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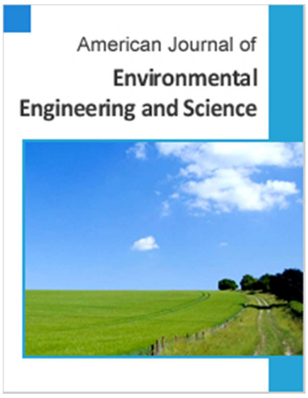

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The Impacts of Climate Change on Water Budget and Crop Yield in Gediz River Basin

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Abstract
Like many river basins in Eastern and Southern Mediterranean countries, the Gediz River Basin also suffers from water scarcity. In this agriculture-dominant basin, the water resources are almost fully allocated, and it is expected that the climate change impacts will exacerbate the water crisis, especially in the hot and dry summer seasons. Being able to assess the ability of the basin to satisfy potential water demands is crucial in order to plan for future and make reasonable decisions. Recently, a lot of efforts have been made to better characterize and model the possible impacts of climate change; one of which is the project “Climate Change Scenarios for Turkey”, funded by TUBITAK (The Scientific and Technological Research Council of Turkey). Within the project, the detailed regional projections, which can constitute the main inputs of the studies related with climate change impact/adaptation, have been developed. In this study, the project results downscaled to the Gediz River Basin are used in the Water Evaluation and Planning (WEAP) model, in order to assess the climate change impacts on water budget of the basin in future. The WEAP is forced to simulate the water system between 2010 and 2100 with the time series of temperature, precipitation, evapotranspiration and surface runoff data which are obtained by web-based data dissemination system of the project. The used data are the simulation results of ECHAM5 (European Centre Hamburg Model version 5) general circulation model and RegCM3 (Regional Climate Model version 3) regional climate model, and base on IPCC (Intergovernmental Panel on Climate Change) A2 emission scenario. The water-related changes due to climate change are evaluated in accordance with the WEAP model results for three (30-year-long) periods. A comprehensive assessment on water budget of the basin is given with respect to variations in supply reliability, unmet demand and crop yield. The results indicate that the basin will suffer from water shortages especially after 2050, and the amount of unmet water demand will be greater than supplied water. In that respect, the decrease in crop yields is obvious.

1. Introduction

At the most basic level, two related global trends greatly exacerbate the water crisis. These trends relate to the rapid increases in population growth and economic development, both of which strongly increase water demand as well as pollution. On the contrary, the quantities of water that any country can economically develop, unfortunately, continue to decrease or remain limited. For the above and a variety of other reasons like climate change, improved living standards, urbanization, and industrialization, water managers have been faced with more complex and difficult problems in the early 21st century, and it is expected that coping with water problems will be harder in future. The numerous researches with different approaches subject the impacts of climate change on water resources [1,2,3,4,5,6]. Thereby, understanding the possible impacts of climate change is of great importance for water resources management.

In the Gediz River Basin, the water resources are almost fully allocated, and it is expected that the climate change impacts will exacerbate the water crisis in this agriculture-dominant basin. Recently, a lot of efforts have been made to better characterize and model the possible impacts of climate change [7,8,9,10] one of which is the project “Climate Change Scenarios for Turkey”, funded by The Scientific and Technological Research Council of Turkey [11]. Within the project, the detailed regional projections which can constitute the main inputs of the studies related with climate change impact have been developed.

In this study, the project results downscaled to the Gediz River Basin are used in the Water Evaluation and Planning System (WEAP), in order to assess the climate change impacts on surface water balance of the basin. The water supply and demand interrelations in agriculture, which is the largest water consumer, constitute the main focus of the study. The WEAP is forced to simulate the water system between 2010 and 2100 with the time series of temperature, precipitation, evapotranspiration and surface runoff data obtained by web-based data dissemination system of the relevant project. The basic aim of the study is to reach a comprehensive assessment with respect to variations in supply reliability, unmet demand and crop yield versus changes in precipitation and temperature.

2. Materials and Methods

2.1. Gediz River Basin

The Gediz River, with a length of 275 km, drains an area of some 18000 km^2 and flows from east to west into the Aegean Sea just north of Izmir, Turkey. The Gediz River Basin (GRB) is located geographically at the interval of 38° 01′- 39° 13′northern latitude and 26° 42′-29° 45′ eastern longitude (Fig.1). It has a typical Mediterranean climate with hot, dry summers and cool winters. In the basin, mean annual temperature and mean annual precipitation are 15.6°C and 635 mm, respectively. January and February are the wet, and July and August are the driest months. 75% of the total annual precipitation is observed between November and March.

The basin covers an area of about 110000 hectares which are subject to extensive agricultural practices with large irrigation schemes, as demonstrated in Fig.2. The main crops cultivated are cotton, maize, grape, vegetables and cereals. Due to climatic conditions, irrigation is most important requirement of agriculture which is the main economic activity in the basin. As in many other ‘agriculture dominant’ basins, a great portion of surface water resources, approximately 75%, with a total about 660 10^6 m^3 is allocated to irrigation in the GRB [12].

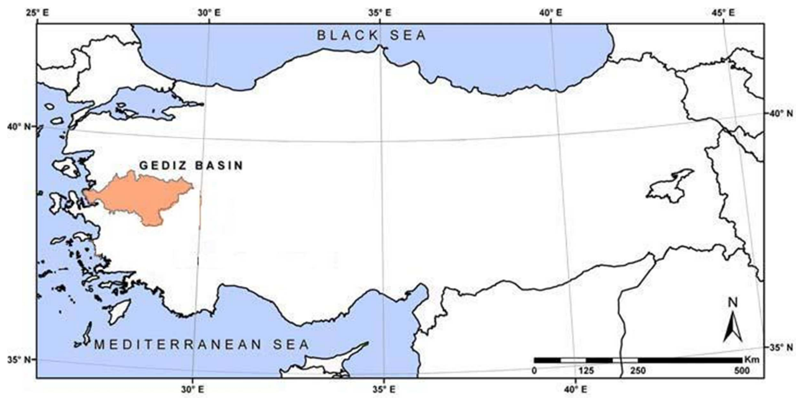

Figure 1. *The Gediz River Basin.*

Figure 2. *The regulators and the irrigated areas (green) in Gediz River Basin.*

The population of the GRB was about 1.7 million in 2000, with an annual growth rate of 1.5%. However, the internal migration from rural to urban areas (especially to Izmir) and the rapid urbanization in the major cities exert pressure on domestic water demand which increases at an annual rate of 2%. The growth of the industrial demand is even more drastic with an annual rate of 10%, due to the rapid industrialization [13].

Due to the antiquity of water conveyance systems (open channel) which lead to high water losses, lack of maintenance of irrigation systems and farmers' lack of knowledge about appropriate irrigation practices, it is certain that the current use of water for irrigation purposes is inefficient. Therefore, the modernization of irrigation techniques should be encouraged, and more productive use of water should be a fundamental objective, not only for agriculture but also for other water demanding sectors.

In this study, although a water resources management model is intended for all Gediz Basin, six large scale irrigation districts are considered as water demand sites due to lack of adequate and reliable data on domestic and industrial water uses that greatly consume groundwater resources.

2.2. Water Evaluation and Planning System (WEAP)

WEAP, developed by the Stockholm Environment Institute, is a practical tool for water resources planning, which incorporates both the water supply and the water demand issues in addition to water quality and ecosystem preservation, as required by an integrated approach to basin management [14, 15]. WEAP, which is free for academic use, is also user friendly, easy-use software, and its applications generally involve the following steps:

(i) System definition including time frame, spatial boundary, system components and configuration

(ii) Constitution of 'current accounts' which provides a snapshot of actual water demand, resources and supplies for the system

(iii) Building scenarios based on future trends on hydrology, management strategies, technological developments and/or other factors that affect demand, supply and hydrology

(iv) Evaluating the scenarios with regard to criteria such as adequacy of water resources, costs, benefits, and environmental impacts.

WEAP operates on a monthly time step, starting from the first month of the current accounts year and continuing up to the last month of the last scenario year; it computes water mass balance for every node and link in the system for the simulation period. The detailed features of WEAP can be found in [16] and user guide of the model [17].

3. Modeling Gediz River Basin in Weap

3.1. Analysis Setup

The Gediz River network with primary tributaries, meteorological stations, stream gauging stations (SGS) and reservoirs can be seen in Fig.3. Demirkopru and Gol Marmara are the reservoirs that supply water for downstream irrigation demands. Demirkopru Dam supply water for all the six irrigation districts while Gol Marmara is operated to fulfill the water deficit in summer season. Since there are no sufficient and reliable long term streamflow data for the rivers that feed Afsar and Buldan dams, these dams are not taken into account in this study.

In WEAP, the monthly operation rules of the reservoirs are introduced with the initial storage and the buffer coefficient which is the fraction of water in the reservoir available each month for release. In accordance with the monthly operation reports of the reservoirs which are taken from the annual operation reports of DSI II.Regional Directorate, the buffer coefficients are determined through the calibration process. The leakage losses are assumed equal to zero in the computations.

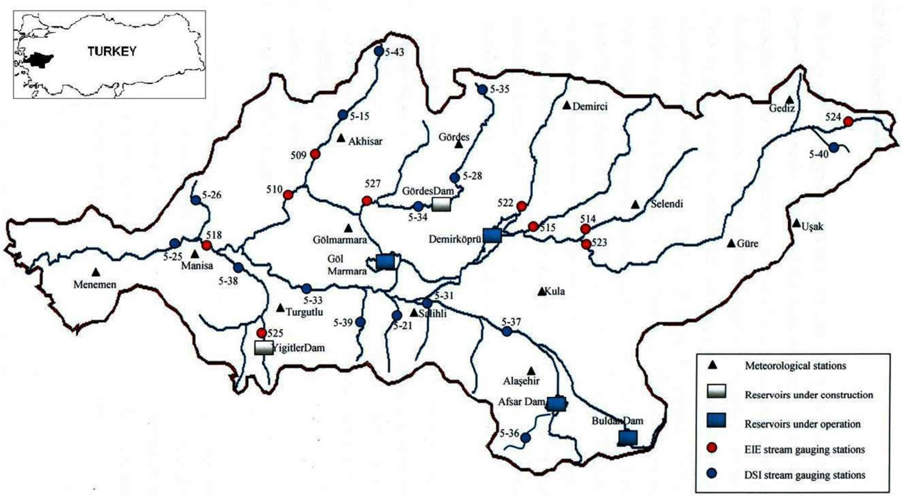

Figure 3. The Gediz River Basin.

In the analyses, the Adala, Ahmetli and Menemen irrigation districts (IDs) are taken into account as demand sites. The crop pattern data are obtained from the DSI II.Regional Directorate in Izmir. The priority of each demand site is equally set to 1 to reflect the highest priority. Although the main crops in the GRB are cotton, maize, grape, vegetables and cereals, their cultivation areas differ within the IDs. The crop coefficient (K_c) is another data requirement for the analyses. K_c is crop specific and varies by the length of the crop development stages as well as climate conditions. The CROPWAT software developed by FAO is an essential tool to develop K_c values. Although the K_c values are determined within this program, the K_c values determined by DSI are used in the analyses. This is considered as a reasonable way to simulate the real water allocation paradigm and also to calibrate the model since the water allocation is managed by DSI. The WEAP schematic where the Gediz River Basin is demonstrated within a node-link network is given in Fig.4.

Physical and contractual constraints of regulators and canals are also incorporated to analyses. Since the water distribution scheme in tertiary canals is out of the scope of the study, only the conveyance losses (including the evaporation and leakage losses) in the main and secondary canals are accounted with a general loss rate.

The 'current accounts' in WEAP terminology, represents the basic definition of the water system in its present state, and is assumed to be the starting year for all scenarios. It includes the specifications of supply and demand data for the first year of the study on a monthly basis. Since the current accounts is inferred to as 'the best available estimate of the system', the long term monthly averages of runoff as well as the monthly averages of temperature, precipitation and evapotranspiration are used to develop the current accounts, and set to the year 2009. The crop pattern in current accounts year is assumed as the descriptive pattern of the demand sites in 2009. With respect to crop yield analysis, required maximum yield data are taken from Turkish Chamber of Agricultural Engineers. The yield response factor (k_y) which refers to the relationship between relative yield decrease and relative evapotranspiration, are obtained from FAO [18].

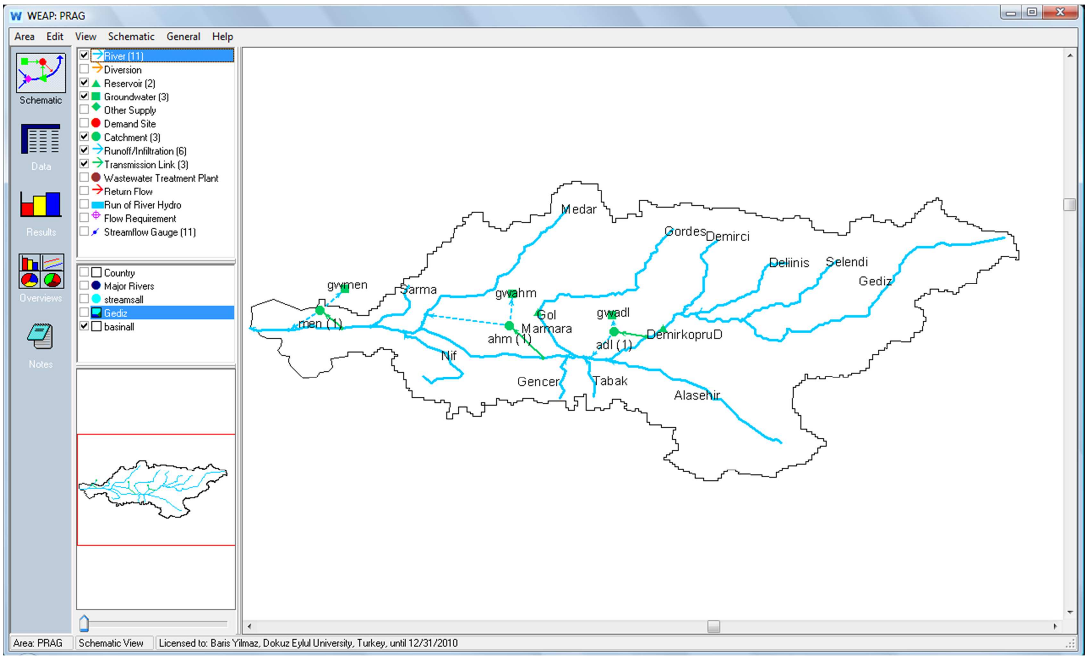

Figure 4. *The schematic used in WEAP.*

3.2. Model Calibration

The SGS 518 and the storage volumes in Demirkopru Dam are used to calibrate the model. Since the operation rules of the dams are irregular and are arranged according to the yearly water demands, the calibration is executed individually with the relevant data for the years from 1995 to 2003. The calibration graphs those refer to 2001 (dry year), 1996 (normal year) and 1999 (wet year) are depicted in Fig.5. The Nash-Sutcliffe Efficiency (NSE) and Pearson's correlation coefficient (r) are represented the model performance as 'very good' [19]. Through the model calibration, transmission link loss rate, irrigation efficiency and the irrigation return flow rate are determined as 32%, 60% and 16%, respectively. Since the irrigators prefer to fulfill the irrigation demands in July and August, the buffer coefficients are set to 1 (no restriction) for these months. However, if the storage volume of the Demirkopru Dam is available (e.g. higher than 650 10^6 m^3 in June and higher than 300 10^6 m^3 in September), water releases are allowed in early and late irrigation season with the buffer coefficients 0.1 and 1.0, respectively. These results are in accordance with the rates mentioned by DSI engineers as well as the buffer coefficients which are similar with water allocation principles of DSI [20].

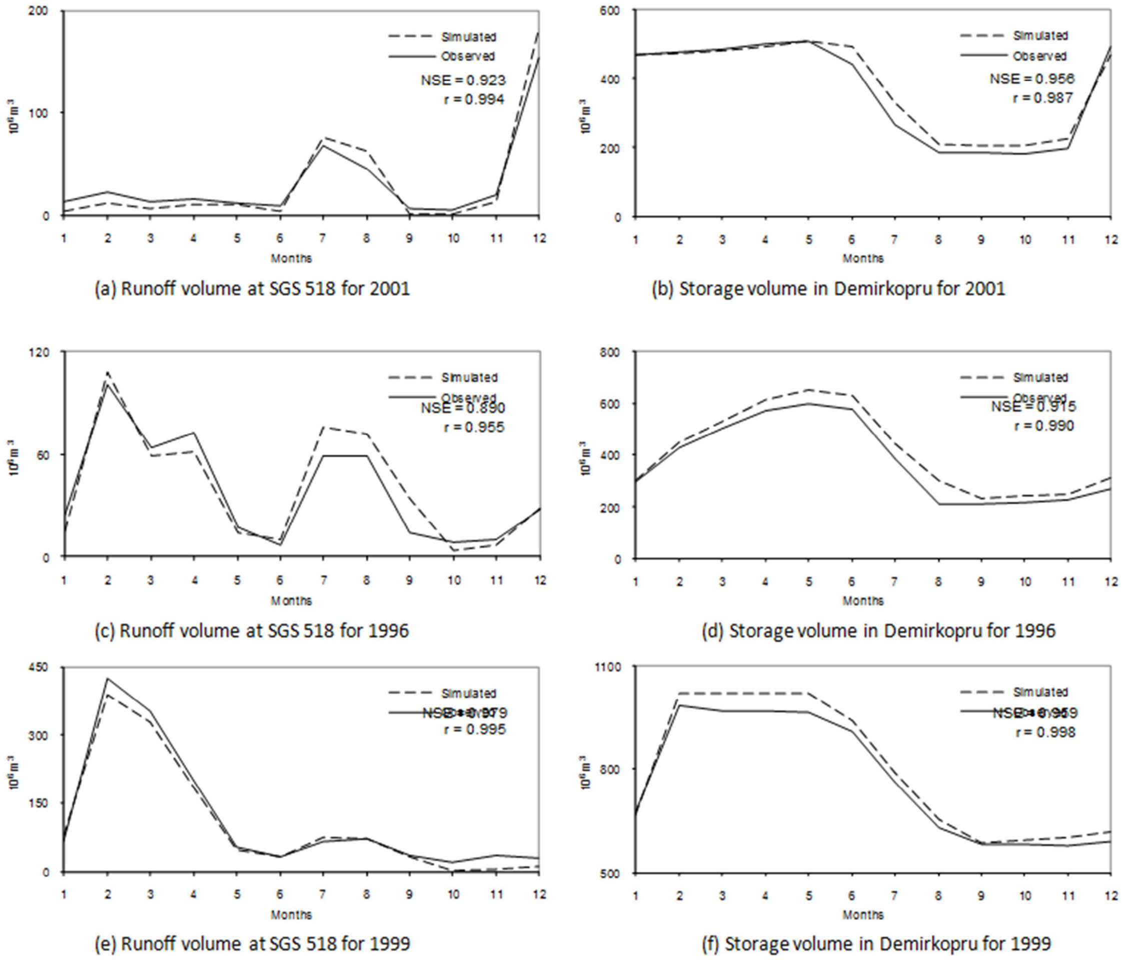

Figure 5. *The calibration graphs.*

3.3. Climate Scenario

In order to assess the climate change impacts on surface water balance of the basin, the aforementioned project's results are used in WEAP model. The used climate scenario data are the simulation results of ECHAM5 (European Centre Hamburg Model version 5) general circulation model and RegCM3 (Regional Climate Model version 3) regional climate model, and base on IPCC (Intergovernmental Panel on Climate Change) A2 emission scenario. The detailed data (the expected total precipitation and seasonal temperature changes) are obtained from the web-based data dissemination system of the project [11]. For the Gediz Basin, it is reported that 4% and 8% decrement in total winter season precipitation should be expected between 2041-2070 and 2071-2099 periods, respectively. Moreover, increase in summer season temperatures can be estimated with a range of 2 and 4°C in future.

4. Results and Discussion

For a first insight, water budget evaluation in summer season (as a total of June, July and August) is given for all simulation period in Fig. 6. Here, due to climate change impacts increase in total water demand is significant, and it is obvious that the basin will suffer from water shortage. Especially some years after 2050, the amount of unmet water demand is greater than supplied water. That is dramatic than that initially expected.

Figure 6. *Summer season water budget in Gediz Basin.*

The transmission link losses almost 30% of water passing through the link and low irrigation efficiency (60%) due to irrigation systems that employ wild flood and furrow methods are considered as the primary reasons for high amount of unmet water demand. In the current system, total losses are almost 220 10^6 m^3, and that is approximately equal to supplied water. In other words, total losses of the system constitute half of total water demand.

Water-related changes due to climate change are also evaluated in accordance with the project results for three (30-year-long) periods, namely A (2011-2040), B (2041-2070) and C (2071-2099). Since Supply/Demand ratio (S/D) is a valuable indicator for water resources management, it is computed for summer months of each period (Table 1). Obviously, climate change impacts exacerbate the water scarcity when the time elapses, and it is not seen possible to fulfill the total demand in any period.

Table 1. *Average S/D ratios for the time periods.*

	A	B	C
June	0.47	0.39	0.34
July	0.61	0.57	0.52
August	0.69	0.64	0.59
Total summer season	0.60	0.53	0.49

The average unmet demand amounts for each period are calculated for summer months in Table 2, where max and min amount of unmet demand are given to reach an idea about the intensity of deficit.

Table 2. *Amounts of unmet water demand in summer months for the time periods (10^6 m^3).*

	A			B			C		
	max	mean	min	max	mean	min	max	mean	min
June	120	61	0	123	89	30	162	108	8
July	107	67	14	110	83	37	133	104	77
August	64	38	23	66	49	21	82	63	43

In Table 3, decreases in crop yield relative to max crop yield (%) are summarized. The decrease in crop yield can be explained by the yield response factors (k_y) of crops as well as decrease in available irrigation water due to climate change impacts. The k_y of maize (1.25) is higher than k_y of cotton and grape (0.85). Therefore, the yield decrease in maize is expected to be higher than cotton, if evapotranspiration deficits occur.

Table 3. *Decreases in crop yield relative to max crop yield (%).*

	A	B	C
Cotton	32	37	42
Grape	29	34	41
Maize	48	59	67

5. Conclusion and Recommendation

Following from the above results, the major achievements derived from the analysis of possible climate change impacts in the Gediz River Basin can be summarized as follows:

i) The Basin is already under water stress and is also quite sensitive to drought conditions. If the pessimistic conditions which lead to decreased water supply and increased water demand occur, the resulting water deficits will significantly affect the agricultural sector. Accordingly, efficient water management policies are crucial to solve water problems and to ensure sustainable development in the Gediz River Basin.

ii) Replacement of the water conveyance system by pressured lines coupled with the application of water saver technologies such as drip irrigation methods is seen as the most efficient management strategy for the Basin. With this strategy, it is possible to minimize the negative impacts of climate change. It should be noted that, the proposed alternative should be supported by additional measures, such as crop change applications. On the other hand, the proposed alternative should be the basic and long term policy for socio-economic development in the Gediz River Basin.

iii) If the proposed alternative is implemented in earliest time, this will ensure more benefits in agriculture and will lead to economic achievements.

iv) The developed methodology is a valuable tool for the assessment of water resources systems and illustrates an efficient implementation of water resources management approach. By further studies, possible management alternatives should be evaluated in similar manner to reflect the improvements of sustainability indicators.

v) The WEAP model is a potentially useful tool for planning and management of water resources, and it provides a comprehensive, flexible and user friendly framework for evaluation of management strategies.

vi) For water resources management in developed countries, similar approaches have been widely used, but have not yet been effectively implemented for other river basins of Turkey. It is recommended to increase the number of similar studies that will also incorporate groundwater resources, water quality, industrial and domestic water demand, if adequate and accurate data is available.

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