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Impact of Climatic Change on the Irrigated Agriculture–Case Study: Seyhan River Basin

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Abstract

Climate change will have an especially negative impact on the Mediterranean region in the twenty-first century. Rising temperatures and more severe droughts will have an impact on precipitation patterns and, as a result, on water resources. The temperatures in the Mediterranean region are expected to rise +3 to 5 °C by 2100. The water-poor countries are likely to be the most affected by 2100, and rainfall is likely to decrease by 20–30% in the countries to the south of Mediterranean. Against these challenges, countries invest in large irrigation projects to increase welfare and to alleviate economic disparities within regions. Lower Seyhan Irrigation Project (LSIP) in southern Turkey is such a project initiated for hydro-energy, irrigation, drainage and flood control. This paper evaluates the adaptation capacity of the Lower Seyhan Irrigation Project area to the future climate change as a case study. The case study reflects the outcomes of the Turkish Japanese bi-lateral project entitled "Impact of Climate Changes on the Agricultural Production System in Arid Areas - ICCAP". The surface temperature may increase by 2.0 °C to 3.5 °C respectively by 2070. The total precipitation will decrease by 25% in the LSIP area.

1. Introduction

Over the last century, rainfall has decreased throughout the Mediterranean region. The impact of climate change and temperature increases has received the majority of the recent attention paid to global warming or the greenhouse effect by relevant sciences.

Adana region -located on the eastern Mediterranean- with it fertile lands and abundant water resources play a foremost role in Turkish agriculture. It produces, for example, 55% of total maize and 60% of total citrus production of Turkey. Its farmers are one of the most productive and efficient as well as modern, eager to adapt to new technology. Average yields are one of the highest in Turkey. The farmers of this region can and do compete with farmers of richer nations in terms of quality and quantity.

Large scale irrigation projects increase food and fiber production, improve welfare and also alleviate economic disparities between developed and underdeveloped regions, thus providing social and economic justice. Lower Seyhan Irrigation Project (LSIP) located in central-south Turkey on Eastern Mediterranean initiated in the late 1950's is a pioneer in Turkey's huge scale irrigation projects. Considered as one of the most progressive and exclusive investments the country has undertaken, LSIP is a multipurpose project put into operation for irrigation, drainage, flood control and hydroelectric energy production.

In spite of all the positive achievements, LSIP just like other huge scale irrigation investments also have many shortcomings and deficiencies. Determining the strengths, accomplishments as well as degree of realization of the irrigation project's initial objectives, weaknesses, failures, insufficiencies and project's limitations, therefore, are of utmost importance in the planning, implementation and supervision of such intended projects. Such an evaluation may help shed light for future irrigation and drainage investments elsewhere in the country and thus improve the performance of large-scale public irrigation projects. With this objective in mind, this study was undertaken to assess the performance of irrigation and drainage systems in LSIP under Impact of Climate Change on Agricultural Production) project which is a multidisciplinary cooperative research project with Japanese (RIHN, Research Institute for Humanity and Nature, Kyoto, Japan) and Turkish (TUBITAK, Turkish Scientific and Technical Research Council, Ankara, Turkey) scientists.

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2. Projection of air temperature and precipitation

Climate change in the Seyhan basin was projected by Yano et al. (2007) as part of the ICCAP project. They revealed variations of annual mean temperature and precipitation collected from four GCM-based models for 111 years from 1990 to 2100 in Adana are shown in Fig. 1 as the difference from 1990 – 2004 mean. Four models tested are: CGCM2 model of Canadian Center for Climate Modeling and Analysis (CCCma), ECHAM4/OPYC3 model of Max Planck Institute für Meteorologie (MPIfM), CGCM2.2 model of Meteorological Research Institute (MRI) and AGCM + CCSR OGCM model of Center for Climate System Research and National Institute for Environmental Studies (CCSR/NIES). The MRI data are not available at the IPCC web-site. The inverse distance weighted approach was used to calculate these statistics for Adana using predicted values at the four nearest surrounding grid points. Annual temperature increases gradually. According to the linear regression equation, averaged surface temperature is estimated to increase by 3.1-8.6 °C over the period of 1990 to 2100. The CCSR/NIES and MRI results show the highest and lowest increases, respectively, among the four models. Although annual precipitation denotes noticeable variations year by year, it is not likely that it will have increased in the future (Yano et al. 2007).

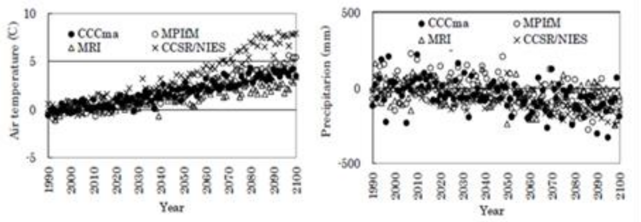

Figure. 1. Projections of air temperature and precipitation difference from 1990 – 2004 mean (Yano et. al., 2007).

Figure 2 illustrates monthly fluctuations in potential evapo-transpiration from a reference crop (ETref) to represent the atmosphere's evaporative demand. ETref was calculated with the Penman-Monteith equation based on the GCM and RCM data and the observed data. Calculated potential ET from the different climate data shows the similar monthly variations with the air temperature variations. Because potential ET is the most important parameter for predicting water demand, it's assumed that using the original GCM and MRI data will yield incorrect findings (Yano et. al. 2007).

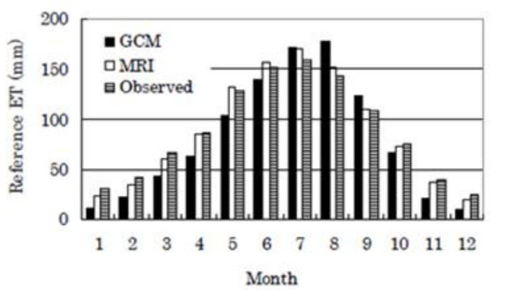

Figure. 2. Calculated reference ET from the GCM, MRI and observed data (Yano et. al., 2007).

3. Water Balance Change Due to Global Warming

Table 1 and Table 2 show the average values and standard deviations of the water balance components for the periods of 10 years beginning in 1994 and ending in 2070, as well as biomass, grain yield, and growing duration for wheat and second crop maize, respectively. Since CO2 concentration in 2070s is estimated to increase up to doubling concentration under SRES A2 scenario, calculations were done for under doubling CO2 concentration condition. In doing calculation, the percent change in acclimatized photosynthesis rate was assumed to be +27% and +4% for wheat and maize, respectively (Cure and Acock, 1986). It is well-known that actual ET decreases considerably due to stomata closure under elevated CO2 concentration (e.g. Ainsworth and Long, 2005; Yano et al. 2007).

For the period 2070-2079, the percent change in transpiration for wheat and maize was reduced by 17 percent and 26 percent, respectively (Cure and Acock, 1986; Yano et al. 2007)). Comparison of calculated actual ET between the current climatic condition and the future for the GCM, MRI and CCSR/NIES data shows the decrease of 28%, 8% and 16%, respectively for wheat and 24%, 28% and 26%, respectively for maize, reflecting the different rises in air temperature in the future (Yano et al. 2007).

The evaporative demand of the atmosphere will increase as the temperature of the atmosphere rises in the future. However, decrease in actual ET for both wheat and maize shown in Tables 1 and 2 can be attributed to reduction of growing days and LAI due to temperature rise and transpiration reduction due to stomata closure regardless of increase in evaporative demand (Yano et al. 2007).

Table 1. Predictions of the combined effects of projected climate change with elevated air temperature and doubling CO_2 concentration with transpiration reduction due to stomata closure for wheat (Yano et al. 2007)

Model	Period	Precipitation (mm)	ET (mm)	Irrigation (mm)	Biomass (ton/ha)	Grain yield (ton/ha)	Growth days
GCM	1994 - 2003	535.0 ± 186.3	349.2 ± 35.2	0 ± 0	17.5 ± 1.8	5.0 ± 0.9	198.5 ± 7.8
	2070 - 2079	503.6 ± 211.8	250.9 ± 32.1	16.6 ± 36.9	16.8 ± 2.0	5.8 ± 0.8	174.1 ± 6.6
MRI	1994 - 2003	597.9 ± 190.1	301.8 ± 30.1	24.8 ± 45.3	16.9 ± 1.7	4.5 ± 0.9	188.1 ± 5.8
	2070 - 2079	313.9 ± 82.5	276.6 ± 20.9	68.9 ± 56.8	23.3 ± 0.9	6.1 ± 1.3	181.3 ± 4.1
CCSR	2070 - 2079	308.0 ± 88.1	252.5 ± 26.7	79.2 ± 88.1	19.0 ± 2.1	5.6 ± 0.9	167.6 ± 4.5

Table 2 Predictions of the combined effects of projected climate change with elevated air temperature and doubling CO_2 concentration with transpiration reduction due to stomata closure for maize (Yano et al. 2007)

Model	Period	Precipitation (mm)	ET (mm)	Irrigation (mm)	Biomass (ton/ha)	Grain yield (ton/ha)	Growth days
GCM	1994 - 2003	47.5 ± 23.8	414.1 ± 26.1	375.5 ± 51.7	27.3 ± 1.5	15.1 ± 1.3	115.9 ± 3.8
	2070 - 2079	24.9 ± 18.0	314.0 ± 23.7	318.4 ± 27.6	22.6 ± 1.6	11.4 ± 1.2	106.7 ± 0.7
MRI	1994 - 2003	9.8 ± 6.0	439.8 ± 5.8	423.1 ± 7.8	30.1 ± 1.0	16.4 ± 0.9	118.8 ± 2.9
	2070 - 2079	8.5 ± 8.0	317.6 ± 5.9	331.4 ± 36.0	31.0 ± 1.0	16.9 ± 0.8	115.8 ± 2.4
CCSR	2070 - 2079	10.7 ± 17.1	326.6 ± 5.2	328.2 ± 24.8	29.2 ± 0.8	15.5 ± 0.7	109.8 ± 1.3

4. Description of Lower Seyhan Irrigation Project (LSIP)

LSIP area is located on the southern part of Turkey on the eastern Mediterranean (Figure 3). Seyhan Plain is the largest and the most important deltaic plane in southern

Turkey. This important project covers an area of 204,000 ha of which 174,000 ha is irrigable. The area is bordered by the Mediterranean Sea on the south, by the foot hills of the Taurus Mountains on the north and by Berdan River on the west and Ceyhan River on the east. The area is divided in two parts by the Seyhan River which flows from north to south through the plain. The part between Seyhan and Berdan Rivers is known as "Seyhan Right Bank" or "Tarsus Plain" with a completed irrigation network for 64,400 ha, and the other part located between Seyhan and Ceyhan Rivers is called "Seyhan Left Bank" or "Yuregir Plain" with a completed network for 68,200 ha. The average slope varies between 1% and 0.1% from north towards south.

LSIP area with its fertile lands and abundant water resources plays a foremost role in Turkish agriculture. It produces, for example, 55% of total maize, 60% of total citrus and 25% of total watermelon production of Turkey. Favorable climate conditions permit cropping year around allowing both single (wheat, corn, cotton, soybeans, onions, potatoes, melons, etc.) and double cropping (usually corn or soybeans after wheat harvest in late May or after onion harvest in April). Note that wheat is seldom irrigated, it is mainly rainfed.

Figure 5. Map of Turkey (Seyhan Basin in box), Seyhan Basin and LSIP

5. Climate Change Adaptation of The LSIP Results

ICCAP's General Circulation Models (GCMs) reflects snow storage and stream runoff in the Seyhan Basin are likely to decline in the future (2070–2100) due to a warmer environment (Fig. 3) (Kanber et al. 2019). The LSIP considers three future scenarios: (a) Land and water use will be the same as now, (b) Adaptation 1: land and water use will be under low-investment conditions, and (c) Adaptation 2: land and water use will be under high-investment conditions. Figure 3 illustrates that in the current climate, the maximum snow water equivalent (SWE) is around 0.4 Gt, but in the future climate, it will drop to 0.1 Gt. The yearly evaporation rate for the Seyhan delta (irrigated region) is over 800 mm, requiring nearly 500 mm of irrigation water during the hot and dry summer growing season. As a result of the decreasing snow cover, these areas will be exposed to greater shortwave sunlight (albedo effect), which will lead to higher evaporation in the spring. According to Fujinawa et al. (2007), more energy will result in a shorter crop maturity period, but the amount of irrigation water required will rise due to higher evaporation demand during the growing season and lower soil moisture at the start of the growing season. According to the results given by Tezcan et al. (2007), the decrease in the mean annual snow storage is about 14.56 km3 in the warming up period. The major decrease will occur in Aladağlar, the south-east slopes of the Erciyes and the north of the Göksu Basin. Reduced snow storage will have an impact on spring discharge in the Zamanti and Göksu Basins, which feed the Seyhan River.

Similarly, future inflows will be far lower than current levels. Furthermore, the drops in inflow expected for April, May, and June will be higher than those predicted for the other months, and the peak monthly inflow will occur earlier than it does now, resulting in a drastic reduction in inflow. Fewer flood events are estimated to occur during the warm season, when the decreased river flow may lead to water scarcity in the LSIP area (Watanabe 2007). However, Tezcan et al. (2007) have reported that the months for peak flow will be the same in both the present and warm up periods using the Mike-She simulation program.

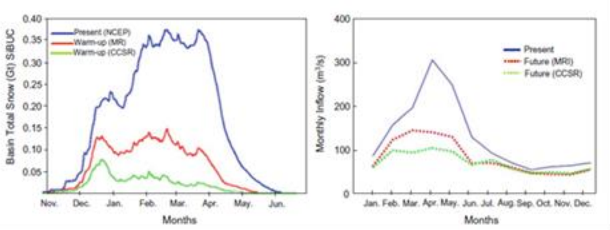

Figure. 3 Total snowfall in volume equivalent to water (Gt) (left) and the changes in Seyhan River flow (right) predicted from different models of MRI (red), CCSR (green) and present (blue). Source Fujinawa et al. (2007: 56)

The reliability index, defined as the ratio of water supply to water demand, is a measure of whether or not water demand can be met by a reservoir's supply or the degree of water scarcity. Currently, the dependability index is around 0.4, indicating minimal water stress; however, in the future, it will vary from 0.4 to 0.7 for Adaptation 1 (high water stress) and 0.5–1.0 for Adaptation 2 (very high-water stress) (Fujinawa et al. 2007). As a result, the reservoir volume in the future and Adaptation 1 will be lower than it is now, and the reservoir will be devoid of water in a few circumstances. Based on the precipitation estimates of the MRI and CCSR models, the dam reliabilities in the future and Adaptation 1 will change from 0.95 to 1.0. In Adaptation 2, the reservoir is frequently empty and reliability ranges from 1.0 to 0.7 according to future data projected by the MRI and CCSR models (Kanber et al. 2019).

Climate change, on the other hand, is expected to reduce the water budget elements in the warm-up period compared to now. The CCSR climate data reveal a greater decrease than those of the MRI data. Reduced precipitation limits the decline in actual evapotranspiration. During the warm-up phase, precipitation may drop by 29.4% (MRI) and 34.7 percent (CCSR), reducing river flow by 37.5 and 46.4 percent, respectively. As a result, groundwater recharge in the Seyhan Basin will drop by 24.7 and 27.4%, respectively. The majority of the springs in the basin will become dry due to the decline of the groundwater level below the spring level.

Climate change will have a significant impact on groundwater supplies in the LSIP area. Reduced Seyhan River recharge will result in a reduction in subsurface recharge to the LSPP area from higher elevations in the north of the region. The change in groundwater storage in the LSIP area as a result of climate change. The most major effects are a decrease in recharge at higher elevations and an increase in abstraction due to surface water resource constraints. As the head degrades, salty water will infiltrate the LSIP area. In the case of a 50% increase in the groundwater abstraction in the warm-up period of 2080, the seawater intrusion will reach 10 km inland (Tezcan et al. 2007). At the same time, groundwater salinity in the LSIP area's coastal zone will reach 25% of the seawater composition.

6. Conclusion

Implementation of Lower Seyhan Irrigation Project has increased agricultural production considerably, thereby affecting the livelihood of many people in a positive way. However, introduction of irrigated agriculture has also brought problems related to irrigation, drainage and high-water tables due to inadequate management and excess water use. Evaluation of LSIP reveals that expected full productivity has not been realized yet and that this huge investment has many shortcomings which should be monitored carefully and closely in order to shed light for similar future investments. Water should be considered as an important and valuable input through effective measures and should be efficiently utilized by the users. Volume based water charges should be preferred over area-crop basis for conserving this valuable commodity.

The conclusion of this chapter, based on the research and modeling studies indicated above, is that agriculture in the LSIP area may be impacted by future expected climate change. Precipitation in Adana is expected to fall by 42–46 percent by the 2070s. The reduced precipitation would primarily occur throughout the winter. To deal with the dry winter, irrigation would be required in the early spring for tree crops and vegetables. In addition, as a result of the predicted climatic change, irrigation demand would rise and the irrigation season would lengthen. As a result, the LSIP may need to adjust crop and irrigation management in order to react to situations where water is scarce. The LSIP features two large-scale reservoirs as water sources upstream. Climate change-related decreases in river discharge would entail determining a resource-wise adaptive capability. The 30,000 hectares of increased irrigation expansion in the Phase IV area, on the other hand, will result in an additional water shortfall in the future.

In addition, effective changes in water consumption and irrigation system management should be made to improve the LSIP area's adaptive capacity to climate change. The gravity water distribution system should be converted to a closed system, and emergency measures to avoid erosion and sedimentation in the water basin and water storage buildings should be performed. As a result of this work, high levels of efficacy in terms of water supply and utilization would be achieved.

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