Impacts of climate change and distribution of precipitation on hydroelectric power generation in Turkey

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Abstract. The growing energy demand besides the rapidly developing consumer sector is of great importance on a global scale. In this study, hydroelectric energy recovery in Turkey, which is affected by the negative consequences of climate change, were taken into account. Increased irregular rainfall patterns and drought events as a consequence of global climate change pose a significant danger to hydroelectric power potential. Kızılırmak River has an important position on account of hydroelectric energy. In this study, the yearly flow rates of 2 stations determined by months in the Kızılırmak basin were supplied from the State Water Works (DSI) current and observation annuals. Analysis was conducted for two stations between 2005 and 2015. In addition, using ERA5 Ensemble satellite data, the group was analyzed using "climate data operators" (CDO), a map of Turkey's total annual average rainfall and annual average temperature with a resolution of 12.5 km x 12.5 km between 1979 and 2019. According to our analysis, Turkey's average annual precipitation between 1979-2019 was 527.61 mm, and the highest annual average temperature in the 30-year data set between 1979-2019 was 15.31°C in 2010 and 2018. The average temperature in 2019 is 14.96°C.

1. Introduction
Climate change, by bringing along its negative consequences, has become one of the main problems in the world and has attracted the interest of Turkey and the energy sector and has brought about the need to work on this issue.

The IPCC report found that climate change and global climate change causes are among the causes of anthropogenic causes. Estimated anthropogenic global warming increases by 0.2°C every ten years owing to past and ongoing emissions. Human activity is predicted to be in the range of about 0.8°C to 1.2°C, resulting in warming of about 1.0°C from pre-industrial levels. If global warming continues to increase at the current pace, it seems like to reach 1.5°C by 2030-2052 and a peak temperature of 2°C by 2100 [1]. Given this risk because of climate change, the final share of renewable energy should reach 65% by 2050, up from 19% in 2017 [2]. Turkey has an important position in connection with the potential of hydroelectric energy and other renewable energy sources [3,4].

In our study, the effects of climate change and rainfall distribution on hydroelectric energy in Turkey were examined. Turkey's average annual temperature between 1981-2010 increased by 1.9°C, with 15.4°C in 2018 being the second warmest year since 1971. Turkey's average rainfall in 2018 (658.7 mm) was observed to increase by 30% compared to the average rainfall in 2017 (506.6 mm) and an increase of 14.8% compared to the country's normal [5].
In Turkey and other countries of the world, there are studies on the change of temperature and precipitation parameters on hydroelectric production, which are among the important elements of climate and climate change. A significant increase in drought was observed in the Kızılırmak Basin during 12 and 60 months using the SYI (Standard Precipitation Index) method [6]. In the same basin, according to the trend analysis approach, it is seen an increase in temperature and a decrease in rainfall [7]. An upward trend in average annual temperature and a downward trend in total annual precipitation may be the menace of drought [8]. It has also been emphasized that the water flow is directly mean to the rainfall, and therefore the hydroelectric output power will fall in proportion to the precipitation [9].

2. Materials and methods
The Kızılırmak Basin (1355 km) covers an area of 78.180 km², a significant portion of Turkey's water potential (3.5%) with an annual flow volume of 6.48 billion m³ [6], [7], [10]. In this study, annual flow rates of 2 stations determined in Kızılırmak Basin according to the months obtained from State Water Works (DSI) current and observation annals. 2 stations (Sarımsaklı Baraj Giriş, Hüseyinli) indicated on the Google Earth map are shown in figure 1. Analysis was conducted for the two stations between 2005-2015. Furthermore, using ERA5 Ensemble satellite data, a map of the total annual average rainfall of Turkey with a resolution of 12.5 km x 12.5 km between 1979 and 2019 and the average annual temperature was analyzed using “Climate Data Operator” (CDO) [11]. In addition, adjacent grids in the study area were identified and regional precipitation amounts were analyzed.

3. Result
The average precipitation of Turkey between 1979-2019 is shown in figure 2. According to this map, the region with the most precipitation is the Eastern Black Sea region.
Turkey's total annual average precipitation between 1979-2019 was 527.61 mm. In the 30-year data set, the highest precipitation was 614.9 mm in 1988. The lowest precipitation was observed in 2008 with 418.2 mm. The average rainfall in 2019 was 578.5 mm. The average annual rainfall of Turkey is shown in figure 3.

![Total Mean Precipitation of Turkey Between 1979-2019](image)

**Figure 3.** Total mean precipitation of Turkey between 1979-2019.

The highest average annual temperature in the 30-year data set from 1979-2019 is 15.31°C in 2010 and 2018. The average temperature in 2019 is 14.96°C. Average annual precipitation amounts between 1979-2019 and temperature values between the same years are shown in figure 4.

![Average annual rainfall and temperature graph](image)

**Figure 4.** Average annual rainfall and temperature graph.

![Average annual rainfall amounts](image)

**Figure 5.** The adjacent grids of the Sarımsaklı Baraj Girişi and average annual precipitation amounts.
Reference points are also marked in figure 5 and figure 6 to determine the regional precipitation amount of the 2 stations selected in this study. Accordingly, 8 different neighboring grids close to the reference points (1.Grid, 2.Grid, 3.Grid, 4.Grid, 6.Grid, 7.Grid, 8.Grid, 9.Grid). The amount of precipitation at these points was determined and studied. Accordingly, the total average rainfall of Sarımsaklı Baraj Girişi station between 1979-2019 is 136.96 mm, and for Hüseyinli station is 124.47 mm. (It is accepted that the grids show a homogeneous distribution). Precipitation in regions where the stations are located in close value with average precipitation of Turkey. This analysis shows that the results are consistent.

Figure 6. The adjacent grids of the Hüseyinli and average annual precipitation amounts.

The average monthly flow rate of the stations examined between 2005-2015 is shown by year in figure 7 and figure 8. The maximum flow rate for Hüseyinli station in February 2012 was 185 m³/s. It had a dry season of two months in 2007 and four months in 2010. Also, no data entry was found in 2009. The maximum flow rate for Sarımsaklı Baraj Girişi station in April 2015 was 4.29 m³/s. In July 2014, a minimum flow rate of 0.61 m³/s was observed.

Figure 7. Hüseyinli station average annual flow rate graph from 2005 to 2015.

Figure 8. Sarımsaklı baraj girişi station average annual flow rate graph from 2005 to 2015.
4. Discussion

In our study, the total annual average precipitation in Turkey with a resolution of 12.5 km x 12.5 km between 1979 and 2019 using ERA5 Ensemble data and the average annual temperature amount were analyzed using CDO. An increase of 4.07°C was found when looking at the lowest and highest annual average temperatures between 1979-2019. Between 1979-2019, Turkey's average annual precipitation (527.61 mm) was not significantly reduced after 2008.

Average annual flow rates of 2 stations determined for our study were obtained from the State Water Works (DSI) current observation annuals. The average monthly flow amounts compared to the years shown in figure 7 and figure 8 were compared with the average precipitation and temperature data compared to the years shown in figure 4. A decline in rainfall and an increase in temperature tended to decline in flow rates at 2 stations. A decline in flow rate means a decline in hydroelectric output power.

In 2019, Turkey had an average annual Area precipitation of 585.1 mm. This value was 1.9% more than the 1981-2010 average precipitation (574 mm). Monthly precipitation in February, March, May, September, October, November of 2019 was below the average amount of rainfall in 1981-2010, and in the other months of 2019 has been above average in the work [12]. The value differences between the two studies can be caused by data set differences in the workspace or by the methods used.

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