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Assessing Climate Change Impacts on Gediz Basin Water Balance with WEAP Model

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***Abstract*— The Gediz Basin is an agriculture-dominant river basin in the west region of Turkey, and it suffers from water scarcity especially in drought periods. Since the water resources are almost fully allocated in the basin, it is expected that the negative impacts of climate change will exacerbate the water crisis. In this study, the climate change impacts on water balance in the Gediz Basin are investigated. The simulation results of ECHAM5 (European Centre Hamburg Model version 5) general circulation model and RegCM3 (Regional Climate Model version 3) regional climate model are used in Water Evaluation and Planning System (WEAP), in order to estimate the supply/demand ratios, amount of unmet demand as well as the decreases in crop yield due to irrigation water deficit. The WEAP model is forced to simulate the water system until 2100 with the time series of temperature, precipitation, evapotranspiration and surface runoff data projected for the Gediz Basin. The outputs of the model are evaluated for three (30-year-long) periods, and for all three indicators it is concluded that the climate change impacts will worsen the current status dramatically. The possible strategies for adaptation and mitigation of climate change impacts are recommended.**

Keywords*— *Climate change impacts; water resources; water demand; WEAP; Gediz Basin.

I. INTRODUCTION

Scientists from the Intergovernmental Panel on Climate Change (IPCC) carrying out global warming research have recently predicted that average global temperatures could increase between 1.4 and 5.8 °C by the year 2100. Some of the primary effects of climate change for water resources include air and water temperature increases; changes in levels and distribution of rainfall and snowfall; storm intensity increases; sea level rise; and changes in coastal/ocean characteristics.

Higher air temperatures are expected to have several impacts on water resources including diminishing snow pack and increasing evaporation, which affects the seasonal availability of water. Additionally, higher water temperatures also reduce dissolved oxygen levels, which can have an effect on aquatic life. Changing precipitation patterns are expected to result more frequent and intense floods and droughts. Rising sea levels have serious effects on coastal cities and cause destructive erosion, flooding of wetlands, contamination of aquifers and agricultural soils, lost habitat for fish, birds, and plants.

Like many Mediterranean basins, in the Gediz Basin climate change is likely to increase water demand while shrinking water supplies. This shifting balance challenge water managers to simultaneously meet the needs of growing communities, sensitive ecosystems, farmers, energy producers, and manufacturers. In this study, the Water Evaluation and Planning System (WEAP) is used to assess the climate change impacts on surface water balance of the basin. The water supply and demand interrelations in agriculture are constituted the main focus of the study. The WEAP is forced to simulate the water system between with the time series of temperature, precipitation, evapotranspiration and surface runoff data. 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.

II. MATERIALS AND METHODS

A. *Case Area*

The Gediz Basin (Fig. 1) is surrounded by mountains in the north, south and east directions, and is located geographically at the interval of 38° 01′- 39° 13′ northern latitude and 26° 42′-29° 45′ eastern longitude, and has a typical Mediterranean climate with hot, dry summers and cool winters. The mean annual temperature is 15.6°C, and average annual precipitation is 635 mm. The basin involves the large fertile plains which are subject to extensive agricultural practices with large irrigation schemes covering an area of about 110,000 hectares. The main crops cultivated are cotton, maize, grape, vegetables and cereals. Irrigation is the most important requirement of agriculture which is the main economic activity in the basin; therefore a great portion of surface water resources, i.e., 75%, is allocated to irrigation. 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. Considering the impacts of climate change, it is certain that efficient use of water should be a fundamental objective, not only for agriculture but also for other water demanding sectors.

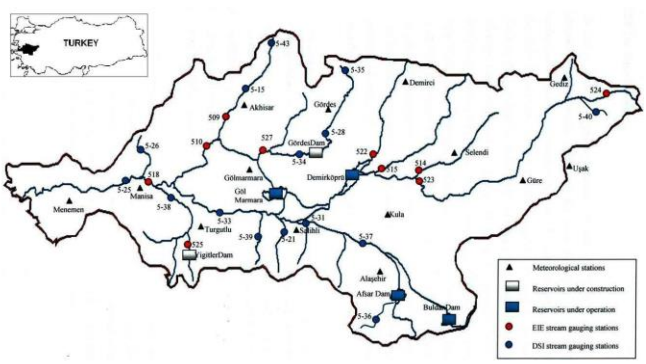

Fig.1. Gediz Basin

B. Data

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 general circulation model and RegCM3 regional climate model, and base on IPCC B1 emission scenario. The detailed data are obtained from the web-based data dissemination system of the project [1]. According to B1 scenario, a little increment (0-0.4 mm/day) in total winter season precipitation can be expected between 2040 and 2069. However, increase in summer season temperatures can be estimated with a range of 1 and 4 °C in future. 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. 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. The crop coefficients (Kc) of main crops are determined by the CROPWAT software which is developed by FAO. 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 (ky) which refers to the relationship between relative yield decrease and relative evapotranspiration, are obtained from FAO [2].

C. Model

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. 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 user guide of the model [3].

D. Calibration

The SGS 518 and the storage volumes in Demirkopru Dam are used to calibrate the model. The calibration is executed with the relevant data for the years from 1995 to 2003. The calibration graphs for the SGS 518 streamflows and the Demirkopru Dam storage volumes are depicted in Fig. 2 and Fig. 3, respectively.

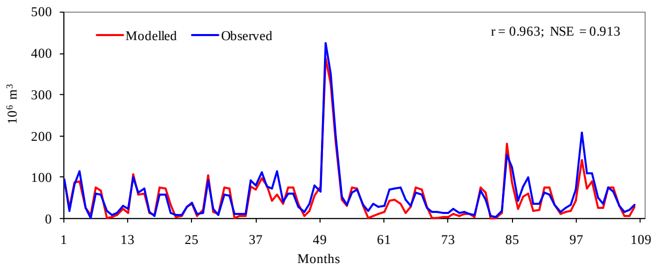

Fig.2. Calibration graph for SGS 518 streamflows

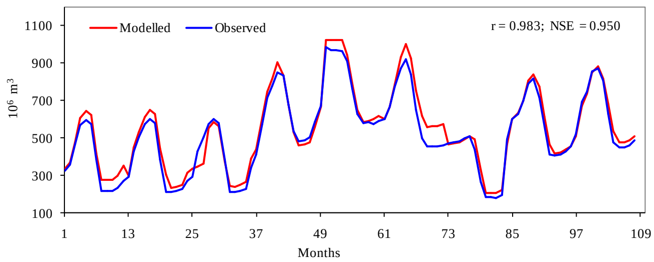

Fig.3. Calibration graph for Demirkopru Dam storage volumes

The Nash-Sutcliffe Efficiency (NSE) and Pearson's correlation coefficient (r) are represented the model performance as 'very good' [4]. 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 650 106 m3 in June and higher than 300 106 m3 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 [5].

III. RESULTS AND CONCLUSION

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. 4. 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.

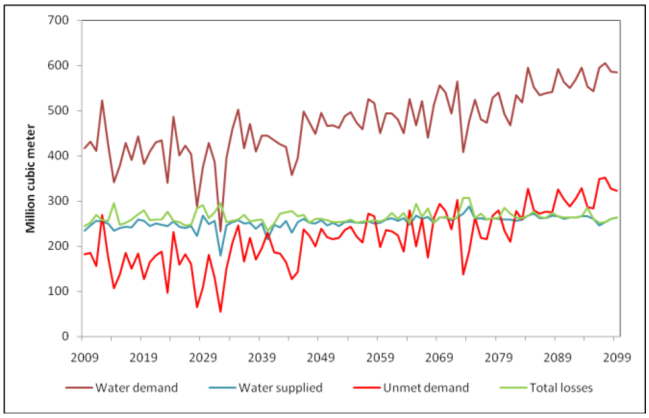

Fig.4. Summer season water budget in Gediz Basin

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 I. AVERAGE S/D RATIOS FOR THE TIME PERIODS

	A	B	C
June	0.55	0.51	0.41
July	0.63	0.60	0.57
August	0.72	0.68	0.65
Total summer season	0.62	0.59	0.54

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 II. 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	57	0	113	66	0	126	87	5
July	87	63	29	105	73	39	113	87	54
August	57	34	15	50	40	23	66	48	24

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 (ky) of crops as well as decrease in available irrigation water due to climate change impacts. The ky of maize (1.25) is higher than ky of cotton and grape (0.85). Therefore, the yield decrease in maize is expected to be higher than cotton, if evapotranspiration deficits occur.

TABLE III. DECREASES IN CROP YIELD RELATIVE TO MAX CROP YIELD (%)

	A	B	C
Cotton	30	33	37
Grape	27	30	35
Maize	46	52	59

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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