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Determination of climate change impacts on Mediterranean streamflows: a case study of Edremit Eybek Creek, Türkiye

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ABSTRACT

The growing population contributes to an increase in greenhouse gases and affects the environment in a negative manner. To determine and predict the impact of climate change on hydrological processes, and to examine the status of our current/future water resources, hydrological modeling is of great importance and various models are utilized in this regard. In this study, the hydrological impact of climate change on a river in Türkiye, located in the Mediterranean Basin, has been revealed using a hydrological model, Hydrologiska Byråns Vattenbalansavdelning (HBV). Precipitation, temperature, and streamflow data from 1979–2021 were used for model calibration, validation, and warming processes, and model performance was assessed using the Nash–Sutcliffe efficiency (NSE) coefficient criterion. The established model's NSE performance has been determined as 0.66 for calibration and 0.69 for validation. The hydrological model was run with climate projection data (representative concentration pathways (RCP4.5 and RCP8.5)) to predict streamflows for the projection period (2023–2092). The evaluations conducted using the hydrological model for the period between 2023 and 2092 vunder the RCP8.5 scenario indicate a statistically significant decreasing trend of streamflows due to climate change. However, for RCP4.5, no trend was detected in streamflows for the projection period. From a seasonal perspective, while the greatest decrease in trends is expected to occur in autumn according to the RCP 8.5 scenario, all seasons are anticipated to exhibit significant decreasing.

Key words: climate change, HadGEM2, HBV, hydrological modeling

HIGHLIGHTS

- The changes in precipitation and temperature alter the hydrological processes in Mediterranean watersheds.
- The projected changes over a Mediterranean basin in Turkey show a significant decrease for flows according to the RCP8.5 scenario.
- The flows of Eybek Creek lessens ~40% up to 2092.
- Streamflows are expected to decrease in all seasons but the maximum decrease will be in fall.

1. INTRODUCTION

The world population is increasing rapidly. The growing population is leading to an increase in the use of water. The rise in water consumption will result in water stress in the coming years. The increase in population is also causing land-use change, deforestation, environmental degradation, and consequently climate change, and deterioration of water resources and their pollution. Therefore, a planned management of water resources and their usage is crucial. In addition to population growth, climate change is also significantly affecting water resources. The extent of the impact of climate change on water resources and its future implications can be predicted through hydrological models coupled with climate projections.

Numerous studies, including Önol & Semazzi (2009), Öztürk *et al.* (2011), Demircan (2019), Aksu (2021), Selek & Aksu (2020), and Erlat *et al.* (2022), have consistently reported significant increases in both mean and extreme temperatures across Türkiye, accompanied by a decrease in precipitation levels over several locations. These observed climate changes have undeniable implications for the hydrological system. In this study, we specifically focused on assessing the impact of projected

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climate changes on a creek located in the western part of Türkiye, which falls under the Mediterranean climate, as reported by the Intergovernmental Panel on Climate Change (IPCC) (Arias *et al.* 2021), and is highly vulnerable to the climate change.

The frequency and severity of hydrological droughts are increasing due to human activities such as land-use changes and agricultural intensification, with notable impacts observed in regions like the Mediterranean area and northeast Brazil (Abbas *et al.* 2021; Vicente-Serrano *et al.* 2020). In the North Aegean basin, including Edremit, projections anticipate increased precipitation. However, the 12-month Standardized Precipitation Evapotranspiration Index (SPEI) reveals extended drought periods with heightened severity and intensity (MGM 2014). This discrepancy is attributed to amplified convective precipitation leading to heavier rain within the overall precipitation, along with prolonged intervals between precipitation events. According to Demircan (2022), runoff from intense rainfall does not enhance water resources; instead, it pollutes and harms them. Consequently, Demircan advocates for incorporating hydrological models into climate projection-based water planning and management efforts to enhance accuracy.

Climate models are primary tools used to make climate forecasts on seasonal to decadal timescales, project future climate scenarios, and investigate the response of the climate system to various forcings (IPCC 2013; Demircan *et al.* 2014, 2015, 2017). Climate models are mathematical representations of the climate system. These models have been tested against various observational data to successfully reproduce current and past climate change observations. Regional information is used as input for climate simulations. There are three categories of scaling methods: general circulation models (GCMs), regional climate models (RCMs), and statistical/empirical downscaling methods. GCMs simulate natural processes occurring in the global climate. However, their spatial resolution is not detailed enough. Therefore, they incorporate regional information for more dynamic downscaling over larger areas (Vozinaki *et al.* 2018). RCMs are limited-area models that can be compared with the atmospheric and land surface components of Atmosphere–Ocean General Circulation Models (AOGCMs) and are often run without interactive ocean and sea ice components. They represent climate processes and are generally used for dynamic downscaling from global model simulations to provide more detailed information over specific geographical regions (Laprise *et al.* 2008; Rummukainen 2010; IPCC 2013; Demircan *et al.* 2014, 2015, 2017; Abbas *et al.* 2022a, 2022b).

Numerous studies in various fields have been conducted to examine the potential effects of climate change (Selek *et al.* 2016; Abbas *et al.* 2022a, 2022b). Some studies have utilized various models such as Hydrologiska Byråns Vattenbalansavdelning (HBV), The Hydrologic Modeling System (HEC-HMS), Système Hydrologique Européen (MIKE SHE), The Soil & Water Assessment Tool (SWAT), the Water Evaluation And Planning system (WEAP), among others. The HBV model, which is used in hydrological modeling studies, has been applied in ~30 countries. It has been extensively tested and used in various research projects. The HBV model aims to perform precipitation–runoff simulations, determine and model the hydro-meteorological effects of climate change. HBV has been used in different countries, including Türkiye, Greece, eastern Nepal, northern Cameroon, Kyrgyzstan, and others (Normand *et al.* 2010; Hagg *et al.* 2018; Vozinaki *et al.* 2018; Özkan 2019; Şorman *et al.* 2020; Nonki *et al.* 2021; Uysal *et al.* 2021; Yıldırım *et al.* 2021).

In this study, the aim was to determine the hydrological impact of climate change in the Eybek watershed located in Edremit district of Balıkesir province. The HBV model was chosen to gain insights into the changes occurring in hydrological processes due to climate change and to determine its impact on these processes. The information about the study area, the climate projection data, and HBV model are introduced in Section 2. Then, results are presented in Section 3. Some conclusions are discussed in Section 4.

2. METHODS

2.1. Study area

The Eybek Creek is located between 27°3′43″ east longitude and 39°37′8″ north latitude. The station named Çamcı-Eybek D. Streamflow Observation Station (D04A031) is situated in Çamcı village, Edremit district, Balıkesir province, in the northern Aegean basin. It has been operational since 1979, and its catchment area is 25.93 km^2 at an elevation of 80 m above sea level. The study area is shown in Figure 1.

The study area is influenced by the Mediterranean climate, covering a large part of the Aegean region, the western part of Inner Anatolia, and the southern slopes of the Taurus Mountains in the Mediterranean region. Snowfall and frost events are rare in the coastal zone. In higher elevations, winters are snowy and relatively cold. The natural vegetation in the coastal belt consists of forest types that require high temperatures, light, and are resistant to drought. In areas where forests are disturbed, evergreen maquis formations are present. Coniferous forests dominate in higher elevations. The central district of Edremit is

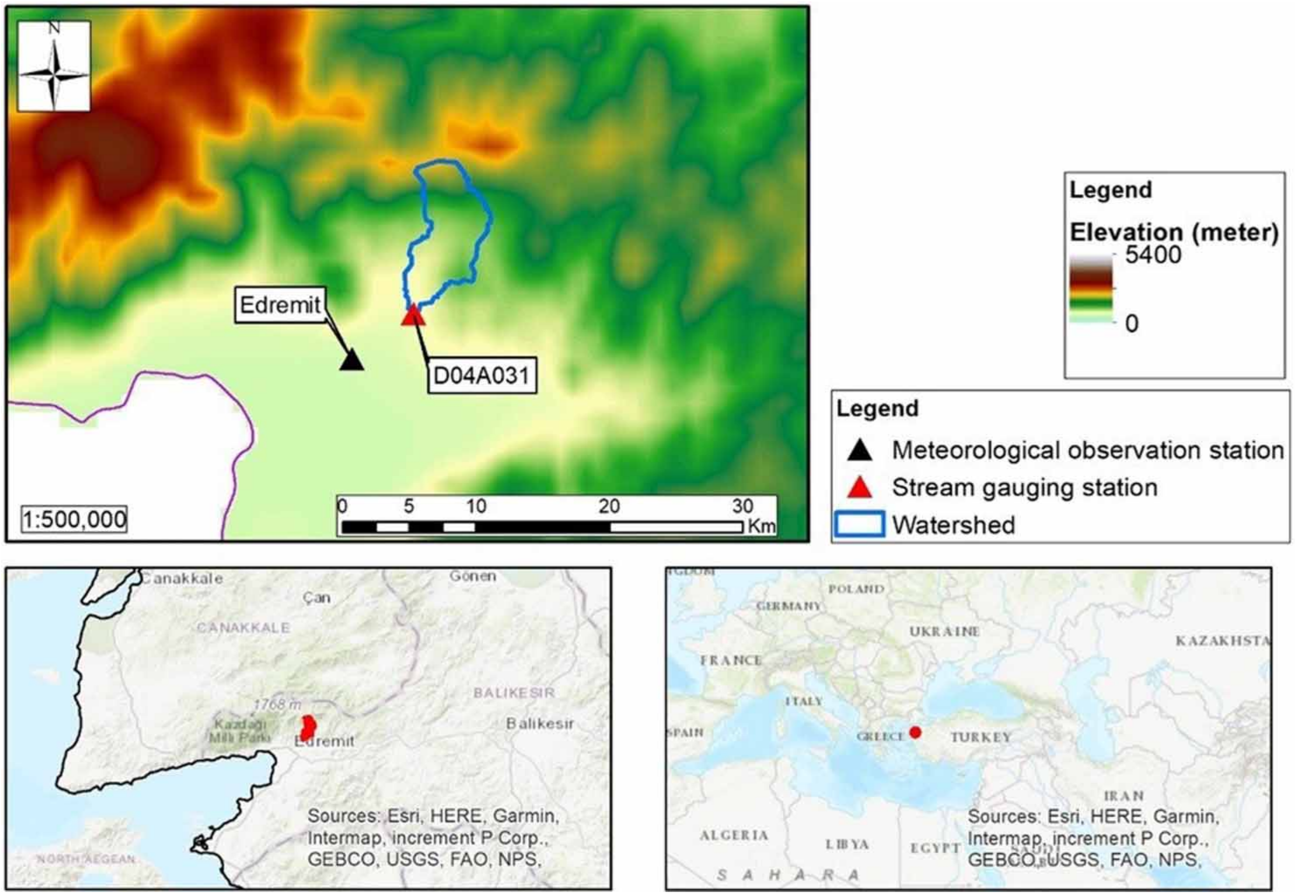


Figure 1 | Study area, Eybek Creek, streamflow gauging station and meteorology station.

located at an elevation of 16 m above sea level, while the highest mountain within the district boundaries, Sarıkız Peak of Mount Kazdağı, reaches an altitude of 1,767 m.

In the study area and its surroundings, precipitation is generally in the form of rain. Although there are occasional snowfalls during the winter months, they do not significantly impact the magnitude of floods. The project area primarily receives its precipitation from moist frontal systems that come over the Aegean Sea. Convective-type instability rains often occur in small areas during spring and summer, bringing heavy rainfall in a short period. During spring and winter, frontal systems associated with low-pressure systems from the Balkans and the Mediterranean deposit high amounts of rainfall on the basin. The orographic effect in the higher elevations of the basin enhances the amount of precipitation at the upper altitudes of the basins.

The prevailing climate type, the Mediterranean climate, is characterized by generally hot summers and not excessively cold winters and springs. However, in some years, cold frontal systems coming from the Balkans can cause harsh winter conditions in the area. Conversely, during years dominated by frontal systems coming from the Mediterranean, the winter months are mild and rainy. The data used in the study cover the water years from 1979 to 2021, and the observed lowest temperature average at Edremit meteorological observation station was ~– 3.4 °C, while the highest temperature was ~34.7 °C during this period.

2.2. Data and methodology

The study utilized temperature and precipitation data obtained from the Edremit Meteorological Observation Station and daily streamflow data from the Çamcı-Eybek streamflow station. For this study, daily streamflow data for the Eybek watershed from 1979 to 2021 were used. The streamflow data were obtained from the State Hydraulic Works of Turkey. We applied standard data-quality checks, such as identifying missing data and outliers. We did not fill the data gaps but utilized the currently available data. The hydrological processes of the basin were analyzed using the HBV model. Hadley Centre Global Environment Model version 2 (HadGEM2) dynamic climate model data (temperature and precipitation) were used as input for hydrological model for the projection period.

HadGEM2 is a GCM developed by the Hadley Centre for Climate Change of the UK Met Office. It was used in the Fifth Assessment Report (AR5) of the IPCC (Demircan *et al.* 2014, 2015, 2017). The HadGEM2 family of models includes a comprehensive representation of the Earth system, incorporating the atmosphere–ocean configuration, dynamic vegetation, and an extended vertical structure in the atmosphere that also includes a well-resolved stratosphere. The standard atmospheric component of HadGEM2 comprises 38 pressure (sigma) levels that extend to ~40 km altitude and has a horizontal resolution of 192 × 145 grid cells on a global grid structure (with a grid spacing of 1.875° longitude and 1.25° latitude). HadGEM2 is reported as one of the most suitable global models for Türkiye and region (Akçakaya 2015).

In September 2007, the IPCC organized an extensive expert meeting to develop new emission/concentration scenarios for use in the IPCC Fifth Assessment Report. The aim was to obtain a new approach to climate change scenarios. As a result of this meeting, a set of new emission/concentration scenarios was created (Demircan *et al.* 2014, 2015; Demircan *et al.* 2017). Four scenarios were determined, named representative concentration pathways (RCPs): RCP3-PD (490 ppm), RCP4.5 (650 ppm), RCP6.0 (850 ppm), and RCP8.5 (1,370 ppm). The numbers in the RCP extensions (values given in parentheses) represent the radiative forcing (watts/m^2) resulting from the corresponding greenhouse gas emissions. Scenarios rely on projections of greenhouse gas emissions caused by factors such as countries' population, energy usage, land-use change, industry, etc., and differentiate according to measures taken nationally and internationally. RCP8.5 denotes the situation where measures are not taken. Since the indicators after 2010 indicate that the realization of RCP3-PD is almost impossible, RCP4.5 and RCP8.5 have become the most preferred scenarios. RCP4.5 is considered the best-case scenario likely to occur, and RCP8.5 is considered the worst-case scenario likely to occur. The hydrologic model, coupled with climate projections, was analyzed over cumulative 10-year periods from 2023 to 2092, marking the end of the projection period. This study period was chosen to assess current short-term, medium-term, and long-term changes in the hydrological system.

2.3. HBV model

The HBV model was developed by Sten Bergström at the Swedish Meteorological and Hydrological Institute (SMHI). Over the past 20 years, the HBV model has been frequently used for streamflow simulations in Sweden. Additionally, the model has been applied in ~30 countries and continuously tested with modifications in various research projects. The HBV model is a hydrological tool used for simulating various processes, including water resources management, flood forecasting, planning, climate change analysis, hydrological research, and water-quality management, spanning a broad spectrum of hydrological applications.

The operating principle of the model is illustrated in Figure 2, and the primary reasons for selecting the HBV model in this study are outlined below:

- conceptual model for flow simulation,
- a simple structure,
- division of the watershed into sub-basins, elevation zones, vegetation areas, etc.,
- easy to understand, learn, and implement,
- good results in many applications,
- moderate input data (Seibert 2005).

HBV, a conceptual rainfall–runoff model, simulates the flow process in the watershed using precipitation, temperature, and potential evapotranspiration data (Şorman *et al.* 2009). Table 1 illustrates both the data utilized in the HBV model and the generated outputs. The model estimates the daily flow of rivers using daily areal precipitation, temperature, and potential evapotranspiration as its inputs. It comprises five modules: the precipitation routine, soil moisture routine, baseflow routine, fast runoff routine, and flow routing routine (Seibert 2005). Depending on whether the measured temperature is below or above the specified threshold, the precipitation is simulated as either snowfall or rainfall.

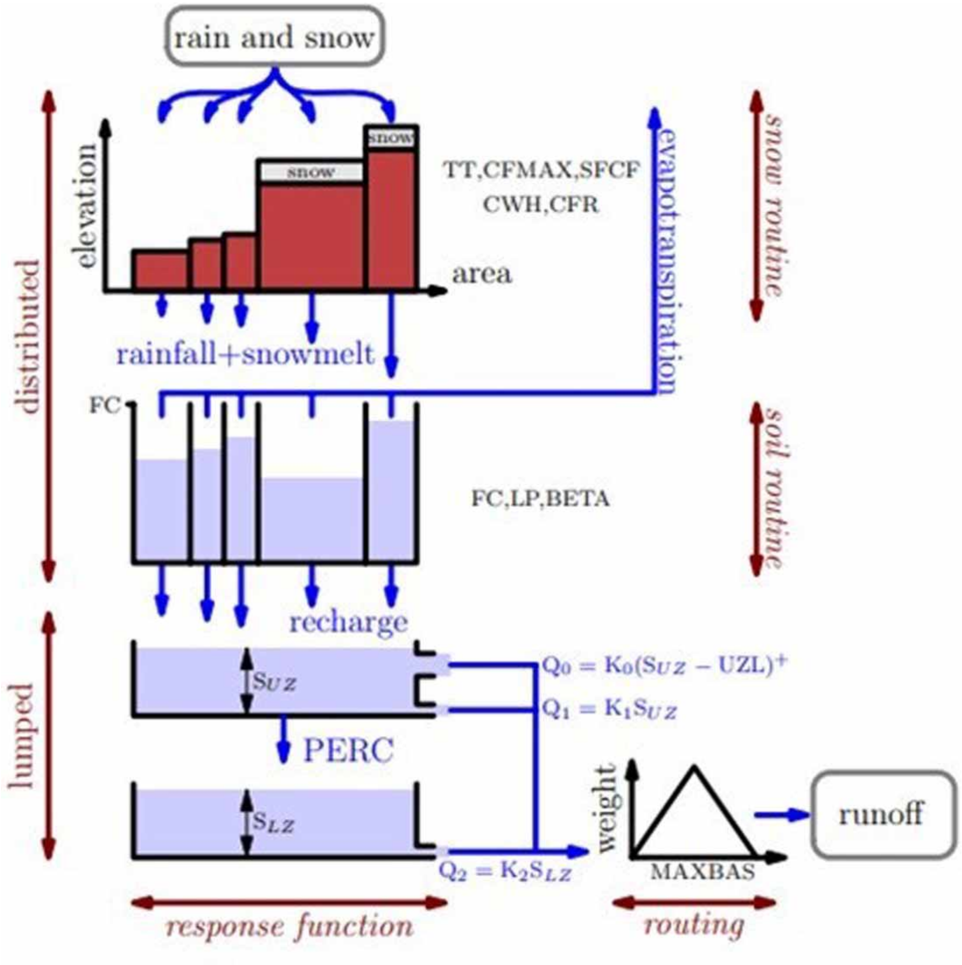


Figure 2 | Flowchart of HBV (Driessen *et al.* 2010).

Table 1 | HBV model input/output data (Seibert 2005)

Sub-model	Input data	Output data
Snow routine	Precipitation, temperature	Snow pack, snowmelt
Soil routine	Potential evapotranspiration, precipitation, snowmelt	Actual evapotranspiration, 'soil moisture', groundwater recharge
Response function	Groundwater recharge, (potential evapotranspiration)	Runoff, 'groundwater level'
Routing routine	Runoff	Simulated runoff

The HBV model includes a warm-up period, which converts the standard initial values to appropriate values based on meteorological conditions and parameter values. Typically, a warm-up period of 1 year is considered sufficient for this purpose (Seibert & Vis 2012). During the warm-up period, the model is allowed to adjust its internal state variables and parameters to better represent the hydrological processes in the specific watershed under consideration. This period ensures that the model reaches a stable and representative state before the actual simulation period begins.

The HBV model contains numerous parameters representing different hydrological conditions and characteristics of the watershed. Calibration of these parameters is necessary for conducting flow simulations (Bhattarai *et al.* 2018). The purpose of calibration is to reduce uncertainty. Calibration can be done automatically or manually, depending on the techniques used to derive model parameters and parameter estimates (Şorman *et al.* 2009). The calibration period should include various hydrological events, and a period of 5–10 years is generally considered sufficient for calibrating the model.

After calibrating the model with parameters, the process of testing the model performance with independent data is referred to as validation. This is done to assess how well the model performs with parameters calibrated for a different period (Seibert 2005). Monte Carlo is one of the calibration techniques. Monte Carlo involves determining various parameter sets and upper and lower bounds for each parameter, simulating a large number of data points to demonstrate how well the model results match the observed data. This helps to show the efficiency of the model in simulating the data optimally.

The Nash–Sutcliffe efficiency (NSE) is a commonly used metric to evaluate the performance of hydrological models. The NSE is a statistical measure that quantifies how well the model simulations match the observed data. It is calculated as

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n} (Q_i^{\mathrm{obs}} - Q_i^{\mathrm{est}})^2}{\sum_{i=1}^{n} (Q_i^{\mathrm{obs}} - \bar{Q}^{\mathrm{obs}})^2} \tag{1}$$

where Q_i^{obs} is the ith value of the observed daily flows, Q_i^{est} is the ith value of the estimated daily flows, and n is the total number of observations.

The NSE ranges from negative infinity to 1, where a value of 1 indicates a perfect match between the simulated and observed data, and higher values indicate better model performance. A value close to 1 suggests a good fit between the model and the observed data, indicating higher efficiency and accuracy of the model simulations (Table 2). Conversely, a negative NSE indicates that the model performs worse than simply using the mean of the observed data as predictions.

3. RESULTS

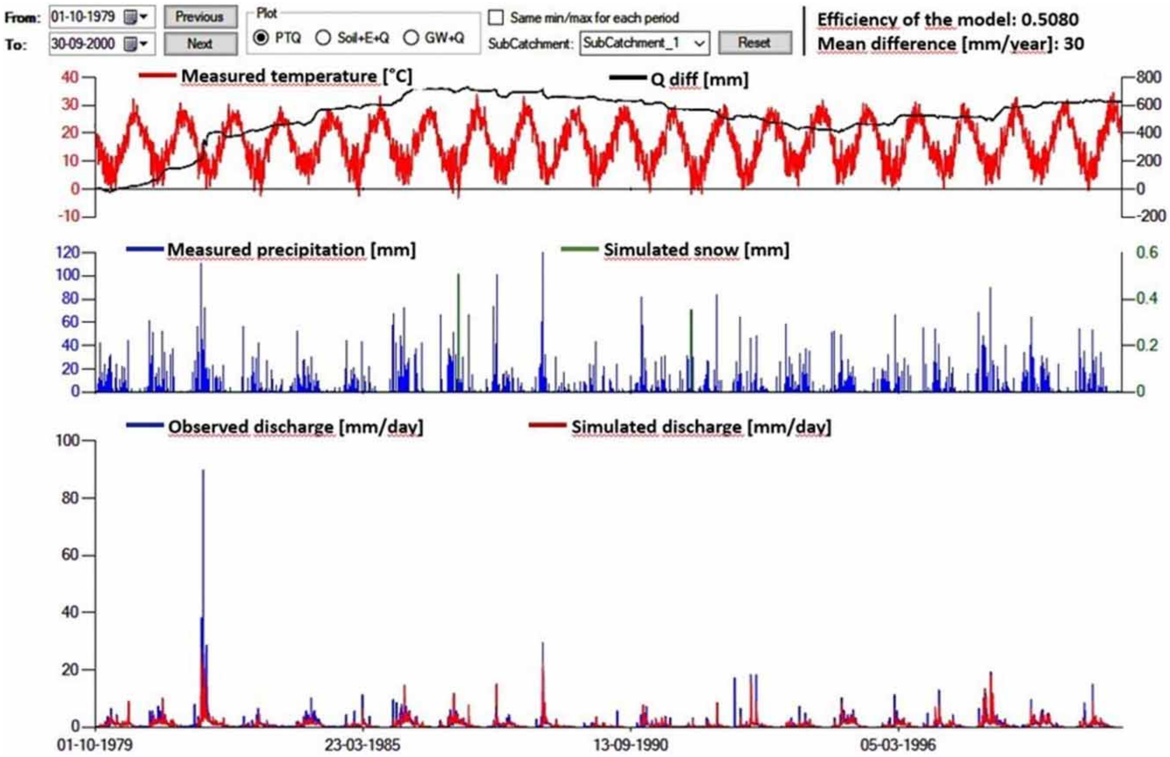
In the first part of the study, the temperature, precipitation, and streamflow data obtained from State Hydraulic Works and State Meteorology Services of Türkiye were adjusted to fit the HBV model inputs. The temperature data were converted to °C, the precipitation data were converted to mm, and the streamflow data were converted from m^3/s to mm/day format. These modified datasets were then organized as input data for the HBV model and saved under the name 'PTQ.txt' to create the HBV model input dataset.

Numerous studies have documented a significant increase in temperatures in recent years within the study area (Öztürk *et al.* 2011; Türkeş 2012; Aksu 2021). Moreover, the region has been witnessing shifts in seasons, with summers forwarding by 2.1 days per decade (Aksu 2022). To lessen the impact of these changing conditions on the performance of hydrological models, we selected the most recent and representative time period. Nevertheless, we have reported the hydrological model performances for two periods: the full observation period and the most representative short term. The first period is from 1980 to 2021, covering 42 water years, which was divided into two halves. From a hydrological perspective, validation and calibration periods should be equal, or the calibration period should be longer. In our study, due to the representation of the most significant period being short, we divided the data into two equal parts. We applied this method for both the long and short periods for the consistency of the study. The first 21 years (1980–2000 water years) were used for calibration, and the following 21 years (2001–2021 water years) were used for validation. The NSE values obtained for calibration and validation were 0.51 and 0.52, respectively. Calibration and validation graphs are shown in Figures 3 and 4, respectively.

The second period is from 2014 to 2021, covering 8 water years, which was also divided into two halves. The first 4 years (2014–2017 water years) were used for calibration, and the following 4 years (2018–2021 water years) were used for

Table 2 | NSE performance ratings (Nash & Sutcliffe 1970; Moriasi *et al.* 2007)

NSE	Performance rating
$0.75 < \mathrm{NSE} < 1.00$	Very good
$0.65 < \mathrm{NSE} < 0.75$	Good
$0.50 < \mathrm{NSE} < 0.65$	Satisfactory
$\mathrm{NSE} < 0.50$	Unsatisfactory



From: 01-10-1979
To: 30-09-2000

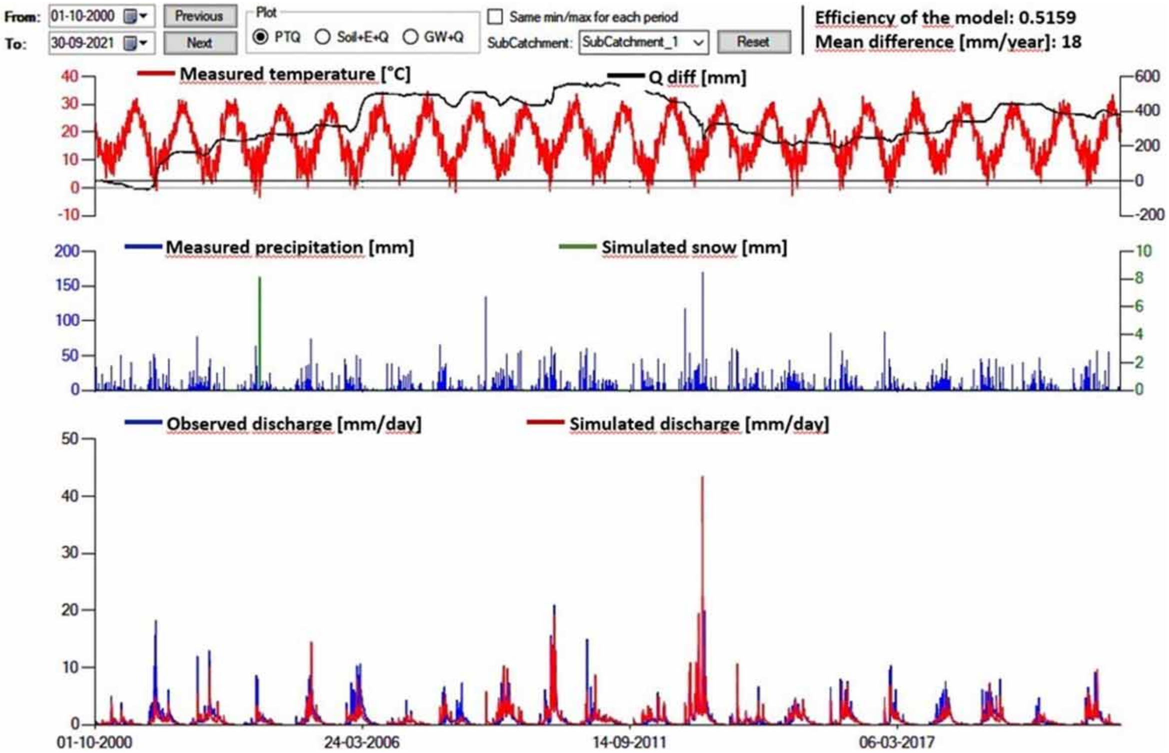
Plot: ● PTQ ○ Soil+E+Q ○ GW+Q

☐ Same min/max for each period

SubCatchment: SubCatchment_1

Efficiency of the model: 0.5080
Mean difference [mm/year]: 30

Figure 3 | Calibration results of period 1.



From: 01-10-2000
To: 30-09-2021

Plot: ● PTQ ○ Soil+E+Q ○ GW+Q

☐ Same min/max for each period

SubCatchment: SubCatchment_1

Efficiency of the model: 0.5159
Mean difference [mm/year]: 18

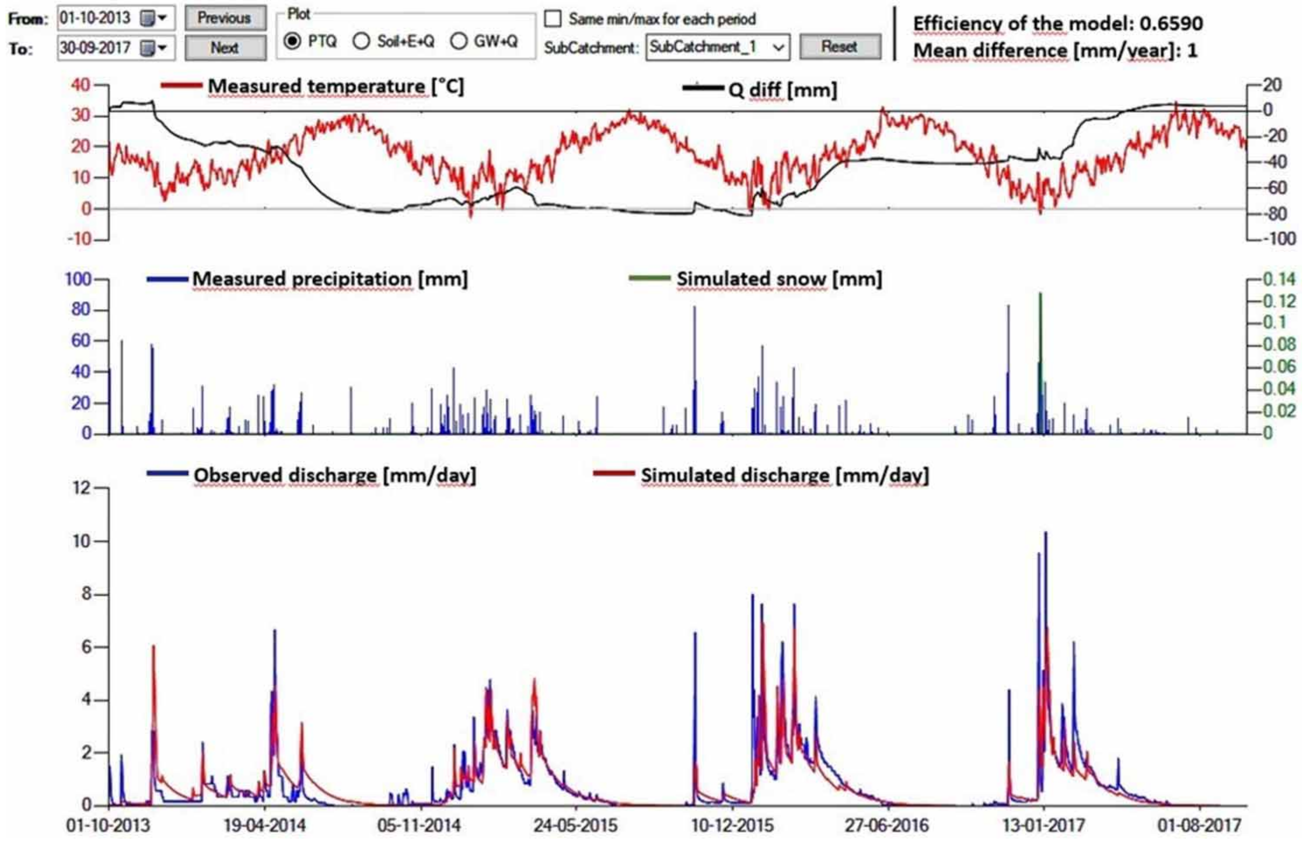
Figure 4 | Validation results of period 1.

validation. The NSE values obtained for calibration and validation during this period were 0.66 and 0.69, respectively. Calibration and validation graphs are shown in Figures 5 and 6, respectively.

The NSE values obtained for both periods are reasonably good, indicating that the HBV model performed well in simulating the streamflow for the given datasets. The validation outcomes surpass those achieved during the calibration phase. During validation, hydrological processes are simulated under conditions and data beyond those utilized for calibration. This period may have provided hydrological conditions better suited to the model structure or parameterization, thereby enhancing performance. Conversely, the data from the calibration period may have inadequately represented the entire spectrum of hydrological variability, resulting in less than optimal model performance. In conclusion, the factors contributing to the improvement would be contingent upon the hydrological model's characteristics, the calibration and validation data, and the hydrological processes under simulation. The calibration and validation processes are essential to ensure the reliability and accuracy of the model's performance under different hydrological conditions.

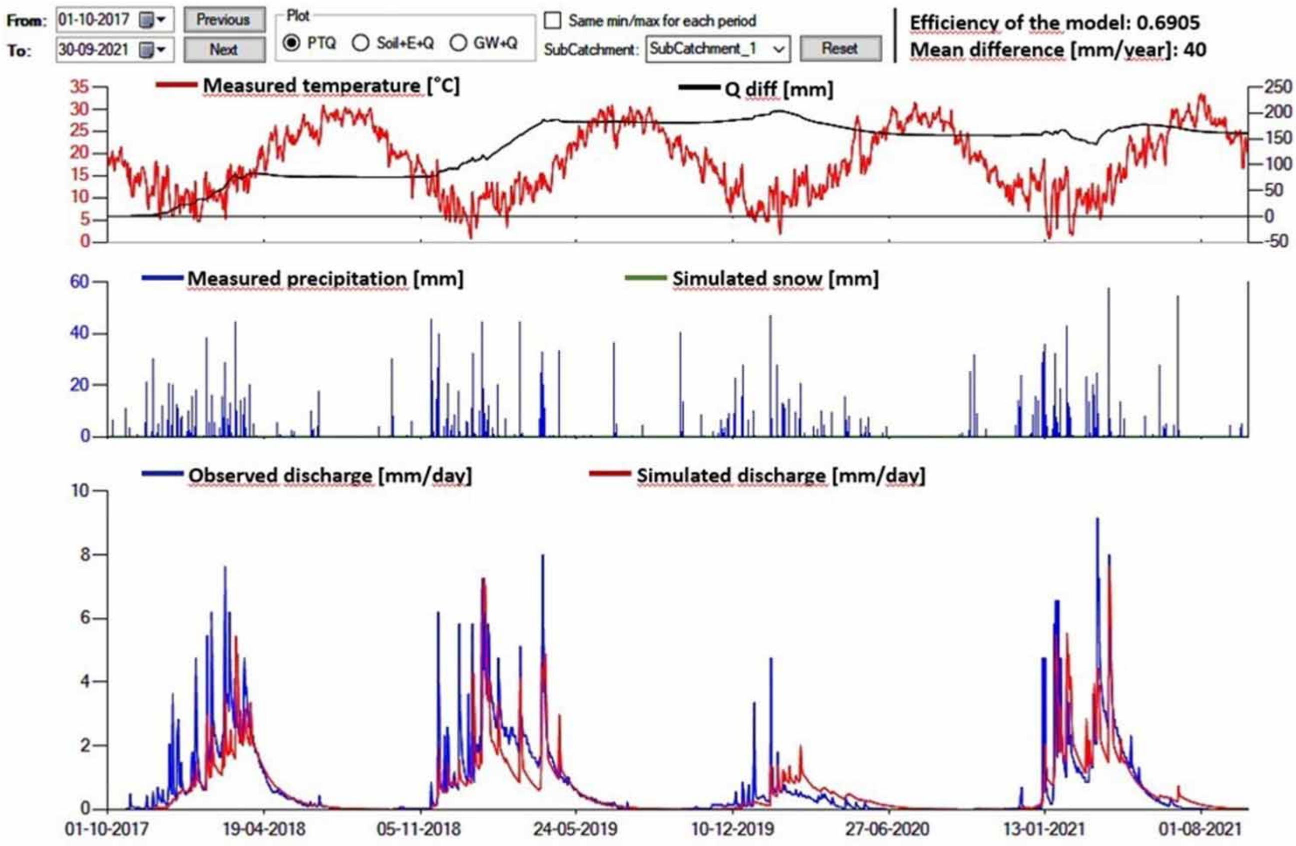
Due to the reasons mentioned above, we ran the hydrological model established for the second period to simulate future streamflows, which we evaluated as better representing hydrological processes in the watershed. The model was run using HadGEM2 dynamic climate model projection data for the RCPs, specifically RCP4.5 and RCP8.5 scenarios, for the period between 2023 and 2092. The results were visualized in the form of graphs showing the 10-year total streamflows and the 10-year seasonal totals.

According to the graph of 10-year total streamflows for the RCP4.5 scenario (Figure 7), the flow is projected to be at its lowest between 2063 and 2072 and at its highest between 2033 and 2042. The R^2 value was calculated to be 0.49 based on the Pearson correlation coefficient (R) and the corresponding P-value. However, the regression line indicates a decrease in streamflows; this value is not statistically significant for confidence intervals, indicating that the result is not statistically meaningful. Based on this, it can be inferred that the RCP4.5 climate scenario will not have a significant impact on the hydrological processes of the Eybek Stream watershed.



From: 01-10-2013
To: 30-09-2017
Plot: ● PTQ ○ Soil+E+Q ○ GW+Q
☐ Same min/max for each period
SubCatchment: SubCatchment_1
Efficiency of the model: 0.6590
Mean difference [mm/year]: 1

Figure 5 | Calibration results of period 2.



From: 01-10-2017
To: 30-09-2021
Plot: ● PTQ ○ Soil+E+Q ○ GW+Q
☐ Same min/max for each period
SubCatchment: SubCatchment_1
Efficiency of the model: 0.6905
Mean difference [mm/year]: 40

Figure 6 | Validation results of period 2.

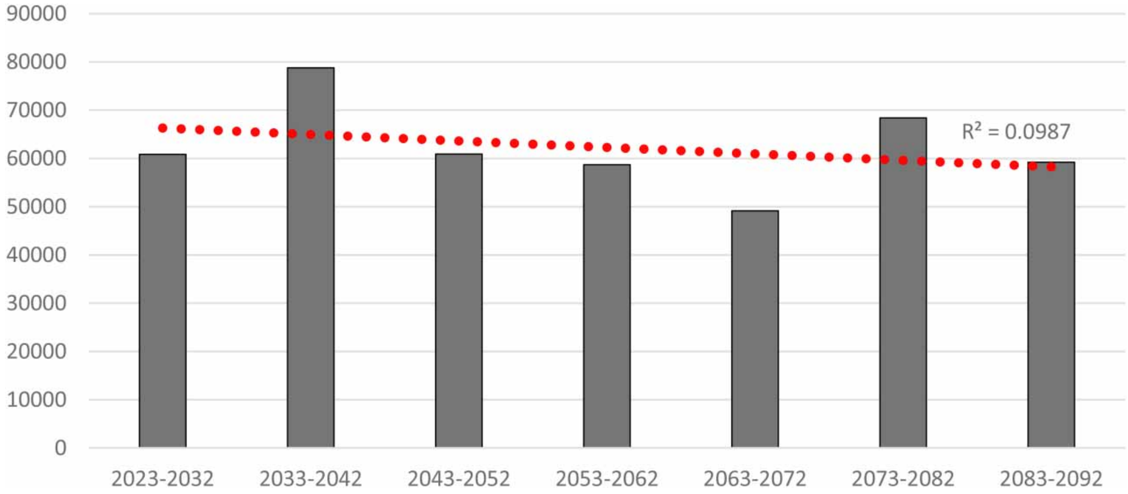


Figure 7 | Decadal annual total streamflows according to the RCP4.5 climate projection scenario.

The projected total streamflow values are estimated to be ~49 million m^3 at the lowest and ~78 million m^3 at the highest. These values represent the potential range of total streamflows that may occur within the study period.

According to the graph of 10-year seasonal total streamflows for the RCP4.5 scenario (Figure 8), it can be observed that the highest flow occurs during the winter season, while the lowest flow occurs during the autumn season. Specifically, the winter season experiences the highest flow between 2033 and 2042, with a total of ~37 million m^3. On the other hand, the lowest flow in the autumn season is estimated to be ~4 million m^3 during the same period (2033–2042).

These results indicate that under the RCP4.5 scenario, the winter season is expected to have the highest total streamflow values, while the autumn season will have the lowest total streamflow values for the specified 10-year periods. In parallel with the annual analyses, consistent with the seasonal analysis results, no significant changes in streamflows are observed under the RCP4.5 scenario.

According to the graph of 10-year total streamflows for the RCP8.5 scenario (Figure 9), it is projected that the lowest flow will occur between 2083 and 2092, while the highest flow will be experienced between 2023 and 2032. The R^2 value is given as 0.705, and the corresponding P-value calculated from the Pearson correlation coefficient (R) is 0.018. Based on this result, it can be said that there is a decreasing trend at a 5% confidence level.

The projected total streamflow values under the RCP8.5 scenario are estimated to be ~52 million m^3 at the lowest and ~85 million m^3 at the highest. From 2023 to 2052, the flow values are observed to decrease, then increase from 2053 to 2062, and

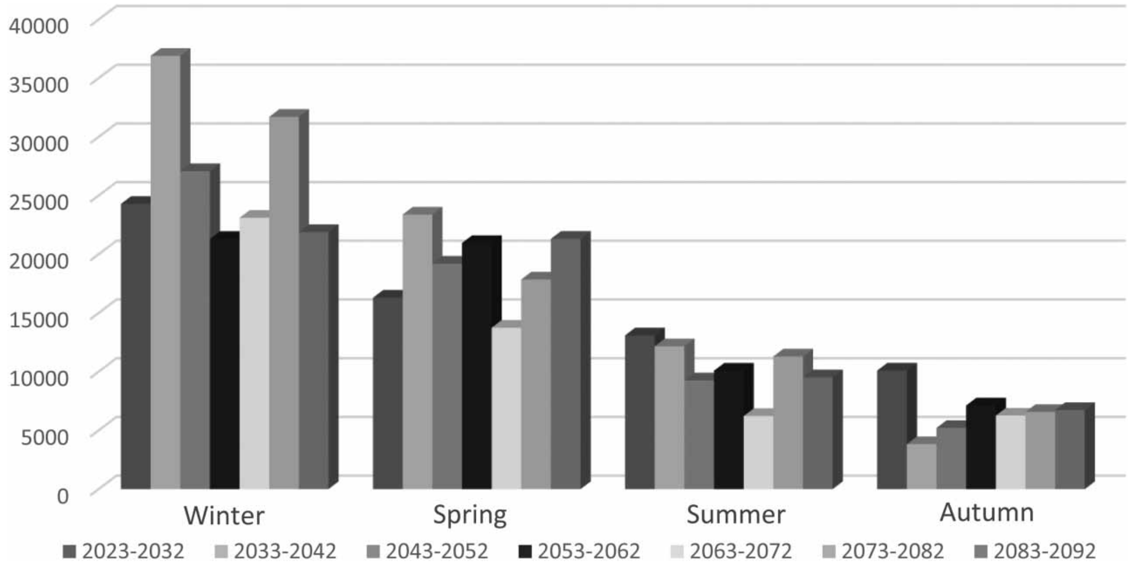


Figure 8 | Decadal seasonal total streamflows according to the RCP4.5 climate projection scenario.

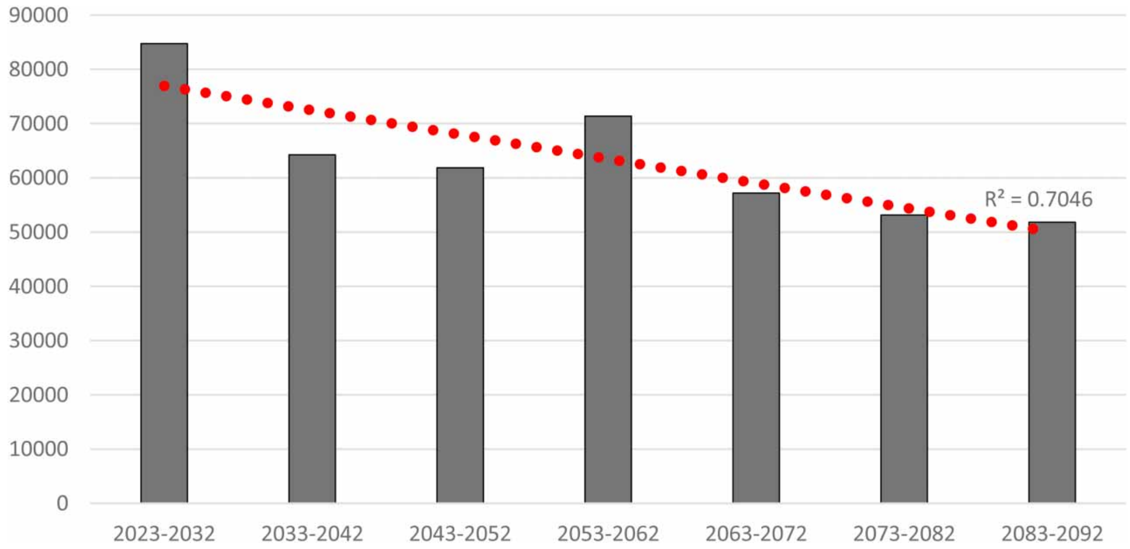


Figure 9 | Decadal annual total streamflows according to the RCP8.5 climate projection scenario.

finally decline steadily until 2092. According to the long-term projection results, the RCP8.5 scenario indicates a significant decrease in the annual water potential of the Eybek Stream.

According to the graph of 10-year seasonal total streamflows for the RCP8.5 scenario (Figure 10), it can be observed that the highest flow occurs during the winter season, while the lowest flow occurs during the autumn season. Specifically, the winter season experiences the highest flow between 2053 and 2062, with a total of ~37 million m^3. On the other hand, the lowest flow in the autumn season is estimated to be ~3 million m^3 during the period 2083–2092.

These results indicate that under the RCP8.5 scenario, the winter season is expected to have the highest total streamflow values, while the autumn season will have the lowest total streamflow values for the specified 10-year periods.

The evaluations conducted using the HBV-Light model for the period between 2023 and 2092 under the RCP8.5 scenario indicate a regular decreasing trend of flows due to climate change. Consequently, as precipitation decreases over time, it will lead to a reduction in streamflow. Considering that Balıkesir province receives the highest amount of precipitation during the winter months, it is observed that the total streamflow in the Eybek basin is highest during the winter season. However, starting from the winter season and progressing toward the spring, summer, and autumn seasons, a consistent decrease in streamflow values is evident. In the long term, it is clearly evident that the greatest decrease in streamflows occurs during the autumn season; however, significant decreases are also observed in all other seasons. The reduction in surface water during the autumn season, which is the period with the lowest groundwater levels in the study area, poses an additional risk, particularly for the agricultural sector.

These findings suggest that the region is likely to experience a reduction in water availability and flow due to the anticipated decrease in precipitation and increase in temperature under the RCP8.5 scenario. This information is crucial for water resource management and planning in the Eybek basin, as it highlights the potential impacts of climate change on streamflow and water availability in the future years. Adaptation and mitigation strategies may be necessary to address the challenges posed by the decreasing streamflow and water resources in the region.

4. CONCLUSION AND DISCUSSION

Based on the evaluations conducted for the Eybek basin under the RCP4.5 and RCP8.5 scenarios, it is inferred that temperatures will rise and precipitation will decline, resulting in a decrease in water quantity in the basin, leading to more severe and frequent drought periods from 2023 to 2092. In parallel with current study findings, if the RCP4.5 scenario is realized, it is estimated that there will be no significant impact on the basin's water resources. However, according to the RCP8.5 scenario, it is projected that the basin's water resources will decrease by ~40% annually. Studies by Türkeş (2012) and Öztürk *et al.*

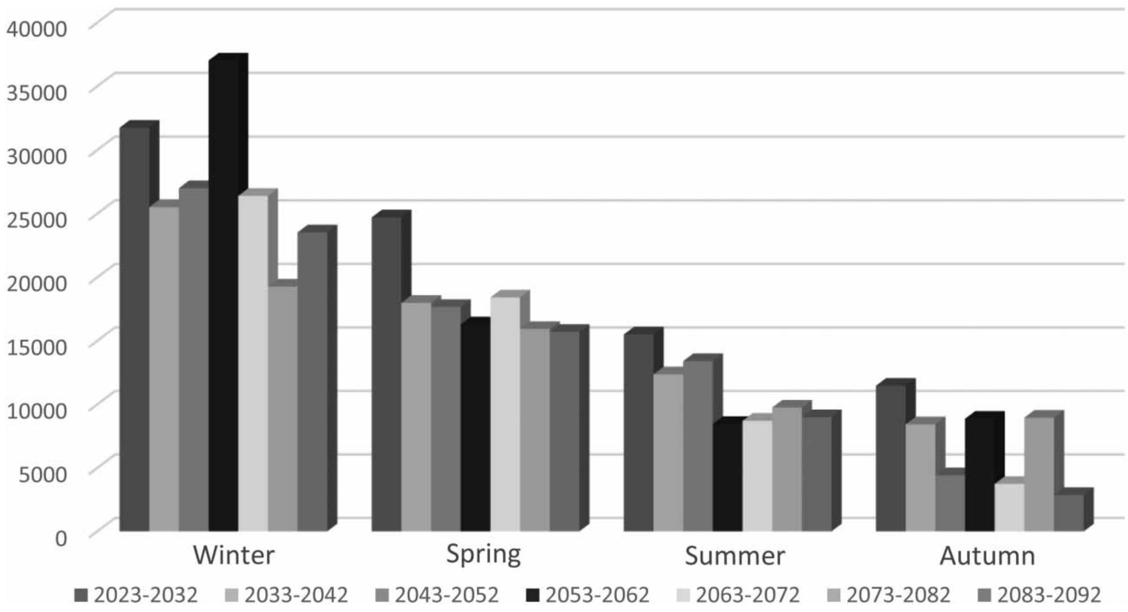


Figure 10 | Decadal seasonal total streamflows according to the RCP8.5 climate projection scenario.

(2011) have highlighted the significant increase in temperatures in Türkiye since the 1980s and the strengthening trend of this warming. They also noted a clear decreasing trend in precipitation (aridification) when examining changes in rainfall. According to their research, temperatures are projected to rise by 3–7 °C in the second half of the 21st century in Türkiye, with the southern and western regions dominated by the Mediterranean climate experiencing less precipitation throughout the year. The outputs of this study are also in line with the reported results as the increasing drought severity and intensity over western Türkiye (Eris *et al.* 2020). Türkiye will be significantly affected by decreasing precipitation and increasing temperatures due to climate change. Türkeş (2021) also emphasized that future climate change, driven by increased greenhouse gas emissions, will result in even hotter days, more severe heatwaves, further decrease in precipitation, and fewer cold and frosty days.

The use of climate models to project various climate scenarios indicates that there will be a climate with less precipitation and warmer days. This is likely to lead to increased evapotranspiration, reduced soil moisture, and decreased streamflow, all of which contribute to more severe drought events. All these findings are applicable to the Eybek basin as well. The temperature has increased, and based on the HBV model used for future years, a statistically significant decreasing trend in total streamflow has been observed under the RCP8.5 scenario at a 95% confidence level. Decreases in precipitation have also resulted in a noticeable decrease in streamflow. However, it is essential to mention that in hydrological modeling, calibration is often done using observed data from a specific period. Consequently, any changes in the hydrological system that occurred after the calibration period may not be fully represented in the model, especially when using climate projection data for future years (Okkan & İnan 2015). Therefore, while the model provides valuable insights into potential changes in the hydrological system, it is essential to consider uncertainties and limitations associated with projecting future hydrological conditions based on past calibration. Both climate models and hydrological modeling involve inherent uncertainties due to the complexity of Earth's climate system and the limitations of modeling techniques. These uncertainties arise from various factors such as parameterization of physical processes, spatial and temporal resolution, initial conditions, and scenarios of future greenhouse gas emissions. For instance, different representations of cloud formation or ocean–atmosphere interactions can lead to divergent projections of future climate conditions. In hydrological modeling, uncertainties stem from factors like input data quality, model structure and complexity, parameter estimation, and the representation of hydrological processes. Variability in land surface characteristics, such as soil properties and land-use changes, further adds to these uncertainties. Discussing these uncertainties helps researchers assess the reliability and robustness of their findings. Approaches to addressing uncertainties may include sensitivity analyses, ensemble modeling using multiple models, and quantifying uncertainty ranges in model outputs. This comprehensive approach enhances the credibility of modeling results and supports informed decision-making in areas such as water resource management and climate adaptation strategies.

Increasing temperatures and precipitation, as observed in various climate scenarios, have interconnected effects. Elevated temperatures can lead to shifts in winter precipitation from snow to rain, and accelerate snowmelt in spring. The rise in temperatures intensifies evaporation, particularly in coastal regions during spring and summer, contributing to higher precipitation levels. This, coupled with the convective nature of seasonal precipitation, can result in extreme precipitation events, potentially leading to flooding and landslides. Moreover, heightened temperatures are linked to the occurrence of extreme weather events like storms, hail, and waterspouts. These interactions highlight the need for comprehensive adaptation measures, policy adjustments, and continued research to address the multifaceted impacts of these changes (Demircan *et al.* 2017).

Seasonally, the largest decrease in streamflows is expected to occur during the fall, according to long-term projections. This decrease in streamflows during the season with the lowest groundwater levels in the basin will have a negative impact on all water-dependent sectors, particularly the agricultural sector. In addition to the decrease, seasonal shifts, which are not within the scope of this study, are also an important topic for future research. Aksu's (2022) study on seasonal variations in Türkiye for the period 1965–2020, taking into account climate change and variability, revealed significant trends in the length of seasons, average temperatures, and the timing of season onset. Seasonal temperatures have shown substantial changes, especially after the late 1990s, with a breakpoint detected in the beginning of the summer season in 2005 in the Aegean and Mediterranean regions. Seasonal temperatures increased during all four seasons, with the highest rate of increase observed in the summer season. The length of the autumn season has shortened, particularly in the eastern Marmara, Western and Central Black Sea regions, and especially in the Aegean region. Throughout the country, the summer, spring, and autumn seasons have shifted forward, while the winter season has remained almost constant. The observed changes in temperature patterns are likely to affect the quantity and timing of river flows.

Given these findings, it is crucial for future studies to focus on the timing of maximum and minimum river flows. Understanding the impact of climate change on the timing of flow events can provide valuable insights for water resource management, flood risk assessment, and ecosystem conservation. Additionally, changes in seasonal temperature patterns can influence evapotranspiration rates, soil moisture, and overall hydrological processes, further affecting river flows.

Overall, this study highlights the importance of considering the impacts of climate change on seasonal variations, temperatures, and the timing of seasons, as well as their implications for river flow patterns. Such studies are essential for developing effective adaptation and water management strategies in the face of ongoing climate change impacts.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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