Abstract

There is a close link between climate change and water resources due to the strong relationship between climate and hydrology. Global warming induced changes in temperature and precipitation severely affect water resources, therefore water availability for residential, agricultural, industrial and environmental uses, and hydro-electricity generation purpose. Effects of climate change will be greater in the regions, which are more fragile and thus vulnerable to climate change. Turkey, in particular snow dominated east Anatolia, and Mediterranean parts, have already been influenced adversely by climate change. Therefore, it is essential to carry out hydro-meteorological impact studies in Turkey to have better understanding of effects of climate change. This study aimed to provide a review of selected studies, which investigated climate change impacts on hydro-meteorology and water resources in Turkey, in order to put a light on the future climate change studies for Turkey.

Keywords: climate change, hydro-meteorology, Turkey, impact studies

1. Introduction

The globally averaged combined land and ocean surface temperature data demonstrated warming of 0.85 [0.65 to 1.06] °C, for the period of 1880-2012 [1]. It is not reasonable to explain this much warming with natural variability alone. Human activities induced greenhouse gas emissions to the atmosphere is the very likely reason behind this unusual warming. According to the Intergovernmental Panel on Climate Change (IPCC), global surface temperature change for the end of the 21st century is likely to exceed 1.5°C in comparison to 1850 to 1900 for all representative concentration pathway (RCP) scenarios except RCP2.6. It should be noted that some RCP scenarios showed that it is likely to exceed 2°C [1].

Global warming (temperature increases) results in alterations in other climate variables such as precipitation and humidity. Changes in amount, intensity and duration of the precipitation later affects stream flow regimes and cause extreme events including floods and droughts. Global scale studies demonstrated that precipitation amount has increased from 1900 to 2005 in the Northern, Southern and Eastern parts of America, Northern Europe and, Central and Northern Asia. On the other hand, it has decreased in the Mediterranean, Southern Africa and Southern Asia [2]. IPCC (2007) reported that the regions affected by droughts and floods have increased since 1970s in parallel to higher warming rates in the second half of the 20th century with respect to the first half.

Turkey is shown among the countries which are fragile to effects of the climate change, since its climate shows characteristics of Mediterranean and snow-dominated climate. The West and South parts of Turkey belong to the Mediterranean basin, which is highly vulnerable to the climate change [4]. Unlike to the decreases in the annual number of precipitation days and total rainfall amounts [5], more intense and frequent extreme rainfall events, and thus floods have been observed [6] in the Mediterranean basin. Increased frequency of the floods along with reduction in water availability makes Mediterranean region very sensitive to the climate change. Also, snow-driven Eastern
Turkey has suffered from global warming, since temperature increases have significant impacts on snow occurrence and melting processes. In this paper, effects of climate change on hydro-meteorology in Turkey were briefly discussed in order to put a light on the future climate change studies for Turkey.

2. Study area

Turkey consists of two main lands located in Europe and Asia continents. Geographical location of Turkey is latitudes between 26° and 45° east and longitude between 36° and 42° north. The approximate surface area of Turkey is 783,562 km² [7]. Turkey has seven geographical regions (i.e. 1) Marmara, 2) Black Sea, 3) Aegean, 4) Inner (Central) Anatolia, 5) Eastern Anatolia, 6) Mediterranean, 7) Southeastern Anatolia), which are shown in Figure 1.

![Geographical locations of Turkey](image)

Economically usable water potential of Turkey is 98 billion m³ [9]. Although Turkey does not experience significant water scarcity currently, rapid increases in population, and thus water demand, may cause water stress in Turkey in near future.

Turkey shows wide range of climate variability from extremely cold winters to very hot and dry summers. Northern Turkey (Black Sea region) has cold and rainy climate, whereas the Mediterranean climate (southern and western Turkey) is hot and dry in the summer, and warm and rainy in winter. Summers are very arid and hot, and winters are very cold in the Central Anatolia. On the other hand, eastern Anatolia has short and cool summers, and long and very cold winters [7, 10].

3. Climate Change Effects in Turkey

Climate change impact studies can be broadly grouped into two: historical trends and future projections. In this study, first hydro-meteorological trend studies (temperature, rainfall and streamflow trends respectively) in Turkey were presented. Then, findings of the selected future projection studies were discussed.

3.1. Hydro-meteorological trends

Temperature is a significant parameter for many hydrological processes (e.g., evapotranspiration and snow/ice accumulation and melt). Therefore, it has notable effects on seasonal distribution and amount of stream flows. The most significant warming trends in average temperatures were detected in summer season, particularly in southern and southeastern Turkey [11, 12], whereas in the coastal regions, average temperatures demonstrated insignificant cooling trends in winter season [11, 12]. Maximum temperature increases were reported for all regions in Turkey, and trends were statistically significant in the southern, southeastern and northwestern Turkey [12, 14]. Considering the urban heat island effect (i.e. artificial heating influence caused by buildings and air particles), the most clear warming trends were reported for minimum temperatures (relative to average and maximum temperatures), in particular during summer season [12, 14].

Figure 2 illustrates the approximate location of the stations, in which were considered by some of the temperature trend studies in the literature. Figure 2 also demonstrates the significant warming and cooling temperature trends at these stations by referring triangles for significant warming trends and circles for significant cooling trends.

![Significant temperature trends in Turkey](image)
than 400 mm. Winter is the rainiest season in Turkey (40% of total rainfall), followed by spring, autumn and summer seasons respectively [13].

According to the rainfall trend studies in the literature, the most significant rainfall trends (decreasing) were detected in winter season. These rainfall decreases were remarkable in particular in the Mediterranean and Aegean regions [13]. Demir et al. (2008), MoEF et al. (2008) and Tayanc et al. (2009) reported increasing rainfall trends in the Northern Turkey, and decreasing trends in the South Eastern and more significantly in the Mediterranean and Aegean regions. It is also worth to mention trends in snowfalls. MoEF (2007) stated that snow depth and also the number of snowy days has decreased over the period 1951–2004 in the eastern Anatolia and the eastern part of Black Sea Mountains.

Studies on streamflow trends (e.g., [15]) showed significant downward trends in particular in the western and southwestern parts of Turkey. Yilmaz et al. (2011) detected statistically insignificant decreasing trends in the Upper Euphrates Basin region, whereas Yenigun et al. (2008) reported statistically significant decreasing streamflows trends in the Middle and Lower Euphrates Basins. These decreasing trends in the Euphrates Basin may cause significant problems, since the largest dams of Turkey located in this region and supplying water for domestic, agricultural and hydro-electricity generation purposes. Moreover, Fistikoglu et al. (2006) and Kantarci (2006) detected significant decreasing streamflow trends in the Gediz, Big Menderes and Ergene Basins respectively.

3.2. Future Hydro-meteorological projections

It is very important to develop future projections for at least basic climate variables, and employ these variables in impact studies to have estimations on water potential or availability in future. Despite the importance of these studies, there are limited climate change impact studies in Turkey. MoEF (2008) and Demir et al. (2008) can be shown as the two basic country scale studies in this regard.

Outputs of European Centre Hamburg Model Version 5 (ECHAM5) were dynamically downscaled by regional climate model namely Regional Climate Model Version 3 (RegCM3) to generate future climate projections in MoEF (2008). MoEF (2008) stated that average temperature in Turkey will rise by 2–6°C over 2070–2100 period with respect to 1961–1990 period according to the A2 greenhouse gas emission scenario. In addition to MoEF (2008), Demir et al. (2008) performed climate projections using British Meteorology Office, Hadley Centre for Climate Prediction and Research’s Regional Climate Model Providing Regional Climates for Impacts Studies (PRECIS). Demir et al. (2008) also adopted A2 greenhouse gas emission scenario. They projected 5–6°C increases in mean annual temperature over Turkey except coastal regions. In the coastal regions, temperature increase was found to be 4–5°C. Both studies (MoEF (2008) and Demir et al. (2008)) reported clearer temperature increases in the eastern Turkey in winter season.

Demir et al. (2008) projected mean temperature increase in the eastern Turkey by 4–6°C, while it is 3–4°C in the western Turkey. Demir et al. (2008) reported 4–5°C average summer temperature increase in Turkey. However, inner Aegean, southern Mediterranean, inner western Black Sea regions are expected to warm more by 6–7°C in summer season. MoEF (2008) also projected 3–4°C more temperature increase for the western Turkey relative to the eastern regions in summer season. Average annual temperature increase of Turkey is projected as 2–3°C in summer season by MoEF (2008). Demir et al. (2008) reported overall 4–5°C temperature increase in spring and autumn seasons in Turkey, whereas they projected maximum temperature increase by 5–6°C, and minimum temperature increase by 4–6°C in Turkey.

MoEF (2008) projected overall 20% decrease in precipitation in Turkey. It was explained by MoEF (2008) that decreases in winter season especially for Aegean and Mediterranean coasts, and increase in the northern part of Turkey are more remarkable. Analogues to MoEF (2008), Demir et al. (2008) reported significant rainfall decrease (30%–40%) in Aegean and Mediterranean regions, and also Central Anatolia, Trachea, and Southeastern Anatolia. It is an important note that from west to the east, rainfall reductions are expected to be less by around 5%. Moreover, MoEF (2008) and Demir et al. (2008) estimated up to 200 mm and 300 mm snow depth reductions respectively in higher elevations of the eastern Anatolia and the Black Sea regions. In addition to country scale studies (as briefly explained above), Table 1 demonstrate findings of local future projection studies for rainfall and temperature variables.

Table 1. Future temperature and rainfall projections of local scale studies

<table>
<thead>
<tr>
<th>Author</th>
<th>Study Area</th>
<th>Temp. Projection</th>
<th>Rainfall Projection</th>
<th>Time Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fujihara et al. (2008)</td>
<td>Seyhan Basin</td>
<td>Increase between 2º and 2.7º</td>
<td>Decrease between 25% and 29% decrease</td>
<td>2070s</td>
</tr>
<tr>
<td>Yilmaz and Imteaz (2011)</td>
<td>Upper Euphrates Basin</td>
<td>Increase between 2.3º and 5º</td>
<td>From 15% decrease to 2% increase</td>
<td>2070–2100</td>
</tr>
<tr>
<td>Bozkurt and Sen (2011)</td>
<td>Euphrates-Tigris Basin</td>
<td>6ºC increase</td>
<td>-</td>
<td>2100</td>
</tr>
<tr>
<td>Ozkul (2009)</td>
<td>Gediz and Big Menderes Basins</td>
<td>Increase between 1.2º and 4.4º</td>
<td>Decrease between 5% and 24%</td>
<td>2030–2100</td>
</tr>
</tbody>
</table>

Almost all hydrological impact studies agreed on future streamflow decreases in Turkey. Fujihara et al. (2008) reported decreases in annual streamflow by 118 mm (52%) and 139
mm (61%) in the Seyhan Basin using Meteorological Research Institute (MRI) and Center for Climate System Research (CCSR) models respectively. Tezcan et al. (2007) projected around 40% decrease in streamflows and around 25% decrease in groundwater recharge by 2070s. Ozkul (2009) estimated decreases in surface runoff by 20% in 2030, 35% in 2050 and 50% by the end of the century in the Gediz and Big Menderes River Basins in the western Anatolia. Yilmaz and Imteaz (2011) projected around 20% decrease in total annual surface water potential over 2070–2100 period in the Upper Euphrates Basin. Ozdogan (2011) projected up to 60% decrease in available water in Euphrates and Tigris Basins by the end of the century.

According to the climate change impact studies in the literature, Yilmaz and Imteaz (2014) mapped the high risk zones (Figure 3) in terms of hydro-meteorology in Turkey. Figure 3 indicates which river basins are highly vulnerable to effects of climate change (red colored zones). It should be noted that this map should be updated based on new hydrological impact studies.

![River basins and climate change sensitive regions in Turkey](image)

Figure 3. River basins and climate change sensitive regions in Turkey according to the studies in the literature (Yilmaz and Imteaz 2014)


4. Conclusions

Turkey will very likely experience temperature increases, rainfall decreases, and thus significant reduction in water potential in future. Mediterranean climate zone of Turkey (i.e. the southern and western parts of the country) and snow driven basins in the eastern Turkey are the most sensitive regions to the climate change. Projected increases in summer temperatures has potential to cause more frequent and severe droughts, whereas increases in heavy rainfalls (in particular in Northern Turkey) may cause more frequent floods in future. It is possible to conclude that in addition to water deficit problems due to population growth, urbanisation, low availability of renewable water and overexploited groundwater, global warming is a big threat and should be considered in future water management policies. Since number of hydrological impact studies is limited in Turkey, there is an urgent need to develop hydrological impact studies to have better understanding of effects of climate change on hydro-meteorology in Turkey.

The key word to deal with effects of climate change on water resources is “adaptation”. Adaptation is to develop institutional and political capacities in order to ensure sufficient water supply and water quality against the risks of climate change [26]. Another definition of adaptation is given by IPCC (2014) that adaptation is “the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities”. Most adaptation steps are very beneficial regardless of the climate change impacts. In other words, even if climate change would not impact the regions, adaptation measures are useful for adaptability of water resources to the natural variability of climate patterns. This is called ‘no-regret’ approach [27].

The basic adaptation solutions against the effects of climate change are wastewater treatment and recycled water use, seawater/brackish water desalination, groundwater recharge, improved and efficient irrigation water management, correct crop selection and water sensitive urban design. Several countries have started to consider climate change adaptation plans and policies and to integrate climate-change considerations into broader development plans. For example, In North America, governments conduct incremental adaptation assessment and planning, in particular at the municipal level [28]. Australian government invested on desalination plants in major cities of Australia to avoid water shortage in future. Number of climate change impact studies should be increased in Turkey, and based on the findings from these studies, adaptation policies should be developed and applied strictly for future water safety in Turkey.

References


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