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RESEARCH ARTICLE

Future Hydrological Trajectories of Burdur Lake Under Climate Change and Basin-Scale Human Interventions

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ABSTRACT

Burdur Lake is a saline lake in southwestern Türkiye that has lost approximately 75 km^2, or one-third of its surface area, since 1975. The basin's hydrology has been significantly modified by human activities, including reservoir construction, and water level declines continue with no signs of stabilisation. In this study, the soil and water assessment tool (SWAT) was employed to simulate the hydrological processes in the Burdur Lake Basin and analyse the cumulative impacts of climate change and hydrological modifications. The model incorporated a digital elevation model, land use/cover and soil maps and historical meteorological data. Calibration and validation were performed using the SUFI-2 algorithm within SWAT-CUP, based on streamflow and water volumes in major reservoirs and Burdur Lake. Future hydrological conditions were projected by running bias-corrected precipitation and temperature data from three global climate models (GFDL-ESM2M, HadGEM2-ES, MPI-ESM-MR) under RCP4.5 and RCP8.5 scenarios for 2025–2098. Results indicate that the Burdur Lake Basin can face a 5%–10% decrease in precipitation under RCP4.5 and a 14%–20% decrease under RCP8.5, with minimum and maximum temperatures rising by about 5°C relative to historical values. Simulated lake volumes and levels show continued declines, with water levels falling below the ecological threshold of 835 mASL under all RCP8.5 projections and the HadGEM2-ES RCP4.5 scenario. Although the decrease in water level is slower than in the historical period, the downward trends are projected to continue. This study shows that climate change could create additional stressors on the already altered hydrological conditions of Burdur Lake. Implementation of adaptive and integrated water management strategies is essential to prevent further degradation in the lake's ecological and hydrological balance.

1 | Introduction

Climate change poses one of the most critical challenges for managing and conserving natural resources. It increases surface temperatures, leading to more frequent and intense warm periods. According to the 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), climate change is projected to alter precipitation patterns by increasing overall precipitation and its variability (Douville et al. 2021). As a result, extreme weather events, such as droughts and floods, become more frequent, affecting aquatic and terrestrial ecosystems (Häder and Barnes 2019; Seneviratne et al. 2021; Ummenhofer and Meehl 2017).

Lakes, vital components of the hydrologic cycle, are among the most vulnerable ecosystems to climate change. Lake Hydrology is highly dependent on the changes in precipitation, inflows from surface water and groundwater, evaporation and water demand (Chen et al. 2025; Lubis et al. 2025). Closed-basin lakes in semi-arid regions are susceptible to climate change impacts because they have high evaporation rates relative to limited inflows (Williams 2002; Woolway et al. 2020; Yao et al. 2023).

Even a slight change in precipitation and/or air temperatures can disrupt the balance between inflows and water losses and cause decreases in water volumes/extent, or levels. As these systems have no outflow, the accumulation of pollutants and salts increases, which causes water quality deterioration and loss of aquatic habitat (Whitehead et al. 2009; Wu et al. 2014). Anthropogenic pressures further exacerbate climate change impacts on closed-basin lakes (Yao et al. 2023). Excessive surface water and groundwater withdrawals for meeting agricultural, municipal, or industrial demands reduce inflows further.

Many closed-basin lakes around the world have been experiencing drastic changes (Wurtsbaugh et al. 2017). By using a water balance approach, Wurtsbaugh et al. (2017) showed that the water level decline in Great Salt Lake was due to consumptive water use rather than long-term climate change. The surface area of Dead Sea has declined by 295 km^2 from 1966 to 1998 and water levels went down at a rate of up to m $year^{-1}$, primarily due to water diversions and increased evaporation (Asmar and Ergenzinger 2002; Lensky et al. 2005). The Aral Sea is one of the well-known examples that went through rapid shrinkage between 1960 and 2005 primarily due to impacts on water inflows and withdrawals (Wang et al. 2020). Although the shrinkage slowed down in the recent period, it continued into more recent years. Lake Urmia in Iran lost 30% of its surface area between 1998 and 2008 (Alizadeh-Choobari et al. 2016; Shams Ghahfarokhi and Moradian 2023). These changes were found to be most related to anthropogenic impacts (e.g., agricultural intensification). Lake Bosten is an important freshwater lake in China, which had significant water level and salinity fluctuations from 1958 to 2019 (Tang et al. 2022). The changes were attributed to be related to both human and climate impacts. Reductions in streamflow and increased lake evaporation were found as the reasons for the lowest water levels in the 170-year record in 2022 in the Great Salt Lake in the United States (Bigalke et al. 2025). The combined effects of historical diversions and climate variability caused a rapid decrease in water level between the 1940s and 1980s in Mono Lake in the United States (Gossard et al. 2025). More recently Yao et al. (2023) analysed the condition of 2000 lakes globally using satellite imagery techniques and found that they lost approximately 21.5 trillion litres per year from 1992 to 2020. This study indicated that both climate-driven evaporation increases and anthropogenic water diversions were key drivers for this change. A comprehensive analysis of 655 lakes in Inner Mongolia showed an overall decline of 38.06 $km^2 year^{-1}$ from 1987 to 2023 (Miao et al. 2025). The drivers of the changes were natural factors for some lakes but anthropogenic activities in others.

Burdur Lake (Figure 1) is a closed-basin lake undergoing hydrological changes in recent decades. It is located in the southwest of Türkiye and is the seventh-largest lake in the country. It is an ecologically significant site, designated as a RAMSAR site, a Wildlife Development Area, and a Natural site. The lake and its surroundings host many endemic species of particular ornithological importance. Its saline waters provide a valuable refuge for wildlife. Species found in the lake include *Oxyura leucocephala*, *Netta rufina*, *Aythya ferina*, *Aythya fuligula*, *Anas platyrhynchos* and *Anas clypeata* (Ertuğrul et al. 2017). *Oxyura leucocephala* is the most important bird species, with about 70% of its global population living in and around Burdur Lake (Green et al. 1996). The lake hosts limited fish diversity, but *Anatolichthys burduricus* (Burdur killifish) is endemic to Burdur Lake and critically endangered (Giannetto and Innal 2021). Unfortunately, Burdur Lake has lost about 75 km^2 (or approximately one-third) of its surface area since 1975 (Figure 2), while water levels dropped about 20 m. Water level declines in recent years have not only affected lake morphology but also its salinity and biotic communities (Giannetto and Innal 2021; Saç et al. 2025). Currently, large areas of saline sand pose potential health concerns (Gozukara et al. 2024). The alarming situation in Burdur Lake has received attention from society and government agencies. Several previous studies in the Burdur Lake Basin seek to understand the causes of these changes, often attributing them to the construction of reservoirs and irrigation projects in the upper basin and climatic changes (e.g., Abujayyab et al. 2021; Adaman et al. 2009; Albarqouni et al. 2022; Çolak et al. 2022; Green et al. 1996; Mert et al. 2025; Özüpekçe 2019; Salgut et al. 2022; Soylu et al. 2023; Temiz et al. 2017). The decline in water level has been continuing at a high pace, which creates concerns about Burdur Lake's future, considering the anticipated climate change impacts for the region. If feasible, restoring Burdur Lake water levels requires understanding future climatic settings, as climate projections indicate increasing temperatures, more frequent droughts and shifts in precipitation regimes. These changes could further increase evaporation losses, reduce inflows and lead to water level declines.

In this study, we used the soil and water assessment tool (SWAT) to simulate the hydrological dynamics in the Burdur Lake Basin and generate predictions for future conditions. Burdur Lake is a closed-basin system where long-term and spatially comprehensive monitoring data are limited; therefore, a modelling-based approach was essential to evaluate basin-scale hydrological responses under changing conditions. The novelty of this study lies in its simulation of climate change impacts in a basin that is already under significant human influence. It explores the compound impacts of intensive anthropogenic activities such as reservoir operation and irrigation and climate change.

The main objectives of this study are (i) to assess the cumulative effects of climate change and anthropogenic water diversions and use on the hydrological balance of the Burdur Lake Basin, and (ii) to investigate the potential hydrological challenges that closed-basin lakes may face under the dual forcing of climate change and human activities. The findings from this study provide insight into the long-term vulnerability of closed-basin lake systems and support basin-scale water management planning.

2 | Study Area

Burdur Lake Basin is located in the Lakes Region of southwestern Türkiye, between the latitudes of 37° 28′–37° 54′ North and longitudes of 29° 58′–30° 27′ South (Figure 1). It is a depression basin covering approximately 3450 km^2. Surrounded by mountains, the basin's elevation ranges from 836 to 2316 m, and Burdur Lake is at the lowest elevation, collecting both surface water and groundwater flows.

The climate in the region is continental, with hot and dry summers and cold and rainy winters. The mean annual precipitation

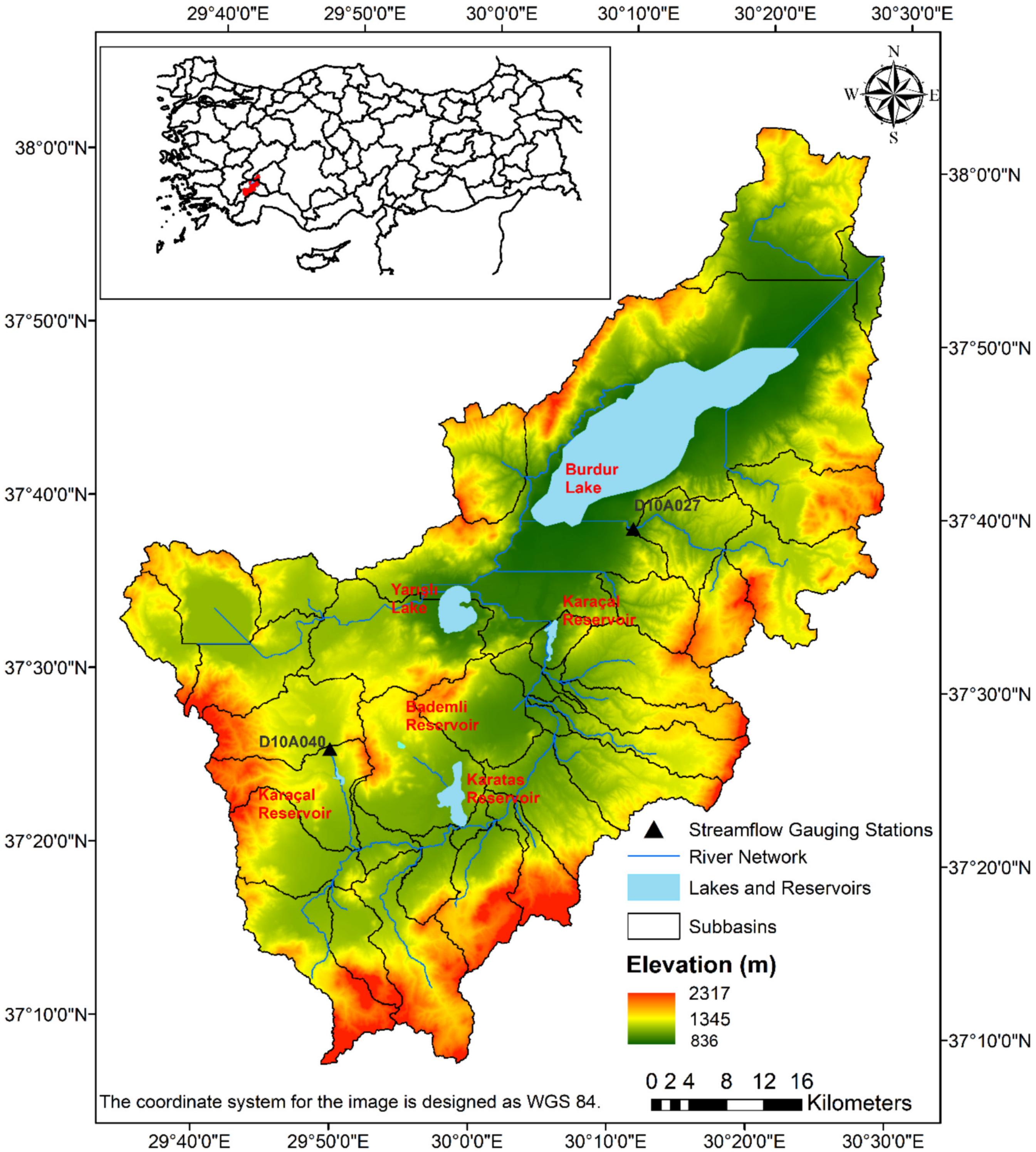

FIGURE 1 | The location and physical characteristics of the Burdur Lake Basin. [Colour figure can be viewed at wileyonlinelibrary.com]

is about 417 mm, and the mean air temperature is 13.5°C based on 1975–2024 data (Figure 3). During the 1975–2024 period, annual precipitation changed between 294 mm and 594 mm, and average annual temperature was between 11.6°C and 15.9°C. The potential evapotranspiration in the basin is around 1200 mm year^{-1}. We notice a clear upward trend in air temperature data; the highest recorded value was in 2024 (Figure 2). Dry and wet periods in the precipitation time series can be observed, but although negative, the rate of change is not notable.

The Burdur Lake Basin lies within an area with a complex geological structure, shaped by faulting and past tectonic activity (Kılıç Germeç 2023). The central rock units include older limestone and ophiolitic (volcanic and sedimentary) formations, overlain by younger sandstone, claystone, marl and conglomerate layers. These younger Pliocene-Quaternary deposits are mostly lacustrine and alluvial sediments that form the current lake basin and surrounding plains. Fault movements have strongly influenced the area since the Pliocene, instrumental

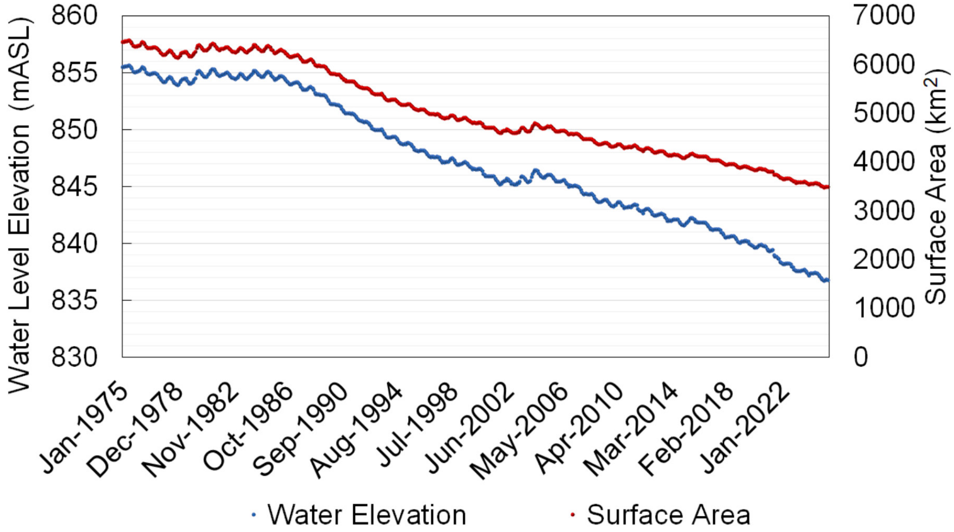

FIGURE 2 | Changes in water levels and extents at Burdur Lake from 1975 to 2024 (data were obtained from State Hydraulic Works in Türkiye). [Colour figure can be viewed at wileyonlinelibrary.com]

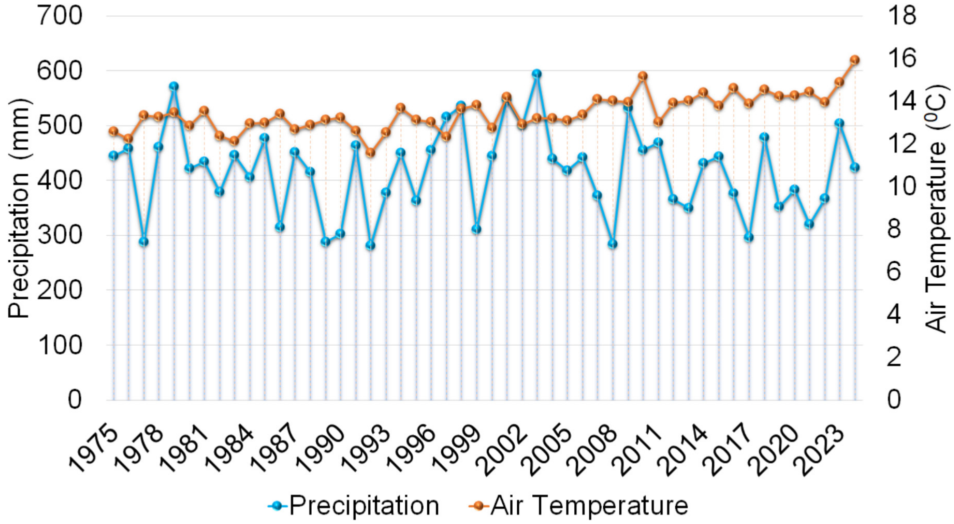

FIGURE 3 | Annual precipitation and annual average air temperature at the Burdur Lake Basin. [Colour figure can be viewed at wileyonlinelibrary.com]

in creating the present-day depression where Burdur Lake is located. The geological structure and sediment types play an important role in groundwater movement, surface runoff and water-rock interactions in the basin (Kılıç Germeç 2023).

Burdur Lake is fed by precipitation, surface flows, and groundwater flows, while evaporation is the largest water loss mechanism. Kılıç Germeç (2023) calculated lake water budget for the 1969–1971 and 2014–2016 periods using a groundwater flow model for the Burdur Lake Basin. Based on this study, precipitation input to the lake was estimated as 86 $mm^3 year^{-1}$ (million $m^3 year^{-1}$), surface runoff input was estimated as 186 $mm^3 year^{-1}$ in the 1969–1971 period. Groundwater input and evaporation were calculated as 94 and 264 $mm^3 year^{-1}$. During the 2014–2016 period, precipitation input was estimated as 43 $mm^3 year^{-1}$, surface runoff estimated was estimated as 59 $mm^3 year^{-1}$, groundwater inflow was estimated 77 $mm^3 year^{-1}$, and the estimation for evaporation was 184 $mm^3 year^{-1}$. Inflows were larger than outflows during the 1969–1971 period but they were smaller during the 2014–2016 period. In another study, precipitation and surface water inflow to Burdur Lake were estimated as 55 and 59 $mm^3 year^{-1}$, while evaporation was estimated as 122 $mm^3 year^{-1}$ and water losses through infiltration as 40 $mm^3 year^{-1}$ (SYGM 2020). These studies shows that the water budget of Burdur Lake has changed significantly in recent decades.

The basin hosts several reservoirs, primarily constructed for irrigation purposes, and a natural lake, Yarışlı Lake, located on the southwestern side of Burdur Lake, but it is not hydrologically connected to Burdur Lake. Among the irrigation reservoirs, Karamanlı, Karataş, Bademli, and Karaçal (Figure 1, Table 1) have comparatively larger storage capacities (> 6 mm^3) and are situated along the Bozcay Stream, the main stream channel flowing from the south to the north. The construction of Karamanlı Dam (1969–1973) and the conversion of Karataş

Lake into a reservoir in 1974 significantly diverted water away from Burdur Lake. After water impoundment began at Karaçal Dam in 2009, almost no water reaches Burdur Lake from upstream, and even the planned irrigation demand of the dam cannot be met because upstream reservoirs had already been reduced (Ataol 2010).

3 | Methods

The methodological approach followed in this study is summarised in Figure 4. SWAT was used to simulate the hydrologic dynamics of the Burdur Lake Basin. The modelling was challenging, as the construction of reservoirs hydrologically

TABLE 1 | Large reservoirs at the Burdur Lake Basin (modified after Ataol (2010)).

Reservoir	Construction date	Surface area (ha)	Volume (mm^3)	Irrigation area (ha)
Karamanlı reservoir	1973	170	24.81	3248
Karataş reservoir	1974	490	65.3	5486
Bademli reservoir	1997	67.5	6.3	507
Karaçal reservoir	2009	540	76	5006

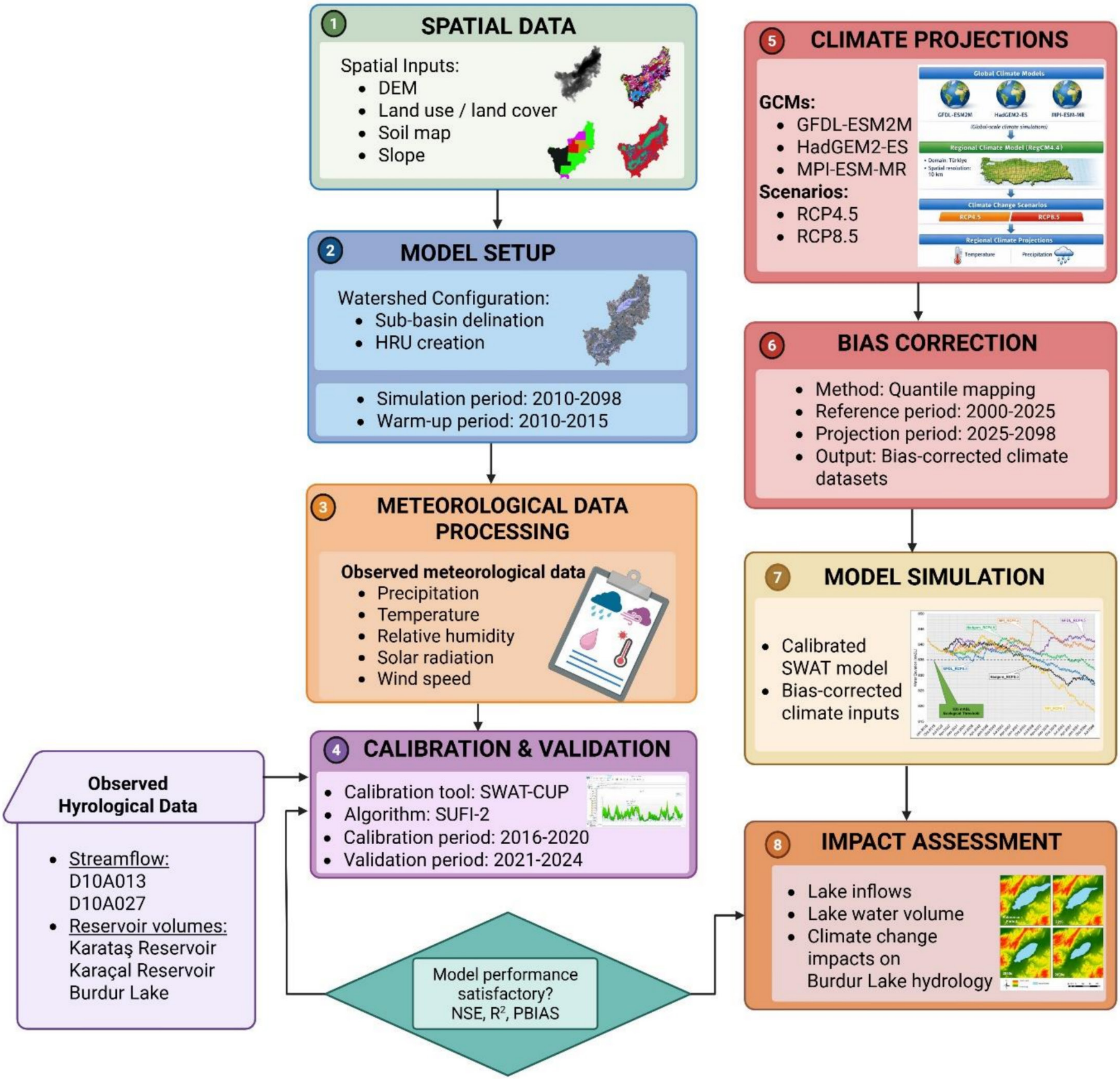

FIGURE 4 | Methodological approach. [Colour figure can be viewed at wileyonlinelibrary.com]

modified the basin. Therefore, we incorporated reservoirs and reservoir operations into the model. Climate projection data produced by the GFDL-ESM2M, HadGEM2-ES, and MPI-ESM-MR models for the RCP4.5 and RCP8.5 scenarios were used to evaluate the impacts of anticipated climatic changes.

Below, a brief introduction to the SWAT modelling approach was presented. We then explain the model development, calibration and validation processes. Finally, we discuss how the scenario analysis was conducted.

3.1 | Theoretical Background on SWAT

SWAT is a watershed-scale, semi-distributed, and physically-based model used in modelling hydrological processes and water quality (Arnold et al. 2012; Neitsch et al. 2005). SWAT has the potential to be used to assess the effects of long-term hydrological changes and land management practices, especially in agricultural watersheds. It has also been used extensively to evaluate hydrological impacts of climate change (Dadaser-Celik 2024).

SWAT processes a digital elevation model (DEM) to divide the watershed into subbasins and then combines subbasins with slope, soil and land use/cover layers to create hydrological response units (HRUs). HRUs are areas with homogeneous land use/cover, soil and slope characteristics. Water flows are estimated for each HRU and then aggregated to create a flow for each subbasin. The flow is routed to the streams and finally to the basin outlet.

In this study, SWAT was chosen as the primary modelling framework due to its robust and accurate ability to simulate future periods in complex, human-modified agricultural basins (Aibaidula et al. 2023b; Gassman, R. Reyes, et al. 2007; Jouma and Dadaser-Celik 2022; Malagó et al. 2017). SWAT provides a hierarchical approach by dividing the basin area into subbasins and then to HRUs. This allows the model to accurately simulate local hydrological responses to various topographic, soil and land use/cover characteristics to capture the spatial heterogeneity of the Burdur Lake Basin. In addition, SWAT's integrated modules for simulating hydrological balances in lakes and reservoirs enable direct quantification of basin inflows and outflows. It is a long-term model, which means that the impacts of climate change and anthropogenic interventions in the basin can be analysed together for long time periods. Finally, SWAT has been used extensively in basins with data limitations, even ungauged basins with success. As the data are limited in the Burdur Lake Basin, SWAT's ability to operate under data scarcity while maintaining sufficient performance has become critical for model selection.

3.2 | Data Used

The data used in this study and the data sources are presented in Table 2. The DEM data were obtained from the United States Geological Survey website. The land use/cover map for the Burdur Lake Basin was obtained from the CORINE 2018 database. The soil map, which includes information about soil types and properties, was acquired from the FAO-UNESCO's World Soil Map. Slope data was generated by the SWAT model based on DEM data. Meteorological data included precipitation, maximum and minimum temperatures, solar radiation, wind speed and relative humidity, obtained from local weather stations in the basin.

We obtained the daily climate projections data from the state meteorological service (MGM) of Türkiye. MGM produced downscaled precipitation and air temperature data for the 2016–2098 period by using data from three global circulation models (GCMs), GFDL-ESM2M, HadGEM2-ES, and MPI-ESM-MR, well representing the climate dynamics of Türkiye based on two RCPs, RCP4.5 and RCP8.5 (Akcakaya et al. 2015). The RCP4.5 scenario assumes that greenhouse gas concentration will peak around 2040, then decline from the mid-century, while the RCP8.5 scenario assumes that greenhouse gas concentration continues to increase throughout the 21st century.

3.3 | Model Setup and Calibration/Validation

The model for Burdur Lake Basin was implemented using SWAT 2016 (Revision 664) within the ArcSWAT interface. It consisted

TABLE 2 | Data source and spatial/temporal resolution for input data.

Data	Spatial/temporal resolution	Data source
Digital elevation model	30 × 30 m	United states geological survey
Land use/cover	30 × 30 m	CORINE 2018
Soil	1/5.000.000	FAO-UNESCO world soil map
Climate	Daily	State meteorology service
Streamflow	Monthly	State hydraulic works
Lake/reservoir volumes	Monthly	State hydraulic works
Precipitation/temperature projections (GFDL-ESM2M)	2.5° × 2.0°	Geophysical fluid dynamics laboratory
Precipitation/temperature projections (HadGEM2-ES)	1.875° × 1.250°	Met Office Hadley Centre
Precipitation/temperature projections (MPI-ESM-MR)	1.865° × 1.875°	Max Planck Institute Meteorology

of 38 subbasins. HRUs were created using a 5% land use, soil and slope threshold, resulting in 687 HRUs. Evapotranspiration was estimated using the Penman–Monteith method, while surface runoff was simulated using the SCS curve number approach. The model was run for the 2010–2098 period. This represents the most extended continuous period with consistent and reliable hydrological observations under the current regulated conditions of the basin. We assumed that no significant changes occurred in land use/cover both in the simulation and projection periods, as major basin interventions were done prior to 2010. The first 6-year period was used as the warm-up period. This warm-up period was applied to allow stabilisation of the main hydrological state variables, especially soil moisture, groundwater storage and reservoir dynamics, under the regulated basin conditions. Using a 6-year warm-up reduces the influence of initial conditions on the simulation results and ensures that the modelled hydrological processes are internally consistent (Arnold et al. 2012).

The SUFI2 algorithm available in the SWAT-CUP software (Abbaspour 2015) was used for model calibration and validation. Although the basin contains multiple streamflow gauging stations, only a few provide long-term and continuous data. The locations of these stations, namely D10A013 and D10A027, were shown in Figure 1. As reservoirs affect the basin hydrology considerably, we also used data on reservoir volumes at Karataş Reservoir and Karaçal Reservoir and water volumes in Burdur Lake during model calibration/validation (Figure 1). Data from the 2016–2020 period were used for calibration, and those from the 2021–2023 period were used for validation, as much as the available data allowed. For Burdur Lake, water level data continued until March 2023. For reservoirs, volume data were available until August 2022. However, for D10A013, data were only available for a very short period (2016–2018); therefore, these data were used only for calibration.

The parameters used in the calibration process were determined based on a comprehensive review of previous SWAT applications in agricultural and data-limited basins, focusing on parameters known to strongly influence surface runoff, baseflow, soil moisture and evapotranspiration processes (Table 3). The parameters listed in Table 3 represent key physical and empirical factors used during model calibration to improve the simulation of hydrological and reservoir processes. CN2 controls surface runoff. ALPHA_BF, GW_DELAY, GWQMN, REVAPMN, GW_REVAP, RCHRG_DP and GWHT are parameters related to groundwater flows. EPCO and ESCO are related to evapotranspiration. SOL_AWC, SOL_K, SOL_BD influence water movement and storage within the soil profile, affecting infiltration and surface runoff. SLSUBBSN, OV_N, CH_N2 and CH_K2 are related to basin and channel characteristics. Snow-related parameters, SFTMP, SMTMP, SMFMX, and SMFMN, and TIMP, control snow accumulation and melt dynamics, which can be important for cold or mountainous basins. The reservoir parameter, EVRSV governs water loss and seepage processes in reservoirs. These parameters are calibrated to ensure a realistic simulation of water balance components such as runoff, infiltration, evapotranspiration and storage. All selected parameters were simultaneously included in the calibration to avoid excluding potentially influential processes.

Various statistical metrics are available in the literature to evaluate the developed model's performance (Bennett et al. 2013). In this study, we used the Nash-Sutcliffe efficiency coefficient (NSE), coefficient of determination (R^2) and percent bias statistic (PBIAS) for performance evaluation. NSE ranges from $-\infty$ to 1 and assesses how good the predictions of the hydrological models are. The values closer to 1 indicate better model performance. The R^2 statistic, varying from 0 to 1, is used to quantify the agreement between observed values and model predictions. Values closer to 1 indicate near-perfect alignment. In contrast, values approaching 0 reflect poor predictive accuracy. PBIAS measures the average tendency of predictions to deviate from observed data. A PBIAS value near 0 indicates minimal systematic error, while negative values suggest overestimation and positive values indicate underestimation. Moriasi et al. (2015) state that the SWAT model performance can be classified as 'satisfactory' when $0.5 < \text{NSE} < 0.7$ and $0.6 < R^2 < 0.75$ for flow predictions at the daily, monthly and annual scales. Model performance was proposed to be 'good' when $0.7 < \text{NSE} < 0.80$ and $0.75 < R^2 < 0.85$ and 'very good' when $\text{NSE} > 0.80$ and $R^2 > 0.85$. The PBIAS values within ±10% are considered 'very good' for streamflow simulations, ±10%–15% are good, ±15%–25% are satisfactory, and values greater than ±25% indicate unsatisfactory model performance.

3.4 | Scenario Analysis

In this study, we used regional climate projections of precipitation, maximum temperature and minimum temperature for the RCP4.5 and RCP8.5 scenarios from the CMIP5 framework based on three GCMs: GFDL-ESM2M, HadGEM2-ES and MPI-ESM-MR (Table 1). The GCMs were selected as they were evaluated as the best models that represent local conditions of Türkiye (Akcakaya et al. 2015). GCM outputs were dynamically downscaled to a 20 km spatial resolution for Türkiye using the RegCM4.4 regional climate model. They have been extensively validated for the complex topography of the region and are widely accepted as a reliable standard for hydrological impact assessments in Türkiye. The continued use of CMIP5 datasets facilitates comparison with previous studies and testing the consistency of results.

To further increase the reliability of the simulations, we applied bias correction with the quantile mapping method (Gudmundsson et al. 2012) for the climate data prediction period (2025–2098) using the observed data of Burdur meteorological station between 1980 and 2000 (Figure 2). 1980–2000 period represents the historical reference period over which the climate model outputs and observations coincide.

The bias-corrected data were run with the calibrated model to simulate future hydrological conditions including the inflows to Burdur Lake and its volumes and water levels. In future projections, land use/cover and anthropogenic activities were assumed to remain constant throughout the simulation period. No additional land-use change, new hydraulic infrastructure, or modifications in irrigation practices were incorporated into the scenario analysis. This assumption was considered reasonable because major hydrological constructions in the basin have already been completed, and the extent and distribution of agricultural areas are currently regulated and have not shown substantial expansion in recent years. Therefore, the future simulations represent climate change impacts under the continuation of existing human interventions.

TABLE 3 | Parameters and parameter ranges used for model calibration.

Parameter name	Parameter types	Description	Parameter range	
			Minimum	Maximum
Surface runoff generation	R_CN2	Controls the potential of rainfall to become surface runoff.	−0.2	0.2
Groundwater/baseflow processes	V_ALPHA_BF.gw	Baseflow recession rate from a shallow aquifer.	0.0	1
	V_GW_DELAY.gw	Lag time for water to reach shallow aquifer.	10	450
	V_GWQMN.gw	Minimum storage for baseflow to occur.	500	5000
	V_REVAPMN.gw	Fraction of deep percolation to deep aquifer.	100	1000
	V_GW_REVAP.gw	Rate of water return from shallow aquifer to soil/roots.	0.02	0.2
	V_RCHRG_DP.gw	Direct percolation to groundwater.	0	0.2
	V_GWHT.gw	Initial water depth in shallow aquifer.	0	10
HRU/surface parameters	V_EPCO.hru	Plant evapotranspiration factor.	0	1
	V_ESCO.hru	Soil evaporation compensation factor.	0	1
Subbasin/runoff parameters	R_SLSUBBSN.sub	Average subbasin slope length.	−0.2	0.2
	R_OV_N.sub	Manning's '*n*' for overland flow.	−0.2	0.2
Channel routing parameters	V_CH_N2.rte	Channel roughness (Manning's *n*).	0	0.3
	V_CH_K2.rte	Hydraulic conductivity of channel bed.	5	130
Soil processes	R_SOL_AWC.sol	Soil available water capacity.	−0.2	0.4
	R_SOL_K.sol	Soil saturated hydraulic conductivity.	−0.8	0.5
	R_SOL_BD.sol	Soil bulk density.	−0.5	0.6
Temperature-related snow process parameters	V_SFTMP.bsn	Snowfall temperature threshold.	−5.0	5.0
	V_SMTMP.bsn	Base temperature for snowmelt.	−5.0	5.0
	V_SMFMX.bsn	Maximum snow melt factor.	0	5.0
	V_SMFMN.bsn	Minimum snow melt factor.	0	5.0
	V_TIMP.bsn	Snow pack temperature lag factor.	0	1
Reservoir parameters	V_EVRSV.res	Is a coefficient that controls the evaporation loss of the reservoir	0.8	1.2

The trends in projected climate and hydrologic data were evaluated using linear regression, where the slope of the fitted line represents the magnitude and direction of the trend. The statistical significance of the trend was evaluated using a *t*-test on the regression slope.

4 | Results and Discussion

4.1 | The Performance of the SWAT Model

The most critical step in applying the SWAT model is the evaluation of the success of the calibration process. Calibration is crucial to verify the accuracy of the mathematical approach established for the basin and to ensure that the model correctly reflects the hydrological characteristics of the system.

Although all parameters listed in Table 1 were included in the calibration and validation process, a global sensitivity analysis was conducted using the SUFI-2 algorithm in the SWAT-CUP to assess the relative influence of individual parameters on model performance. In this approach, parameter sensitivity is evaluated based on the magnitude of the *t*-statistic and the associated *p* value, which indicate the strength and reliability of the relationship between the parameter and the objective function (Abbaspour 2015). The results showed that the models exhibited the highest sensitivity ($p < 0.01$) to CN2, SOL_BD, SOL_K, GW_DELAY and REVAPMN. This result is consistent with the

TABLE 4 | Statistical metrics for the calibration and validation periods.

Variable/performance metric	Calibration			Validation		
	R^2	NSE	PBIAS	R^2	NSE	PBIAS
Streamflow at D10A040	0.53	0.47	10.7	0.7	0.66	12.7
Streamflow at D10A027	0.18	0.16	−3.7			
Volume at Karataş reservoir	0.88	0.88	4.5	0.59	−58.42	15.9
Volume at Karaçal reservoir	0.74	0.68	−12.6	0	−9.22	−24.5
Volume at Burdur Lake	0.95	0.95	−0.1	0.9	0.71	0.3

dominant hydrological characteristics of the basin, where surface runoff, soil characteristics and groundwater processes control streamflow and lake inflows.

The performance metrics for all simulated variables during calibration and validation are summarised in Table 4. A comparison of the observed and simulated variables is presented in Figure 5. The SWAT model generally performed well during calibration and validation periods. The simulated and observed values show good agreement, particularly in the simulation of Burdur Lake's water volumes. For Burdur Lake volumes, R^2 values were 0.95 and 0.90 and NSE values were 0.95 and 0.71 during the calibration and validation periods, respectively. The model accurately captured the temporal dynamics of lake volumes, including the downward trend. According to Moriasi et al. (2015), a hydrological model can be considered satisfactory when NSE and R^2 values exceed 0.5 and 0.6, and PBIAS values fall within ±25% for streamflow simulations. Based on these criteria, the performance metrics indicate that the model provides acceptable simulations for most locations.

However, there were limitations at some locations. For example, during calibration, streamflow at station D10A027 showed relatively low R^2 and NSE values (0.18 and 0.16, respectively), suggesting that the model did not fully capture flow variability at this location. D10A027 is located at the most downstream, accumulates input and parameter uncertainties, and shows the influence of water management activities (Abbaspour et al. 2015; Bosch 2008). Similarly, during validation, the simulated volume at Karaçal Reservoir showed very low R^2 (0) and negative NSE (−9.22). This indicates a significant difference between the simulated and observed data. Predictions of reservoir volumes could be challenging as inter-annual variations in management practices often occur in response to climatic variability and changes in land use/cover upstream (Jouma and Dadaser-Celik 2022; Özdoğan-Sarıkoç and Dadaser-Celik 2024). Reliable data on water withdrawals are often unavailable. In this study, we obtained the average withdrawal amounts for the reservoirs and used them to represent reservoir withdrawals. Despite this, the PBIAS values for most variables remained within acceptable ranges, indicating that the model was generally successful in predicting the overall water balance.

The performance of the SWAT model in the Burdur Lake Basin can be attributed to anthropogenic influences and uncertainties in input data (Abbaspour et al. 2015; Aibaidula et al. 2023b; Yang et al. 2008). Such challenges are even more pronounced in semi-arid regions, where the heterogeneity of hydrological processes and the limited availability of observed data make it inherently difficult to represent basin dynamics accurately (Rocha et al. 2023). In the past, human activities have significantly modified the Burdur Lake Basin's natural hydrological processes. The construction of reservoirs on the main stream channels, water diversions to the agricultural areas and extensive groundwater abstraction for irrigation have changed surface water and groundwater flow characteristics. Land use/cover modifications also affected the evapotranspiration, runoff and recharge patterns. Under these circumstances, it was more challenging for the model to accurately simulate observed streamflow and lake/reservoir volumes (Bosch 2008; Jouma and Dadaser-Celik 2022; Özdoğan-Sarıkoç and Dadaser-Celik 2024). Another challenge in the Burdur Lake Basin was the unavailability of reliable data on reservoir operation principles (Zhang et al. 2013). In this study, the SWAT reservoir module was used using average water release rates, as actual operation rules were not available.

In addition to anthropogenic factors, the input datasets' spatial and temporal quality possibly affected the model's performance. The predictive accuracy of SWAT models depends highly on input data quality, including spatial resolution and temporal completeness of weather and land use/cover data (Gassman, Reyes, et al. 2007). In this study, we obtained the soil data from the FAO/UNESCO World Soil Map, which has a relatively lower spatial resolution. The dataset might not reflect spatial changes in soil characteristics in the Burdur Lake Basin. Similarly, the land use/cover data, obtained from CORINE 2018, may not capture recent changes in land use/cover. Moreover, although the parameters assigned during model calibration considered changes in physical conditions, they were lumped based on HRUs (Me et al. 2015). As a result, the combined effects of human-induced alterations and input data limitations likely explain the moderate predictive capability of the SWAT model for the Burdur Lake Basin. Despite some limitations at specific locations, the SWAT model represented hydrological processes in the Burdur Lake Basin and can be reliably used for further analyses, including water balance assessment and scenario simulations (Harmel et al. 2014).

4.2 | Precipitation and Temperature Projections

The calibrated model was run with bias-corrected climate projections covering the 2025–2098 period, obtained from GFDL-ESM2M, HadGEM2-ES and MPI-ESM-MR models for the RCP4.5 and RCP8.5 scenarios. Projected precipitation and temperature changes were evaluated by comparing their values

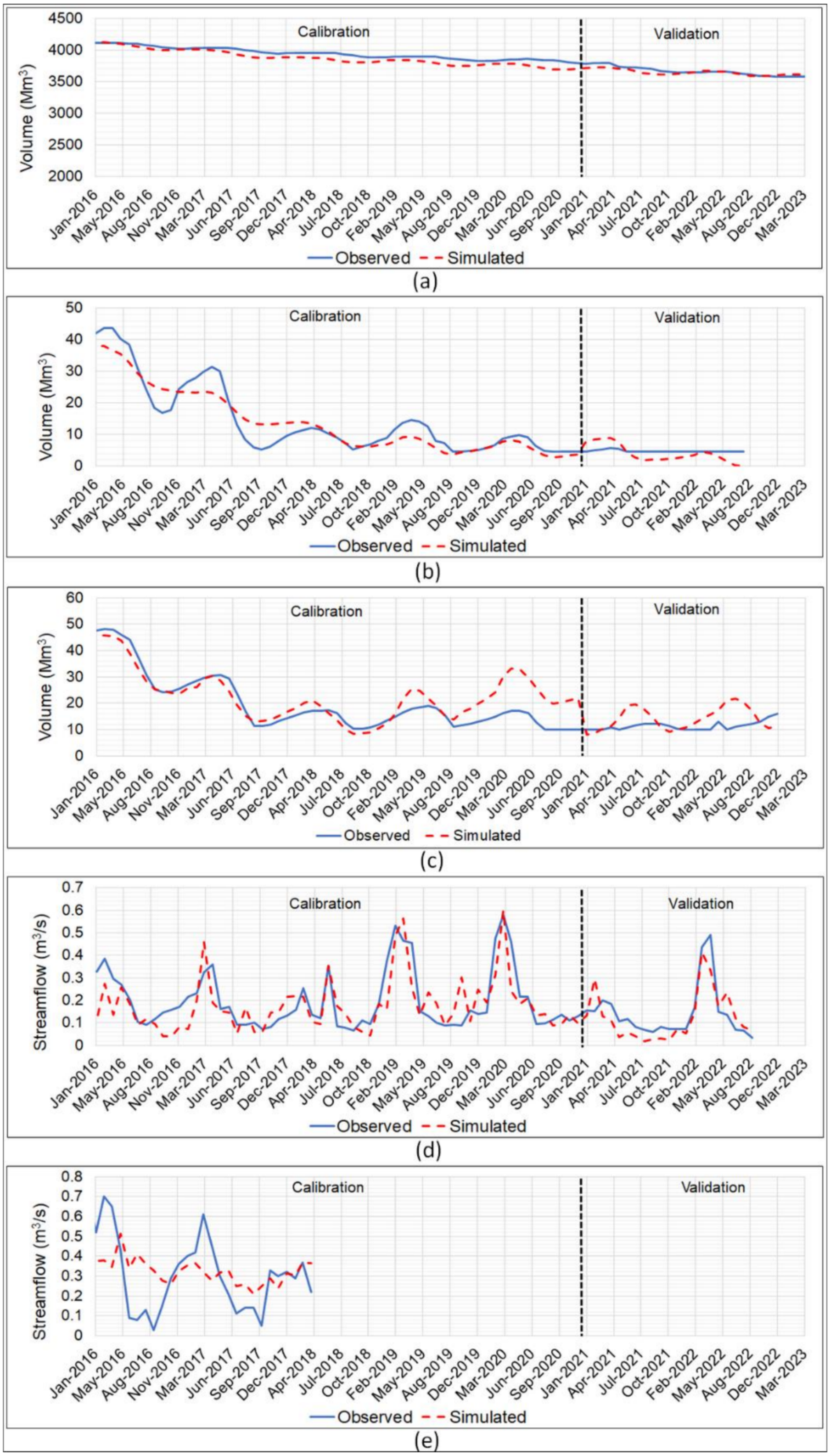

FIGURE 5 | Simulated and observed water volumes at Burdur Lake Basin during calibration and validation periods (a) Burdur Lake, (b) Karataş reservoir, (c) Karaçal reservoir, (d) Gauging station D10A040, (e) Gauging station D10A027. [Colour figure can be viewed at wileyonlinelibrary.com]

with those from the reference period (1980–2000) to characterise the expected future climatological conditions (Table 5, Figure 6).

The observed mean annual precipitation for 1980–2000 was 414 mm. Under the RCP4.5 scenarios, projected mean annual precipitation ranged between 372 and 393 mm with three

TABLE 5 | Statistical characteristics of the climatic and hydrological variables for the reference (1980–2000) and projection (2025–2098) period.

Variable	Statistics	Reference period	GFDL-ESM2M RCP4.5	GFDL-ESM2M RCP8.5	HadGEM2-ES RCP4.5	HadGEM2-ES RCP8.5	MPI-ESM-MR RCP4.5	MPI-ESM-MR RCP8.5
Annual precipitation (mm)	Mean	414	393	350	372	358	393	332
	Max	571	606	555	553	571	710	660
	Min	281	168	209	199	199	229	132
Annual average Maximum temperature (°C)	Mean	19.2	20.8	21.8	22.1	23.2	20.7	21.9
	Max	20.4	22.9	24.5	23.9	25.6	22.8	25.0
	Min	18.0	18.9	19.3	20.4	20.7	19.2	19.4
Annual average Minimum temperature (°C)	Mean	7.3	8.8	9.7	10.0	11.0	8.8	9.7
	Max	8.2	10.3	11.7	11.4	13.5	10.3	12.4
	Min	5.6	7.1	7.8	8.5	8.5	7.4	7.0
Inflows to Burdur Lake (m^3/s)[a]	Mean	2.48	3.97	3.75	3.53	4.18	3.26	4.79
	Max	4.80	16.68	17.30	20.46	38.28	20.45	237.60
	Min	0.82	0.60	0.50	0.38	0.52	0.48	0.35
Burdur Lake volumes (Mm^3)	Mean	5676	3605	3327	3873	3273	3941	3146
	Max	4695	2938	2418	3461	2436	3421	1700
	Min	6418	4166	4140	4268	3724	5036	4279
Burdur Lake levels (mAS)	Mean	851.4	837.7	835.1	839.9	834.8	840.4	833.2
	Max	845.9	831.8	826.6	836.6	826.8	836.2	818.2
	Min	855.3	842.2	842.0	843.0	838.8	848.0	843.0

[a]2016–2020 period.

models, while under the RCP8.5 scenarios, they ranged from 332 to 358 mm. Based on these values, a reduction in precipitation is likely at a magnitude of 5%–10% under RCP4.5 and 14%–20% under RCP8.5 compared to the reference period. The observed annual precipitation varied between 281 mm and 571 mm during the reference period. Projected maximum precipitation values were over the historical maximum in most cases, reaching 710 mm (MPI-ESM-MR RCP4.5) and 660 mm (MPI-ESM-MR RCP8.5). These numbers indicate an increase of up to 24% relative to the observed maximum. In contrast, projected minimums decreased considerably, with values as low as 132 mm (MPI-ESM-MR RCP8.5), indicating a 53% reduction from the historical minimum (281 mm).

When the trends in projected precipitation for the 2025–2098 period were evaluated (Table 6), downward trends were observed in all models except for the GFDL-ESM2M under the RCP4.5 scenario, which showed a slight upward trend. However, no trends were statistically significant at the 0.001 level. Only the trends detected on the projections of HadGEM2-ES and MPI-ESM-MR models under the RCP8.5 scenario were statistically significant at the 0.05 level. The trends projected with different models were consistent with the precipitation changes observed in the region in recent decades. Analysis of trends in observed data from 1975 to 2024 shows that precipitation showed a downward trend in the basin, but it was not statistically significant. Precipitation projections suggest that there will be a general decline in mean annual precipitation and precipitation will show greater inter-annual variability. This pattern of change is generally consistent with many previous studies conducted in the Mediterranean Basin, which projected decrease in mean precipitation (Lionello and Scarascia 2018; Zittis et al. 2019). However, it also supports the findings of Zittis et al. (2019), who mentions that the trends in precipitation is projected to be loss significant compared to those in temperature.

The observed mean annual maximum temperature for 1980–2000 was 19.2°C. Future projections consistently indicate higher values in air temperatures. They ranged from 20.7°C to 23.2°C under the RCP4.5 scenario and 21.8°C–23.2°C under the RCP8.5 scenario, which shows that maximum temperatures will be 1.5°C–4.0°C higher compared to the reference period. The projected annual maximum temperatures reached 25.6°C (HadGEM2-ES RCP8.5), about 5.2°C higher than the maximum temperature in the reference period (20.4°C). The projected minimum temperatures (18.9°C–20.7°C) were also higher than the mean maximum temperatures, which addresses a consistent upward tendency in maximum temperatures. Similarly, the mean annual minimum temperature during the reference

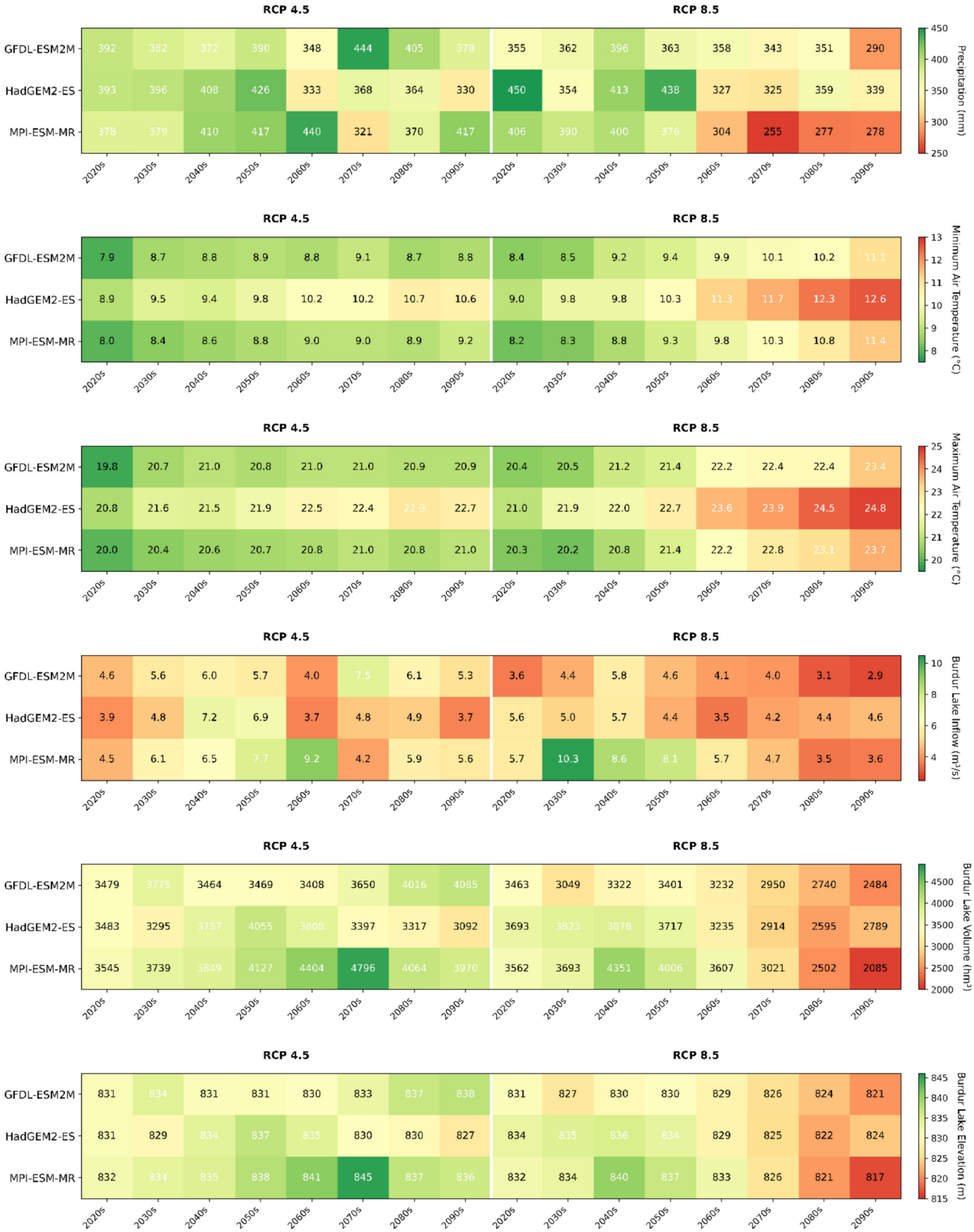

FIGURE 6 | Decadal averages for climatic and hydrological variables during the projection (2025–2098) period. [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 6 | Statistical characteristics of the trends in climatic and hydrological variables.

Variable	Unit	GFDL-ESM2M RCP4.5	GFDL-ESM2M RCP8.5	HadGEM2-ES RCP4.5	HadGEM2-ES RCP8.5	MPI-ESM-MR RCP4.5	MPI-ESM-MR RCP8.5
Annual precipitation	mm/year	0.04	−0.67	−0.76	−1.08[b]	−0.12	−2.40[a]
Annual average Maximum temperature	°C/year	0.01[a]	0.04[a]	0.03[a]	0.06[a]	0.01[a]	0.05[a]
Annual average Minimum temperature	°C/year	0.01[a]	0.03[a]	0.03[a]	0.05[a]	0.02[a]	0.05[a]
Inflows to Burdur Lake	m^3/s/year	0.003	−0.015	−0.018[b]	−0.024[b]	−0.005	−0.052[a]
Burdur Lake volumes	hm^3/year	5.25[a]	−12.49[a]	−5.18[a]	−18.40[a]	8.69[a]	−22.83[a]
Burdur Lake levels	m/year	−0.08[a]	−0.12[a]	−0.06[a]	−0.22[a]	0.10[a]	−0.29[a]

[a]Significant at the 0.001 level.
[b]Significant at the 0.05 level.

period was 7.3°C. It was projected to increase to 8.8°C–11.0°C, about 21%–51% higher than the mean values during the reference period. The highest minimum temperature was 13.5°C, simulated by the HadGEM2-ES model under the RCP8.5 scenario, which was over 5°C higher than the minimum temperature (8.2°C) in the reference period. This reflects a significant warming trend, particularly under RCP8.5 scenarios. The temperature increases expected in the Burdur Lake Basin are consistent with the expectations presented in the latest IPCC report (IPCC 2021). At the local level, Bucak et al. (2017), Gorguner et al. (2019) and Aibaidula et al. (2023a) also projected increases in temperatures by using data from GCMs downscaled to local conditions for Beysehir Lake Basin, Gediz Basin, and Altinapa Reservoir Basin, all locating to the central and southwestern Türkiye respectively.

When the annual maximum temperature projections trends between 2025 and 2098 were evaluated (Table 6), all three models under the RCP4.5 and RCP8.5 scenarios indicated upward trends. These trends were statistically significant ($p < 0.001$) in all cases. The rate of increase varied among the models and scenarios, but they were consistently higher under the RCP8.5 scenarios. The highest trend was detected in the data series produced by the HadGEM2-ES model under the RCP8.5 scenario, and it was 0.0552°C year^{-1}. It was followed by the MPI-ESM-MR (at a rate of 0.0515°C year^{-1}) and GFDL-ESM2M (at a rate of 0.0398°C year^{-1}) models again with the RCP8.5 scenarios. Under the RCP4.5 scenarios, the slopes were much lower with values in the range of 0.0121°C year^{-1} and 0.0292°C year^{-1}. These results consistently show an increasing trend in annual maximum temperature throughout the period, with more pronounced warming expected under the RCP8.5 scenario, consistent with previous literature (Lionello and Scarascia 2018; Zittis et al. 2019).

When the trends in annual minimum temperature projections for 2025–2098 were examined, all three models under both RCP4.5 and RCP8.5 scenarios showed statistically significant upward trends ($p < 0.001$). The magnitude of the trend was more substantial under the RCP8.5 scenarios compared to the RCP4.5 scenarios with all models. The highest rate of change was detected with the HadGEM2-ES model (0.0519°C year^{-1}) under the RCP8.5 scenario. The following highest trends were in the data produced by MPI-ESM-MR (0.0465°C year^{-1}) and GFDL-ESM2M (0.0348°C year^{-1}). Under RCP4.5, the slopes in the range of 0.0104°C year^{-1}(GFDL-ESM2M) and 0.0257°C year^{-1} (HadGEM2-ES). These results refer to a continuous rise in annual minimum temperature during the 2025–2098 period. The RCP8.5 scenarios show the strongest warming. The projections for air temperatures were consistent with historical trends detected in the region (Figure 3), where we detected that average air temperature decreased at 0.042°C year^{-1} from 1975 to 2024.

Overall, the decrease in mean and minimum precipitation and increased maximum values reflect a potential intensification of hydrological extremes in the study area (Tabari 2020). This could result in more frequent droughts and heavy rainfall events during the 2025–2098 period (Donat et al. 2016). Recent studies have shown that droughts in the Mediterranean have become more frequent, prolonged and severe, especially in southern and eastern areas. At the same time, intense rainfall has increased in both frequency and intensity, particularly in the western and northern Mediterranean (Granata et al. 2025). Research using CMIP6 models suggests that meteorological, agricultural, and hydrological droughts will increase in duration, timing and intensity across the Mediterranean (Essa et al. 2023). The increase in both maximum and minimum temperatures also suggests that hot extremes will become more frequent and cold extremes may become less frequent. Such warming will likely intensify evapotranspiration, accelerate soil moisture loss, and increase water stress, particularly when combined with declining precipitation (Donat et al. 2016; Granata et al. 2025). The decreases in precipitation and increases in air temperatures will be more substantial after the 2060s, particularly based on RCP8.5 scenarios (Figure 6). These results are consistent with many other studies conducted for this region, which used data from Version 6 of Coupled Model Intercomparison Project models (CMIP6) and found a similar result (Bağçaci et al. 2021; Essa et al. 2023; Yavaşlı and Erlat 2023).

4.3 | Projected Changes in Inflows to Burdur Lake and Burdur Lake Water Volumes/Levels

Climatic scenarios were run with the SWAT model, and inflows to Burdur Lake and Burdur Lake water volumes and levels were simulated for the 2025–2098 period (Figure 7). The projections of water volume and levels were compared to observations of those variables from the 1980–2000 period. The projected inflows to Burdur Lake were evaluated based on SWAT model outputs for the reference period 2016–2020 (Table 5, Figure 6).

The mean inflow for the 2016–2020 period was estimated to be 2.48 m^3/s with the SWAT model. Unfortunately, we do not have observed data for inflows during the historical period. However, the inflow to the lake was estimated as 5.89 $m^3 s^{-1}$ (186 $mm^3 year^{-1}$) for the 1969–1971 period in a previous study (Kılıç Germeç 2023), which means that the mean inflow during the reference period (1980–2020) was much higher than 2.48 $m^3 s^{-1}$. Still, the mean for the 2016–2020 period provides a reasonable estimate of low inflow conditions in recent years. Projected mean inflows vary by model and scenario, ranging from 3.26 $m^3 s^{-1}$ (MPI-ESM-MR, RCP4.5) to 4.79 $m^3 s^{-1}$ (MPI-ESM-MR, RCP8.5), higher than the 2016–2020 mean but lower than the historical mean of 5.89 $m^3 s^{-1}$. Minimum flows are projected to be very low in all projections (between 0.35 and 0.82 $m^3 s^{-1}$), indicating an increased risk of continuing low-flow conditions. At the same time, projected maximum inflows rise markedly in every model, reaching up to 237.6 $m^3 s^{-1}$ (MPI-ESM-MR, RCP8.5), which points to a much higher likelihood of short-duration, high-magnitude runoff events (Donat et al. 2016). Trend analysis (Table 6) shows that only the trends detected with the MPI-ESM-MR models under the RCP8.5 scenarios were statistically significant at the 0.001 level. Both RCP4.5 and RCP8.5 scenarios produced by the HadGEM2-ES model had negative trends, significant at the 0.05 level. These results suggest that inflows to Burdur Lake will become more variable, having lower base flows and more intense peak flows. These would have important implications for water availability at the Burdur Lake Basin, as the vulnerability of the lakes to climate change is more severe under when base flows are lower (Jiménez-Bonilla et al. 2025).

The models projected a decrease in Burdur Lake's volume with all models under RCP4.5 and RCP8.5 scenarios compared to the reference period (1980–2000). The mean lake volume was around 5676 mm^3 during the reference period. GFDL-ESM2M model projects small fluctuations with no abrupt decline in the long-term under the RCP4.5 scenario. Under the RCP8.5 scenario, water volumes drop especially after 2060, reaching

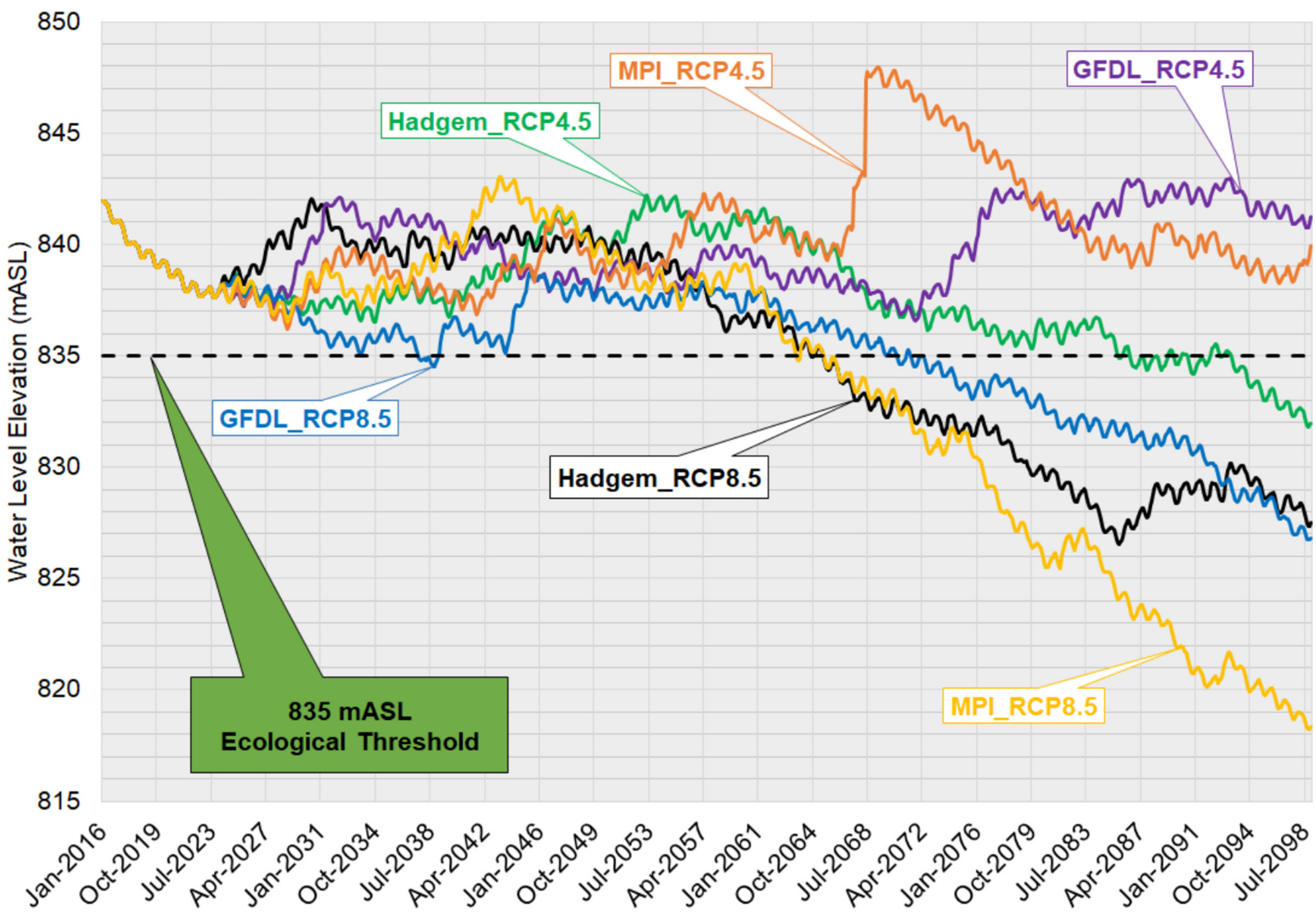

FIGURE 7 | Water level projections for Burdur Lake based on the GFDL-ESM2M, HadGEM2-ES and MPI-ESM-MR models for the RCP4.5 and RCP8.5 scenarios. [Colour figure can be viewed at wileyonlinelibrary.com]

2485 mm^3 by the 2090s. The HadGEM2-ES model shows a steady decline under both scenarios. Under the RCP4.5 scenario, the decline was particularly apparent after the 2060s. Under the RCP8.5 scenario, we see a sharp decline after 2070, and water volumes are 2789 mm^3 by the 2090s. The MPI-ESM-MR model projected relatively stable water levels until 2098 compared to the other two models under the RCP4.5 scenario. Water volumes were around 3970 mm^3 in the 2090s. However, under the RCP4.5 scenario, this model simulated the highest decline among all models, and water levels by the end of the century were 2085 mm^3 by the 2090s. All models and scenarios show a general downward trend in projected water volume from 2016 to 2098. Around 2040–2050, all models show a turning point, where projections with most models change from mild to sharper declines. By 2080, RCP8.5 scenarios simulate lower water levels, pointing to the risks to water availability toward the end of the century. Trend analysis (Table 6) of the water volume predictions shows that significant downward trends ($p < 0.001$) were present in projections produced by all models and all scenarios. The rate of decrease was in the range of 5.18–8.69 $mm^3 year^{-1}$ with the RCP4.5 scenarios and in the range of 12.49–22.83 $mm^3 year^{-1}$ with the RCP8.5 scenarios. If we want to compare these results with observations, we see that the observed water volumes declined at a much larger rate (63 $mm^3 year^{-1}$) ($p < 0.001$) from 1975 to 2024. These results suggest that although the projected decrease rates are expected to slow down compared to the historical trend, the downward trends will continue in the future. The reductions in water volumes can be explained by the combined effects of lower precipitation and higher temperatures, which reduced runoff into the lake (Arnell 1999). Nevertheless, the steady decline across all climate models suggests that Burdur Lake will continue to experience hydrological problems, particularly under more severe emission pathways (RCP8.5). Similar patterns have been reported for other lakes affected by anthropogenic pressures, where compound effects act together to increase system vulnerability (Shirmohammadi et al. 2023; Woolway et al. 2025).

Changes in lake level projections follow the same trends as simulated lake volumes. Lake levels show a continuous decline under future climate scenarios. The mean water level was 851.4 mASL. It is projected to fall to 833.2 and 840.4 mASL values across the different models and scenarios during the reference period. Under the RCP 4.5 scenario, simulated lake levels remain relatively stable, with values between approximately 829 mASL (HadGEM2-ES, 2080s) and 845 mASL (MPI-ESM-MR, 2060s). In contrast, the RCP 8.5 scenario indicates a significant and continuous decline in lake levels, falling below 820 mASL. By the end of the century in some simulations (e.g., MPI-ESM-MR, 2090s). The rate of decrease in water levels was projected to be in the range of 0.06 mASL/year (HadGEM2-ES) and 0.10 mASL $year^{-1}$ (MPI-ESM-MR) under the RCP4.5 scenario and 0.12 mASL $year^{-1}$ (GFDL-ESM2M) and 0.29 mASL $year^{-1}$ (MPI-ESM-MR) under the RCP8.5 scenario. For comparison, observed water levels decreased at a rate of 0.38 mASL $year^{-1}$ ($p < 0.001$) from 1975 to 2024, much higher than the projected trends. However, the projections show that the decrease in water levels will persist in the future.

The decreasing water levels will also lead to significant reductions in surface area (Figure 8). Under the most extreme scenarios, the lake's surface area could shrink to as little as 82.4 km^2 (corresponding to an elevation of 816.6 m ASL). Considering that the average surface area was 187 km^2 during the reference period (1980–2000) and the largest recorded extent was 208 km^2 in January 1975, this represents a loss of more than half of the lake's surface area.

The ecological threshold level of Burdur Lake, which represents the minimum water level required to sustain aquatic habitat, was determined to be 835 mASL (TOB 2018). The simulated minimum levels suggest that Burdur Lake could face critically low stages during prolonged dry periods (Figure 7). These results point to a continued shrinkage of the lake, consistent with its observed long-term desiccation trend. The reductions in lake levels would have implications for the lake ecosystem's hydrology, water quality and ecological characteristics (Jeppesen et al. 2015; Williams 1999).

4.4 | Projected Water Budget

Figure 9 shows the water budget projected by the GFDL-ESM2M, HadGEM2-ES and MPI-ESM-MR models for the RCP4.5 and RCP8.5 scenarios. Predicted inflow and outflow volumes showed significant variability across models and emission scenarios.

During the reference period (2016–2024), precipitation input to the lake was between 41.4 and 65.4 $mm^3 year^{-1}$, averaging 51.6 $mm^3 year^{-1}$. Evaporation was between 176.9 and 241.1 $mm^3 year^{-1}$ with an average of 201.9 $mm^3 year^{-1}$. Average streamflow input to the lake was 89.37 $mm^3 year^{-1}$ (in the range of 52.19–126.97 $mm^3 year^{-1}$). The inflow was lower than the outflow; therefore, the lake has a negative water balance, which explains the downward trends in water volumes.

With the GFDL-ESM scenario, average precipitation input was 54.1 $mm^3 year^{-1}$ (in the range of 24.7–87.7 $mm^3 year^{-1}$) and average inflow due to streamflow was 131.8 $mm^3 year^{-1}$ (in the range of 43.2–327.2 $mm^3 year^{-1}$) during the projection period under the RCP4.5 scenario while average evaporation was 179.3 $mm^3 year^{-1}$ (in the range of 148.9–217.0 $mm^3 year^{-1}$). Under the RCP8.5 scenario, average precipitation, average streamflow inflow and average evaporation were 41.6 $mm^3 year^{-1}$ (in the range of 20.3–69.5 $mm^3 year^{-1}$), 102.8 (in the range of 35.3–97.7) and 160.6 (in the range of 128.5–181.8 $mm^3 year^{-1}$), respectively. These results suggest a slight (about 5%) increase in precipitation and streamflow and a decrease in evaporation compared to the reference period for the RCP4.5 scenario. This result suggests potentially higher water availability and a slight improvement in hydrological conditions in the Burdur Lake system during the projection period. In fact, the water level simulations show the highest water levels by 2098 with the GFDL model under the RCP4.5 scenario. The decline in precipitation and increase in evaporation were projected to be around 20% under the RCP8.5 scenario, in addition to a much lower increase (about 15%) in streamflow input. This creates much lower water levels at the end of 2098.

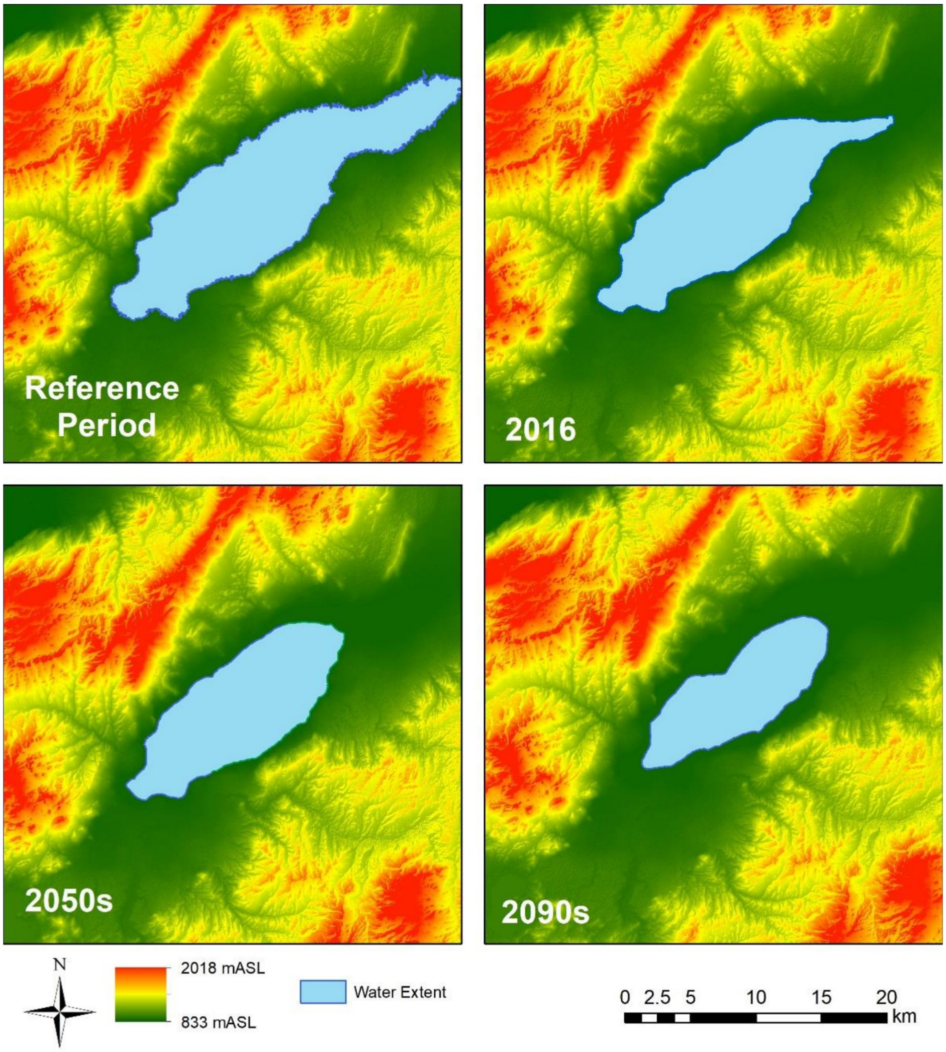

FIGURE 8 | Water extents for Burdur Lake during the reference period (1980–2000) and 2016 and projections for the 1950s and 2090s based on the RCP8.5 scenario of the MPI-ESM-MR model. [Colour figure can be viewed at wileyonlinelibrary.com]

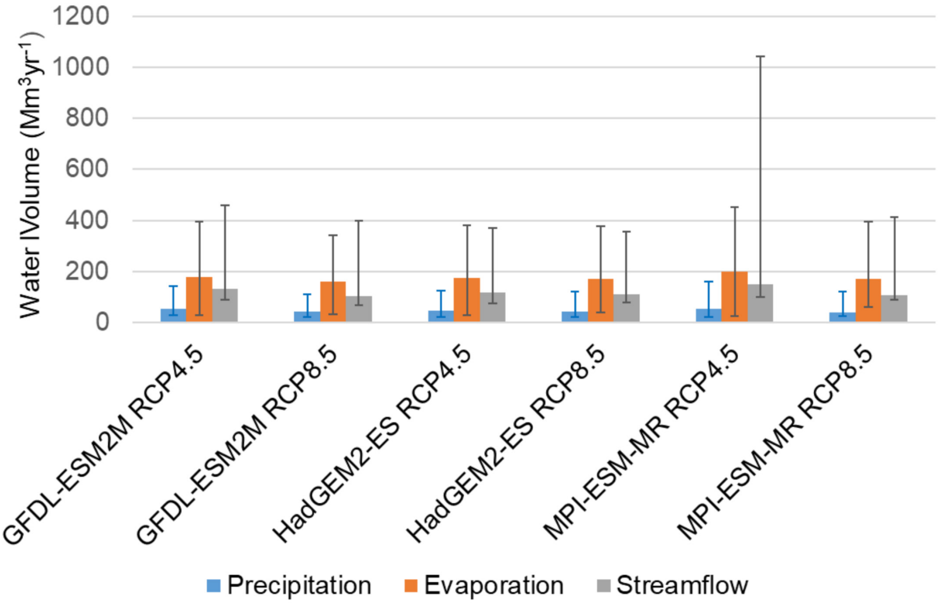

FIGURE 9 | Water budget components based on the GFDL-ESM2M, HadGEM2-ES and MPI-ESM-MR models for the RCP4.5 and RCP8.5 scenarios. [Colour figure can be viewed at wileyonlinelibrary.com]

With the HadGEM2-ES model, average precipitation input was 48.2 $mm^3 year^{-1}$ (in the range of 24.9–78.6 $mm^3 year^{-1}$) and average inflow due to streamflow was 118.3 $mm^3 year^{-1}$ (in the range of 42.2–250.3 $mm^3 year^{-1}$) under the RCP4.5 scenario. Average evaporation was 175.9 $mm^3 year^{-1}$ (in the range of 147.6–206.6 $mm^3 year^{-1}$). Under the RCP8.5 scenario, average precipitation, runoff, and evaporation were 43.2 $mm^3 year^{-1}$ (in the range of 21.8–77.8 $mm^3 year^{-1}$), 111.3 $mm^3 year^{-1}$ (in the range of 31.1–244.0 $mm^3 year^{-1}$) and 167.0 $mm^3 year^{-1}$ (in the range of 129.9–208.9 $mm^3 year^{-1}$), respectively. The decrease in precipitation was about 7% and in evaporation it was 13% compared to the reference period under the RCP4.5 scenario. We also noted an increase in streamflow (15%). Under RCP8.5, precipitation and evaporation were projected to decrease by about 16%, while inflow showed a slight increase.

With the MPI-ESM-MR model, average precipitation input was 54.5 $mm^3 year^{-1}$ (in the range of 32.9–104.7 $mm^3 year^{-1}$) and average inflow due to streamflow was 150.9 $mm^3 year^{-1}$ (in the range of 51.9–890.5 $mm^3 year^{-1}$) under the RCP4.5 scenario. Average evaporation was 201.12 $mm^3 year^{-1}$ (range: 174.7–249.7 $mm^3 year^{-1}$). Under the RCP8.5 scenario, average precipitation, runoff, and evaporation were 38.82 $mm^3 year^{-1}$ (in the range of 12.3–84.3 $mm^3 year^{-1}$), 107.2 $mm^3 year^{-1}$ (in the range of 16.8–304.3 $mm^3 year^{-1}$) and 171.1 $mm^3 year^{-1}$ (in the range of 108.6–222.9 $mm^3 year^{-1}$), respectively. These results refer to a slight decrease (about 6%) in precipitation and in evaporation (about 1%) compared to the reference period under the RCP4.5 scenario, in addition to a rise in inputs from streamflow. Under the RCP8.5 scenario, precipitation and runoff are projected to decrease by about 25%–30%, while evaporation drops about 15%. Drier conditions and more variable hydrologic behaviour could be expected under the higher-emission scenario.

Figure 7 shows an abrupt change in water levels beginning in the 1960s for the projections with the GFDL-ESM2M, HadGEM2-ES and MPI-ESM-MR models under the RCP8.5 scenario, and with the HadGEM2-ES model under the RCP4.5 scenario. To examine the causes of this decline, we examined the water budget components for the 2060–2098 period for these projections. Our analysis showed that precipitation inputs to the lake during the 2060–2098 period were 9%–32% lower than the 2025–2098 average. Similarly, streamflow during the 2060–2098 period was 10 to 33% lower than the 2025–2098 average, while evaporation decreased by only 2%–12%. This result suggests that the drop in lake levels after the 1960s was primarily caused by reduced inflows, rather than changes in evaporative losses. This pattern proves the lake's sensitivity to precipitation and flow reductions under intensified warming scenarios. Even a slight change in inputs caused significant water level decreases.

5 | Conclusions

In this study, the potential impacts of climate change on the hydrology of the Burdur Lake Basin were evaluated by running climate projection data with SWAT. Bias-corrected climate projection data from three global climate models (MPI-ESM-MR, HadGEM2-ES and GFDL-ESM2M) were run with the calibrated SWAT model. Future simulations were conducted for the 2025–2098 period under the RCP4.5 and RCP8.5 scenarios based on the MPI-ESM-MR, HadGEM2-ES and GFDL-ESM2M models. The projected changes in hydrological variables, including streamflow, lake inflow and water balance variables, were evaluated. During these projections, land use/cover conditions and existing anthropogenic interventions (e.g., reservoirs and irrigation practices) were assumed to remain constant, meaning that no additional land use change or new water management developments were considered. Therefore, the results reflect the impacts of projected climate change under the continuation of current human pressures in the basin.

The results of this study should be interpreted considering the limitations related to data availability in the basin. Limited and partly coarse information on basin characteristics, such as land use/cover, soil properties, and reservoir operation rules, may have introduced uncertainty into the simulated streamflow and lake water balance components. Although anthropogenic influences on the hydrological system (e.g., reservoirs and irrigation practices) were represented in the model setup, these were implemented based on available data and simplified assumptions, which may still contain uncertainties in terms of data quality and operational dynamics. Additionally, future climate conditions were simulated using CMIP5 projections rather than the more recent CMIP6. Still, the model could capture the basin's altered hydrological behaviour satisfactorily and created consistent projections for RCP4.5 and RCP8.5 scenarios. While the projections of CMIP5 and CMIP6 show similar large-scale climatic patterns for this region, the modelling framework developed here can be used in the future to incorporate CMIP6 projections.

The projections showed a general decrease in mean annual precipitation and a consistent increase in maximum and minimum temperatures. This refers to a warming and drying trend over the basin, which can alter the hydrological balance of the Burdur Lake by reducing water availability and changing runoff dynamics. Although projected mean inflows to the lake are variable for GCMs, the general pattern suggests more variable hydrological conditions with reduced low flows and more frequent extreme runoff events. The model simulations were conducted using a hydrological system that already incorporates existing anthropogenic components, including reservoirs and irrigation practices. However, future projections were performed under the assumption that these anthropogenic conditions remain unchanged over time. Both lake volume and water level are projected to decline compared to the historical and reference periods, particularly under the RCP8.5 scenario. Therefore, the projected changes primarily reflect the impact of climate change on the current altered hydrological system.

This study demonstrated Burdur Lake's vulnerability to future climatic and anthropogenic pressures. Hydrological modifications in the basin (including reservoir construction and operation) increased the vulnerability of the lake to climatic variations. Even slight changes in precipitation can potentially have long-term impacts on Lake Hydrology. Therefore, regulating water use from streamflow and reservoirs, sustainable use of groundwater resources, and adaptation of efficient irrigation practices should be considered in a more adaptive and integrated water management strategy. Continuous monitoring of climatological and hydrological variables is also critical for future studies. Climate change impacts should be incorporated into basin management plans to mitigate further deterioration of lake conditions and ensure the region's sustainable use of water resources.

Author Contributions

Filiz Dadaser-Celik: conceptualization, methodology, formal analysis, writing-review and editing, supervision, resources, funding acquisition; **Mehmet Soylu:** methodology, formal analysis, data curation, visualization, writing original draft; **Meltem Kacikoc:** conceptualization, methodology, writing-review and editing, funding acquisition.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The spatial data (including DEM, soil, land use/cover data) used in the study are freely available in the public domain. Other data and model outputs are available from the corresponding author upon reasonable request.

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