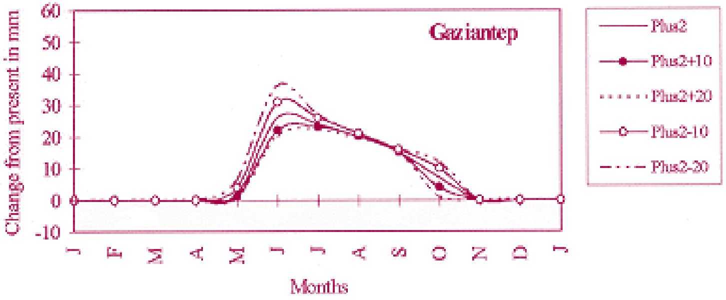
	None
	Adıyaman-Kahta
	Batman-Silvan Bozova-Urfa Dicle-Kralkızı Garzan Mardin-Ceylanpınar Siverek-Hilvan
	Adıyaman-Göksun-Araban Suruç-Baziki

Figure 3. Changes in soil moisture deficit from the present under a +2°C warming and prescribed precipitation changes.

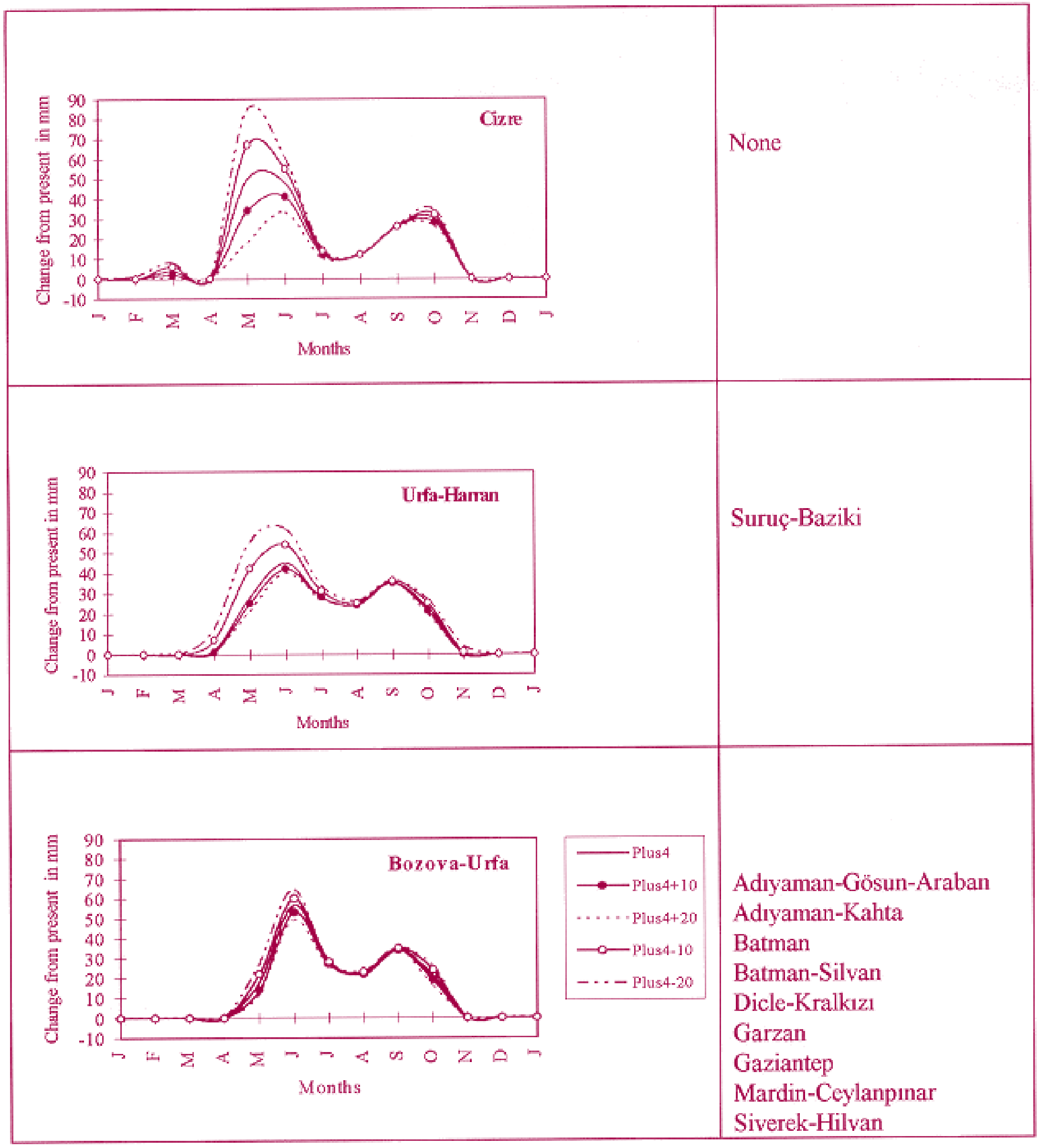


Figure 4. Changes in soil moisture deficit from the present under a +4°C warming and prescribed precipitation changes.

the GAP region is even more pronounced in this figure. Cizre is still the most sensitive to climate changes. In general, an extended period of water deficit, lasting almost 7 months, dominates throughout the region. Western and southeastern parts of the region are most affected by the water shortage. Because winter precipitation in the region is insufficient, a +4°C warming will not cause a major soil moisture deficit during the November–March period. On the other hand, because climatic demand for water increases more than does precipitation during spring and summer, a +4°C warming decreases water availability in all subregions, causing a dry period lasting 6–7 months. This extended period of soil moisture deficit is attributed to the increased spring and summer evapotranspiration and lack of precipitation. An increase in precipitation of at least 20–30% would be necessary to maintain the summer soil moisture content at its present level under a warming of +4°C. As expected, the largest changes in D occur with a +4°C warming combined with a 20% decrease in precipitation. In the Cizre subregion, the change from the present D nearly reached 90 mm in May. The beginning of the water shortage period in the region varies too. In most parts of the region, the soil moisture deficit begins in May and peaks in June. In the southeasternmost parts of the region, where the annual precipitation can be as low as 300 mm a year, the soil moisture deficit begins in April, and the change in D from the present is marked by larger differences. In other words, the timing of D shifts one month ahead in the southeastern portion of the GAP region. Another interesting conclusion is that with a warming of 4°C, the effect of increasing precipitation on reducing the soil moisture deficit is insignificant. In most subregions, increasing precipitation even 20% had little impact on reducing the summer soil moisture deficit. It is possible to conclude that in areas where summers are very dry, additional precipitation increases would not eliminate the adverse impact of warming on soil moisture content.

Results of this study suggest that the projected climate change could have major impacts on the timing and magnitude of soil moisture availability in agricultural areas of the GAP region (Komuscu et al., 1998). Among the most significant results of this study are decreases in soil moisture during the growing season across the region. The severity of the soil moisture deficit increases in the south central and southeastern parts of the region, which already suffer from low precipitation. Because the region receives most of its precipitation during the winter, an increase in precipitation in other months will not eliminate the adverse impact of warming on soil moisture. Summer soil moisture deficits increased substantially under all scenarios. Even a 20% increase in precipitation had very little effect on preventing rapid depletion of soil moisture under the warming scenarios. In other words, the projected temperature changes would be responsible for most of the increase in summer deficits in the GAP region as a result of increased evapotranspiration rates. Intensification of the dryness during the growing season in the region means higher demand for water by crops. A prolonged deficiency of soil moisture may retard plant growth and lead to agricultural drought. This in turn means enhancing the water supplies in the region and preventing crops from being subjected to extended periods of drought and subsequent crop failure. Various adaptation strategies are needed to combat agricultural drought in the region. Adaptation to climate change through new crops and crop varieties, more advanced dry farming methods, improved water management, more efficient irrigation systems, and changes in planting will be important in limiting negative effects of warming and taking advantage of beneficial changes in climate. Continued and substantial improvements in crop yields would be needed to offset the adverse effects of warming and decreased summer soil moisture in the region. Of course, irrigation practices are greatly needed in drought-prone areas for higher crop yields. Higher temperatures and increasing summer soil moisture deficit certainly will boost the demand for irrigation. In addition, if large areas will be irrigated in the region, then the problem of optimum water use will arise as the demand for water by other sectors increases.

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