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1 author:

Özgür Aktaş
Istanbul Medeniyet University
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IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES IN TURKEY

Özgür Aktaş

Istanbul Medeniyet University, Bioengineering Department, D-100 Karayolu Merdivenkoy Mevkii, Kadikoy, Istanbul Turkey
E-mail: aktasozg@gmail.com, ozgur.aktas@medeniyet.edu.tr; Phone: +90216 2803210; Fax: +90 216 2803232

Abstract

Global climate change affects the temperature and precipitation. These changes have serious impacts on the availability of water resources on regional basis. Turkey, being located in the Mediterranean Basin, is predicted to be severely affected by the adverse effects of global climate change, particularly in terms of water resources. It is important to figure out the situation of the country in terms of water scarcity induced by anthropogenic climate change in order to provide rational measures for adaptation to climate change. The paper investigates the impact of climate change on water resources in Turkey at national level by collaborating the related literature, considering both the past observations and future predictions. Legal status of Turkey in terms of climate change, greenhouse gas emissions from Turkey, effects of climate change on temperature and precipitation in Turkey, effects of climate change on water resources potential, sea level rise and floods in Turkey, examples from different regions of the country and measures of adaptation to climate change impacts were investigated extensively.

Key words: adaptation, climate change, greenhouse gas emissions, Turkey, water resources

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1. Introduction

Climate change is a multi-dimensional and complex problem which may result in serious environmental and socio-economic consequences. Climate change may threaten national securities of the countries and the lives of next generations. Climate change is mainly caused by the increase of greenhouse gases in the atmosphere. Greenhouse gases are released as a result of anthropogenic activities as well as natural processes. Particularly, emissions of carbon dioxide from fossil fuel power plants are considered to be the main anthropogenic sources of greenhouse gases. The concentration of greenhouse gases in the atmosphere continuously increases particularly during the last decades. Atmospheric CO_2 has increased from a pre-industrial concentration of about 280 ppm to about 385 ppm at present. The future projections based on several scenarios produced by IPCC (Intergovernmental Panel on Climate Change) foresee notable increases in carbon dioxide emissions and its concentration in the atmosphere, increases in global mean temperatures, climate changes throughout the world and sea level rise. Climate change has direct or indirect impacts on precipitation, sea level rise, coastal areas, water resources, agriculture, biodiversity, forestry, desertification, drought, floods and human health.

Examination of the correlation between climate change and the available water resources is beneficial for efficient water resources management. Predicting the possible impacts of climate change on the water resources is particularly important in terms of sustainable management and long-term planning of water resources. It is important to examine the hydrological processes, availability of water resources and the causes of water deficiency. Based on these investigations future of water resources should be planned.

The geological location of Turkey makes it important in terms of the impacts of climate change

owing to the diverse climatic conditions of the country. Turkey combines the characteristics of the developed water-rich North Mediterranean countries and developing water-scarce South Mediterranean countries (Yildiz and Ozguler, 2005). In literature there are few individual and regional studies regarding the impact of climate change on water resources in Turkey. However, the overall view of the situation in Turkey was previously not examined in the literature. Hence, this paper aims to investigate the impact of climate change on water resources in Turkey at national level by collaborating the related past research.

2. Legal status of Turkey in terms of climate change and greenhouse gas emissions

Turkey's economic, social and greenhouse gas emission indicators are not similar to the developed countries listed in the Annex 1 to the UNFCCC (The United Nations Framework Convention on Climate Change). On the other hand, the total greenhouse gas emissions increased by 119 %, while the GDP (Gross domestic Products) increased by 85 % between the years 1990 and 2007. This means that the increase in per capita greenhouse gas emissions (77 %) was much more than the increase in GDP per capita (44 %). The increase in the total electricity generation was 233 % and the increase in the carbon intensity of the economy was 294 % in the same period. These data indicate that the development in Turkey increasingly becomes energy intensive and fossil fuel dependent.

Turkey became a part to both of the two international agreements, United Nations Framework Convention on Climate Change (UNFCCC) and its implementing instrument Kyoto Protocol. With the decision numbered 26/CP.7 adopted within the framework of UNFCCC in 2001, the position of Turkey is recognized as unique and different than other countries listed in the Annex 1 to the Convention. Since Turkey is not included in the Annex-B list of the Protocol, it does not have any quantitative commitments on greenhouse gas mitigation. However, due to its position, Turkey cannot benefit from the flexibility mechanisms of the Kyoto Protocol.

Establishment of the Coordination Board on Climate Change (CBCC) in 2001 and foundation of the Climate Change Department in the Ministry of Environment and Forestry in 2010 can be considered as important developments in the governmental institutional structure of Turkey. Turkey's "National Climate Change Strategy Document" entered into force as of May 2010 to define the priorities of Turkey under coordination of the former Ministry of Environment and Forestry. However, no quantitative targets on greenhouse gas emission mitigation were defined in this fundamental strategy document, except for 7 % limitation in the greenhouse gas emissions of the energy production sector as of 2020 compared to the business as usual scenario. Turkish Statistical Institute is responsible of development and reporting of the National Greenhouse Gas Inventory, which is among the liabilities of Turkey to the UNFCCC. The focal point for planning, coordination and implementation of scientific and technological studies is the Scientific and Technological Research Council of Turkey (TUBITAK).

The strategy of Turkey on adapting to climate change was reported in the National Climate Change Strategy Document (TRMEF, 2009). Turkey decided to actively participate in the negotiations carried out to establish a comprehensive and functional international cooperation mechanism in combating and adapting to global climate change; to develop the "National Climate Change Action Plan" with a dynamic approach in line with the "National Climate Change Strategy"; to revise the organizational structure for Climate Change; to adapt the 'Information Management' and exchange approach and methodology in the process and to establish a national portal.

3. Greenhouse gas emissions in Turkey

The overall greenhouse gas emissions in Turkey steadily increased during the period between 1990-2008. The emissions for the year 2008 (365.5 million tones) were 96.0% (almost double) more than the emission of year 1990 (187.03 million tones). By the year 2008, the emissions from the energy sector was the largest portion with 75.8%, the emissions from the waste disposal was the second largest one with a value of 9.3%, and the emissions from industrial processes with an 8.1% was in the third place. In greenhouse gas emissions, land use and land use change and forestry, which serve as a sink for carbon dioxide, should also be taken into account. The steady increase in greenhouse gases in the 1990-2008 period was mainly the result of the changes occurring in energy sector and industrial processes. The emission from the waste was constant compared to other sectors. However, the agricultural emission reversely decreased throughout the same period (TSI, 2010).

4. Effects of climate change on temperature and precipitation in Turkey

Climate change affects the availability of water, as well as its quality and distribution. Changes in runoff and in the source of a region's renewable water supply, are the direct results of changes in precipitation and evaporation which are strongly influenced by temperature. Turkey can be considered as a country very vulnerable to effects of climate change because of the presence of several climatic regions (Fig. 1). However, it is important to consider local conditions rather than the whole country for a relatively large country such as Turkey which has a very diverse climate. Arid and semi-arid regions such as the Middle and Southeast Anatolia are under risk of desertification. On the other hand, semi-humid

Aegean and Mediterranean regions will be also affected because of lack of water resources. Different regions of the country will be affected in different ways because of the climatic differences.

Fig. 1. Climatic regions of Turkey

Temperature and precipitation changes are both significant components of climate change. Similar to global changes in temperature, mean ambient temperatures in Turkey have a tendency to increase. Mean temperatures in Turkey increased steadily between 1941-2007, with a trend of 0.64°C/100 years. Particularly highly urbanized area including Istanbul and Izmit as well as south and southeast regions of Turkey has a significant trend of increasing mean temperatures (TRMEF, 2008). In a previous study, the amount of warming for the period 1939-1989 (50 years) was also estimated as 0.32 °C in terms of annual mean temperatures, although the differences were not statistically significant (Kadıoğlu, 1997).

In mid-latitudes and semi-arid low latitudes, impacts of climate change on water resources are decreasing water availability and increasing droughts. Particularly in Southern Europe, climate change is expected to adversely affect conditions leading to high temperatures and drought in regions that are already vulnerable. Climate change reduces water availability, hydropower potential, summer tourism and crop productivity. Annual mean temperatures in Europe are likely to increase more than the global mean.

The highest summer temperatures are expected to increase more than the average summer temperature in Southern and Central Europe. Also, the warming in the Mediterranean region is likely to be the largest in summer. For example, a regional study for a Mediterranean Basin in Southern Italy predicted 3.5-3.9°C increase in annual temperature, 9-21 % decrease in cumulative annual precipitation, and 25.4-41.2% reductions in surface runoff (Senatore et al., 2011).

A regional climate model for the Eastern Mediterranean and Middle East Region also showed about a 10% decrease in precipitation by both middle and end of the century with considerable variations between local areas (Chenoweth et al., 2011). Another regional climate model simulation for the Eastern Mediterranean Region focusing on extreme temperature and rainfall events showed that maximum daily temperature is expected to increase by 2.5-3°C and precipitation extremes are expected to increase with longer dry spells and increases in heavy rainfall in the Jordan River Area (Samuels et al., 2011). However, it is important to note that these changes may vary drastically between regions. For example, in a study considering East Azarbaijan Province of Iran located in the east of Turkey, only 3 % decrase in precipitation was predicted until the middle of this century although a temperature rise of 2.3 °C was predicted (Zarghami et al., 2011). The situation in Turkey has similarities with other countries in the region as seen in detail below. However, in other continents, a reverse situation can occur due to climate change such as predictions of increased overall mean monthly stream flows in some of the watersheds of Malaysia through the middle of the century (Shaaban et al., 2011). Annual precipitation and the annual number of precipitation days are also expected to decrease in the Mediterranean region of Turkey (Ozkul, 2009).

A statistical analysis of rainfall between 1930 and 1993 in Turkey has revealed that area averaged annual rainfall slightly decreased during this period although decreasing trend in annual rainfall was statistically significant in some of the stations located in the Mediterranean region of the country (Türkeş, 1996). However, following the 1990s, decrease in precipitation has been more pronounced. Precipitation in the Mediterranean Basin has decreased by 20% in the last 25 years. It is also expected that decreasing trend will be continued and a serious drop in precipitation is predicted in Turkey's semi-arid Mediterranean, Aegean and Central Anatolian regions along with increased mean annual temperatures. A more recent study examined expected spatio-temporal changes by considering precipitation time series at 165 stations across the country covering the period from 1961 to 2008 (Toros, 2012). The study showed a significant decrease of about 12, 13, and 35 % at all stations in annual, rainy period, and winter season total precipitations, respectively. On the other hand, increases occurred at 19 % in autumn season.

The most marked effect of global climate change on the Mediterranean Basin is expected as more drought conditions. Although summer drought is recognized as a normal climate characteristic of the basin, the risk of summer droughts is likely to increase in the Mediterranean region. The climate change effect on the water resources of Turkey has been studied by several researchers. Demir et al. (2007) investigated climate change effects on temperature and precipitation in Turkey.

They found that while temperature increased in the summer season, the changes in total annual precipitation amounts had a generally decreasing tendency. Mengu et al. (2008) studied climate change effects on agriculture and water resources of Turkey. They concluded that along with an expected increase in temperature of 1-3°C, annual precipitation showed a significant decrease especially in winter, and

stream flow dramatically dropped. It is estimated that summer temperatures in Turkey will rise by 3°C, and winter temperatures by 1-2°C.

According to results from the General Circulation Model (GCM), winter precipitation in southern areas will considerably decrease. Similarly, summer temperatures in many parts of Turkey will rise by 3-5°C, and while spring precipitation may increase by 5-50 mm, summer precipitation may decrease by 5-20 mm.

A project concerned with the effects on agricultural production of climate changes in arid areas (ICCAP) predicted that winter precipitation in Turkey would fall by 42-46% by the 2070s, but that crop requirements would rise by 5-10% (Mengu et al., 2008). Studies on water resources have shown that many catchment areas of Turkey will experience serious water shortages. The trend analyses carried out on observed and validated data of 103 meteorological stations for the years between 1951 and 2004 showed that summer temperatures has increased the most in the western and south-western parts of Turkey, and winter precipitation in the western provinces of Turkey has decreased significantly in the last five decades (Ozkul, 2009).

The area-averaged annual mean temperature increase for Turkey was estimated to be around 2–3 °C until the end of the 21st century. Generally, precipitation decreases along the Aegean and Mediterranean coasts and increases along the Black Sea coast. According to the change in snow water equivalent, the reduction is expected to be up to 200 mm over the high plains of eastern Anatolia and the eastern part of the Black Sea Mountains (Ozkul, 2009). According to scenarios developed by IPCC, more than 20 % decrease in precipitation is predicted both in winter and summer months in Turkey during the 21st century.

5. Effect of climate change on water resources potential in Turkey

In the international category of countries, Turkey is still considered misleadingly to be under low water stress. However, Turkey is not a water rich country. Water resource stress in Turkey is increasing day-by-day because of the global climate change. The greatest adverse impacts of climate change on water resources are expected to occur around the Mediterranean Region and the Middle East. Therefore, Turkey is considered to be affected severely. Between 1970 and 2000, the total amount of runoff and precipitation was estimated to decrease by 21 and 19.3%, respectively in Turkey. Reductions in runoff may be attributed to both decreased precipitation and increased evapotranspiration.

Both precipitation and evapotranspiration are certainly influenced by climate change. Water availability (m^3/yr/capita) in Turkey was predicted to decrease from 3070 in 1990 to a minimum of 700 or a maximum of 1910 by 2050 (Odemis and Evrendilek, 2007). Another study estimated 40% decrease in water resources per capita in Turkey between 1998-2050, based on the projections made for water resources potential and population growth (Angelakis and Kosmas, 2000).

Most of the Near East Region (including Turkey) is predicted to have a decrease in water availability of up to 40 mm per year, and that decrease is predicted to be 80 mm per year in the Anatolian Plateau of Turkey (Cakmak et al., 2009).

The average annual precipitation is about 643 mm in Turkey which corresponds to 501 billion m^3 water. 274 billion m^3 is lost through evaporation. 158 billion m^3 forms the surface flows and 69 billion m^3 water feeds groundwater where 28 billion m^3 of this rejoins the surface waters. Including the 7 billion m^3 water coming from other countries, the renewable water potential of the country is 234 billion m^3 in total. By the year 2050, annual precipitation is expected to decrease to 325 billion m^3 and surface flow is expected to decrease to 130 billion m^3 from the present value of 193 billion m^3 (Sen, 2009a). Table 1 presents the water resources potential and use in Turkey. Available water amount in Turkey is about 1500 m^3 per capita. It is expected to decline to 1000 m^3 in 2050 as a result of population growth and impact of climate change. Only 36% of available water resources is currently being used in Turkey (about 40 billion m^3 of a total of 112 billion m^3). DSI (State Hydraulic Works) aims to increase this ratio (TRMEF, 2008).

Agriculture, with a 74 % share, is the biggest water user in Turkey, followed by domestic (15%) and industry sectors (11%). Industry sector used 4.2 billion m^3 of water in 2000. But with the increasing rate of 4 % every year, water demand of industry sector will become 13.2 billion m^3 in 2030. Agricultural water use of 29.3 billion m^3 is expected to increase to 71.5 billion m^3 and domestic use will increase from 5.8 to 35.3 billion m^3 in 2030 (Tahmiscioglu et al., 2006). As the largest user of water, the agricultural sector is expected to be most severely affected by climate change. The widespread use of inefficient irrigation methods is considered to be an important reason for the predicted future water shortages.

Agricultural irrigation is applied by surface irrigation methods with 94%, sprinkler irrigation and drip irrigation with 6% in Turkey. However, in recent years great importance has been placed on improving irrigation efficiency, and there have been considerable improvements on the application of more efficient irrigation methods (Mengu et al., 2008). In addition to water scarcity, land use and coverage will be eventually affected by climate change (UNDP, 2007). It is estimated that Turkey will experience serious losses in agricultural production as a result of global climate change (Mengu et al., 2008).

Generally, the 25 basins in Turkey experienced a linear trend of 16 % decrease in surface water flow rates between 1995 and 2002 at a mean annual rate of about 4 $m^3 s^{-1}$.

Table 1. Water resources potential and use in Turkey (adapted from Cakmak et al., 2009)

	Surface water	*Groundwater*	*Total*
Renewable water potential (km^3)	193	41	234
Usable water potential (km^3)	98	14	112
Consumption (km^3)	31	12	43

Similarly, there appeared to be a linearly increasing trend in river water temperature, at a mean annual rate of about 0.2 °C. In addition to higher potential of evaporation, warmer water can lead to lower dissolved oxygen concentrations in surface waters. Hence, increased temperatures deteriorate both quality and quantity of river water (Odemis and Evrendilek, 2007). However it is important to note that these reductions in surface waters are not only because of climate change; rather they are more likely to be produced by increasing water extraction and changes in land use.

Climate variations also cause fluctuations in hydroelectric generation. Climate changes that reduce overall water availability will eventually reduce the productivity of hydroelectric facilities (Sen, 2009b). This is particularly important for Turkey that utilizes hydroelectric power for electricity at relatively high amounts.

Climate change may also affect the quality of water as well as its quantity. There is a degradation trend of drinking water quality leading to an increase of risk with regard to potential health impacts, mainly during extreme meteorological events. Among water quality parameters, dissolved organic matter, micropollutants and pathogens are susceptible to rise in concentration or number as a consequence of temperature increase (water, air and soil) and heavy rain falls in temperate countries (Delpla et al., 2009). However, there is a lack of knowledge on the effect of climate change on the quality of drinking water resources in Turkey.

6. Effect of climate change on sea level rise and floods in Turkey

A popular impact of climate change is sea level rise. Turkish costs were mostly affected from the generalized sea level rise of 1-2 mm/year. Main effects of sea level rise are erosion, floods in coastal areas, and salt water intrusion. Higher sea level rises were observed in deltas of big rivers. Flood and sedimentation risks exist in Kızılırmak, Yeşilırmak, Gediz, Seyhan and Ceyhan Deltas (UNDP, 2007). Sea levels in the Mediterranean are expected to rise by 20-40 cm by 2050, and this will affect river deltas more effectively in future, particularly in Turkey (Mengu et al., 2008).

It is usually considered that climate change increases the number of unusual floods. Climate change results in variation of timing, regional patterns and intensity of precipitation. Particularly, the number of days with heavy and intense precipitation increases. Climate change is also expected to result in a change in the relative amounts of snow and rain and in the timing of snowmelt and runoff. Climate change may lead to a shift from snow to rain which could eventually increase the probability of flooding early in the year and reduce the availability of water during periods of peak demand for irrigation (Sen, 2009b). As a possible regional effect of global climate change, floods are recently being experienced in areas where there were no floods reported in the past.

The occurrence of extreme floods has been more frequent in some areas in Turkey. Seasonal fluctuations in flows are mainly affected by warming in the Mediterranean region. In this region, very heavy rainfall may occur and cause destructive flood events. Turkey often undergoes affects of natural disasters. The number of floods and flash floods has increased in the last decades similar to its increase in Europe. For example in the period of 1980-1983 only 3 severe floods were reported in Turkey, whereas in the period of 1998-2002, the number increased to 22 (Tahmiscioglu, 2006).

7. Examples from different regions of Turkey

Ozkul (2009) studied the generation of climate change scenarios, modeling of basin hydrology, and testing of the sensitivity of runoff to changes in precipitation and temperature in the Büyük Menderes and Gediz river basins located in the Aegean climatic region (Fig. 2). Simulation results of the water budget model demonstrated that nearly 20% of the surface waters in the studied basins would be reduced by the year 2030. This will be 35% in 2050 and 50% in 2100. The decrease in surface water will cause water scarcity in agricultural, domestic and industrial use. Besides, increased losses through evapotranspiration of plants (10% by 2030, 20% by 2050) will dramatically increase the need for irrigation water.

Durdu (2010) characterized the effects of climate change on water resources in the Büyük Menderes river basin in western Turkey, based on hydrology, temperature, and rainfall data from the past 45 years (1963-2007). Over the past 45 years, the temperature increased just about 1°C. The long-term trend of annual precipitation demonstrated a decreasing trend; however, it was not found to be statistically significant. The precipitation amount started to decrease in the 1980s, especially in the Afyon and Uşak regions, with a value of –6.8%. Serious water scarcity began to appear in the 1990s, especially in the Aydın region, with a value of –14.4%. The stream flow of the Çine and Akçay rivers

showed a decreasing trend, especially during the period of 1985-1998. The linearly decreasing trend of the stream flow had a strong correlation with changes in temperature and precipitation. An increasing trend in temperature and decreasing trends in precipitation and stream flow in the Büyük Menderes river basin was interpreted to be a result of climate change.

Fujihara et al. (2007) evaluated climate change impacts on water resources of the Seyhan river basin located in Mediterranean region of Turkey (see Figs. 1 and 2). They indicated that, compared with the present, precipitation is expected to decrease and this will result in a considerable decrease in stream flow. Fujihara et al. (2009) developed an approach to simulate flood and drought risks under present and future climate with both present and alternative reservoir rules dynamically downscaled to the Seyhan River Basin in Turkey. A more recent study using a fuzzy cognitive mapping technique applied at a participatory meeting with the stakeholders in Seyhan Basin showed that participants envisioned that water supply, water demand and water use would decline in the future in response to the increasing impact of climate change (Cakmak et al., 2013).

Hydrologic models with a reservoir model were driven using these downscaled data. Relative to the present, two simulations predicted average annual temperature rises of 2.0 and 2.7°C, precipitation decreases of 157 and 182 mm, and annual runoff decreases of 118 and 139 mm, respectively in 2070s. Analysis of the water resources was performed, taking into account changes in water use and examining alternative reservoir rules to cope with the projected changes in runoff and water use. The results indicated that if water use increases and reservoirs continue to operate under the present rules, reservoir reliability will decrease and drought risk will increase. Alternative rules would reduce reliability losses in the reservoir system. An integrated water management was suggested so that operation rules can be changed to meet hydrological and water use conditions.

A recent comprehensive project (Sen, 2010) aimed at predicting precipitation and surface flow until 2050 in water reservoirs of the metropolitan city of Istanbul in Marmara Basin. According to several scenarios, the study showed that, significant decreases are not expected until 2050 in average precipitation and surface flow in water reservoirs of Istanbul although some minor decreases may start after 2040. However, heavy precipitation and extreme floods are expected in the area. The study also approximately predicted precipitation and surface flow in 6 river basins; Firat, Dicle, Seyhan, Gediz, Susurluk and Sakarya. The results showed that significant decreases are expected in precipitation in most of the climatic regions of Turkey, particularly in the South East Climatic Region (Fig. 1).

Another study using different models and scenario simulations pointed out that all scenario simulations indicated increases in winter surface temperatures in the entire Euphrates-Tigris Basin located in the south east of the country, particularly in the highlands reaching up to 6.1°C. Also, all simulations showed decrease in winter precipitation in the highlands and northern parts and increase in the southern parts of the basin.

Simulations pointed out statistically significant decreases (55-87%) in snow water equivalent in the highlands and in annual surface runoff (25-55%) in the main headwaters area as a remarkable impact of warming (Bozkurt and Sen, 2013). A recent study using overlay mapping trend analysis technique also showed decreasing trends in minimum streamflow and increasing trends in the annual mean and maximum temperature and in the annual mean and maximum humidity parameters for many stations in the Euprates Basin (Yenigun and Ecer, 2013).

Average surface flow in Turkey is expected to decrease by 15-20% after 2040. Some important lakes, such as Salt Lake located in the Konya Closed Basin of Middle Anatolia (Fig. 2), are under severe water stress.The climatic data and remotely sensed and treated satellite images showed that water and salt reserve in Salt Lake has decreased between 1987 and 2005 with a ratio of about 30% due to drought and uncontrolled water usage. Salt Lake could be faced with drying in the next few decades. The dry summer season has extremely affected the region for the last two decades. Additionally, the analysis of the meteorological data for 1993–2005 periods showed a simultaneous decrease in mean precipitation between 1.2 and 11.6 mm.

It was suggested that the use of water supplies, especially underground waters, around the Salt Lake should be controlled and the lake should regularly be monitored by current remote sensing data for an effective management of water and salt resources in the region (Ekercin and Ormeci, 2010). In Central Anatolia, particularly shallow lakes are predicted to be severely affected by decreases in precipitation. An analysis of A2 and B1 scenarios of IPCC with the help of the lake-aquifer simulation model showed that climate change has the potential to cause temporary drying of Mogan and Eymir Lakes in Central Anatolia until the end of the century (Yagbasan and Yazicigil, 2012).

Consequences of climate change on groundwater include fluctuation in groundwater level, effects on soil pore water pressure, alteration of groundwater flow regimes, and change in the volume and quality of groundwater resources. Change in temperature and precipitation will influence recharge of the groundwater aquifers causing shifts in water table levels in unconfined aquifers.

Short or mid-term fluctuations of groundwater level due to the climate variation constitute a considerable problem particularly in semi-arid regions such as Central Anatolia. There are not so many studies on the effect of climate change on groundwater in Turkey.

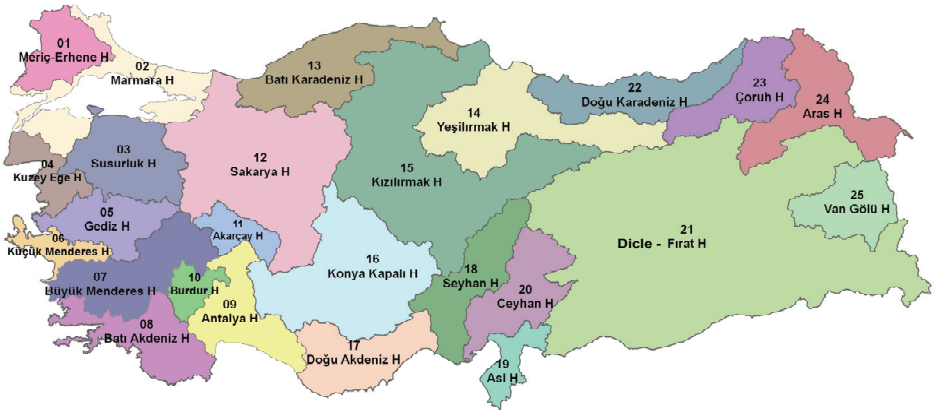

Fig. 2. The spread of 25 hydrological basins in Turkey

A case study on groundwater showed that particularly shallow aquifers are vulnerable to climate change impacts (Apaydin, 2010). The Halacli aquifer is located in the Kizilirmak River basin in central Anatolia (Fig. 2) where semi-arid climate conditions prevail. Groundwater levels declined from 1989 to 1997 although there was no exploitation. However, water levels began to rise afterwards even though exploitation was started in the summer season of 1998. After 2000, even though the amount and duration of exploitations in a year was constant, fluctuation of water level continued. Consequently, it was supported (Apaydin, 2010) that the Halacli aquifer was more vulnerable to climate variability than the existing manmade effects.

8. Adaptation to impacts of climate change on water resources

Water stress in Turkey is predicted to increase with the demographic changes and unfavorable global climatic and economic conditions. Fast implementation of the necessary policy measures at all levels will achieve more efficient use of public resources and water. The National Climate Change Strategy (TRMEF) involved several measures to be taken for adaptation of Turkey to climatic change in terms of water resources. Short term (1 year) activities involved acceleration of activities on improvement of water quality which decreased due to climate change; development of agricultural practices which take into consideration the negative impacts of climate change on water resources for the sustainability of agricultural production; development of projects on measures such as soil cultivation, drainage, irrigation techniques, mulching, in order to prevent the increase in the salinity levels in irrigation areas within the regions where the heat and the evaporation will rise due to climate change; and preparation of implementation and inspection guidelines for flood and landslide Risk Management Plans.

In medium term (1-3 years), water legislation will be improved and the concept of adaptation to climate change will be integrated into the legislation; development of the Watershed Master Plans and River Basin Management Plans for 25 watersheds within the scope of development, multi-purpose usage and protection of all ground and surface water resources in Turkey will be initiated; and the impacts of climate change on water resources (in terms of quantity and quality) will be identified and implementation proposals will be developed for the adaptation of vulnerable areas. In the long term, Watershed Master Plans and River Basin Management Plans will be finalized; Studies will be carried out on volume-based water pricing to ensure the protection and efficient use of water resources; The irrigation networks which cause excessive water consumption and/or have completed their economic live spans will be rehabilitated and /or will be replaced by modern systems, and relevant projects will be supported; Within the scope of the Drought Action Plan, the activities to prevent the negative impacts of drought will be supported, and relevant costs will be covered.

Since agriculture is the biggest water user, irrigation should be improved. It is important to restrict water losses from irrigation infrastructure starting from the high evaporation regions. There have been improvements performed by government subsidies in adopting more efficient water application technologies. The irrigators can be forced to use these technologies by shifting towards volumetric pricing practices (Cakmak, 2009). In the First National Communication on Climate Change (UNDP, 2007), in order to solve the problems associated with water scarcity and desertification, the following were determined as adaptation measures; development of new techniques different from the conventional use of water resources and development of new vegetation resistant to aridity and salinity and able to yield high quality products with a low-quality water.

The sustained well-being of watersheds depends on the identification of watersheds with the most critical issues of water quality and quantity. It is important to ensure efficiency of water use and distribution, and conservation of water resources. Therefore, it is required to improve water

management policies and practices currently applied in Turkey. Effective land use management programs, technological improvements in water distribution and irrigation systems and water demand management efforts among water users may be the adaptation instruments to expected future climate change on watershed basis. Integrated watershed management and river basin management plans will be realized in the near future. In order to adapt coastal areas to climate change impacts, an integrated coastal zone and river basin management is required.

Some measures considered by governmental subsidies for adapting water resources to climate change can be summarized as construction of dams and reservoirs for a controlled use of water in arid regions, preparation of an irrigation action plan for an effective irrigation, transformation into modern irrigation techniques, water transportation between basins, integrated water management for cities, preparation of wastewater treatment action plan and preparation of watershed protection action plans for 25 basins (Fig. 2) in Turkey (TRMEF, 2008).

9. Conclusions

The paper summarizes the situation of Turkey in terms of the impact of climate change on water resources. There have been few studies in the past particularly concentrating on specific regions. These studies indicated that Turkey in overall will be negatively affected from climate change in terms of water availability.

However, most of the hydrological basins in the country have not been evaluated yet. A very comprehensive research project is required to analyze extensively the impact of climate change on water resources at local level considering all meteorological regions and hydrological basins of the country.

Although some adaptation measures have been taken in the last few years, a more comprehensive work will result in more solid policies which may also be a guide for other countries in the region.

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