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IMPACTS OF CLIMATE CHANGE AND ANTHROPOGENIC ACTIVITIES ON THE HYDROLOGY OF BURDUR LAKE BASIN

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Abstract. Burdur Lake, a saline lake located in southwestern Türkiye, has undergone significant water level decline over recent decades, caused by both climatic variability and human interventions. This study employs the Soil and Water Assessment Tool (SWAT) to simulate the hydrological processes within the Burdur Lake Basin and to evaluate the combined effects of climate change and anthropogenic activities, particularly reservoir construction, on the lake's hydrology. Model setup utilized datasets including a digital elevation model, land use/cover, soil properties, and historical meteorological data. Model calibration and validation were conducted using observed streamflow data and water volumes in major reservoirs and Burdur Lake. The SUFI-2 algorithm within the SWAT-CUP software was used for model calibration and validation. To assess future climatic impacts, bias-corrected Global Climate Model (GCM) outputs from GFDL-ESM2M, HadGEM2-ES, and MPI-ESM-MR models for RCP4.5 and RCP8.5 scenarios were used. Simulation results demonstrate that increases in air temperatures are likely in the basin, while precipitation projections were variable under different scenarios. The water volumes in the Burdur Lake continued to decline in majority of the scenarios. This decline was particularly sharper under the RCP8.5 scenarios after 1970s. The results showed that the intense pressure on both surface and groundwater resources in the region has further increased Burdur Lake's vulnerability to climate change.
Keywords: Climate Change, Anthropogenic Impacts, Hydrological Modeling, SWAT, Burdur Lake Basin

1 INTRODUCTION

Climate change significantly affects aquatic and terrestrial ecosystems. It leads to more frequent extreme weather events and poses one of the most critical challenges today. Rivers and lakes, vital components of water resources, are particularly vulnerable. When combined with anthropogenic pressures, climate change drives water bodies into a highly alarming state. Key factors contributing to the volumetric decline in water resources include increased evaporation, altered precipitation regimes, and rising water demand (Sukanya and Joseph, 2023). These factors have been linked to water losses in lakes, wetlands, and rivers (Tramblay et al., 2020). According to the Intergovernmental Panel on Climate Change (IPCC), depending on the policies implemented, global temperatures are projected to rise by 1.4°C to 5.8°C between 2016 and 2100 (IPCC, 2007). In Türkiye, the temperature increase is expected to be between 2.5°C and 4°C, with central regions potentially reaching 5°C and the Aegean and Eastern Anatolia up to 4°C (Talu et al., 2010). Precipitation is projected to decline by 150–350 mm over the same period.

This study investigates the potential impacts of climate change on the hydrology of Burdur Lake in Türkiye. Burdur Lake is a closed-basin lake that has experienced significant water level declines in recent decades due to climate variability, constructions of reservoirs, and extensive use of surface and groundwater resources. It is the seventh largest lake in Türkiye, however, it has lost about 75 km² (or approximately one-third) of its surface area since 1975. In this study, we used the Soil and Water Assessment Tool (SWAT) to simulate water volumes at Burdur Lake from 2025 and 2098. Global Climate Model (GCM) outputs from GFDL-ESM2M (Geophysical Fluid Dynamics Laboratory,) HadGEM2-ES (Met Office Hadley Centre), and MPI-ESM-MR (Max Plank Institute) models for representative concertation pathways (RCP) 4.5 and 8.5 scenarios were used in the simulations. The findings from this study will provide crucial insights into the hydrological challenges Burdur Lake is expected to face in the future.

2 METHODS

In this study, we used SWAT to simulate hydrologic conditions in the Burdur Lake Basin. Bias-corrected lobal GCM outputs from GFDL-ESM2M, HadGEM2-ES, and MPI-ESM-MR models were used to simulate conditions from 2025 to 2098. Below we first provide background şnformation about Burdur Lake Basin and SWAT model. We, then, explain the model development, calibration and validation processes and sceanario analysis.

2.1 Site description

The study was carried out in the Burdur Lake Basin. The Burdur Lake Basin is located between the borders of Burdur Province center, Isparta Keçiborlu and Gönen districts, between 37° 28' – 37° 54' North latitudes and 29° 58' – 30° 27' South longitudes (Figure 1). It is a depression basin formed as a result of tectonic processes. The elevation in the basin varies between 836-2316 meters and Burdur Lake is located at the lowest elevation. The basin area is approximately 3450 km^2, while Burdur Lake covered 215-228 km² around 1970-1975. The lake has dramatically shrunk to 140-153 km² nowadays, representing a loss of about one-third of its original size This decline is largely attributed to climate variability and increased anthropogenic pressures, including extensive water abstraction for irrigation and the construction of numerous dams (Soylu et al., 2023). The climate in the region is continental with hot and dry summers and cold and rainy winters. The mean annual precipitation is about 400 mm and mean air temperature is 13ºC. There are four reservoirs in the basin constructed for irrigation purposes. These reservoirs, namely Karamanlı, Karataş, Bademli and Karaçal, hold almost all water coming from upstream. Groundwater use in the basin is also significant, particularly to the east of Burdur Lake (Davraz et al., 2019).

SWAT is a watershed-scale, semi-distributed, and physically-based model used in modeling hydrological processes and water quality (Arnold et al., 1998). SWAT has the potential to be used to assess the effects of long-term hydrological changes and land management practices, especially in agricultural watersheds. SWAT divides the watershed first into subbasins and then into hydrological response units (HRUs). HRUs are areas that have homogeneous land use, soil, and slope characteristics. Water flows are estimated for each HRU, then they are aggregated to create flow for each subbasin. The flow is routed to the rivers and finally to the basin outlet. SWAT uses a one-dimensional system during groundwater flow and neglects spatial variability in aquifer parameters and regional flow characteristics.

The model for Burdur Lake Basin was developed with the ArcSWAT interface using SWAT2012 Revision 664 version. Digital elevation model (DEM), soil map, land use-cover map, slope information and meteorological data were used for establishing the model (Figure 2). DEM data was obtained from the United States Geological Survey website. 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 Soil Map of the World. Information on was generated by the SWAT model based on DEM data. Meteorological data included precipitation, maximum temperature, minimum temperature, solar radiation, wind speed, and relative humidity and they were obtained from several weateher stations located in the basin.

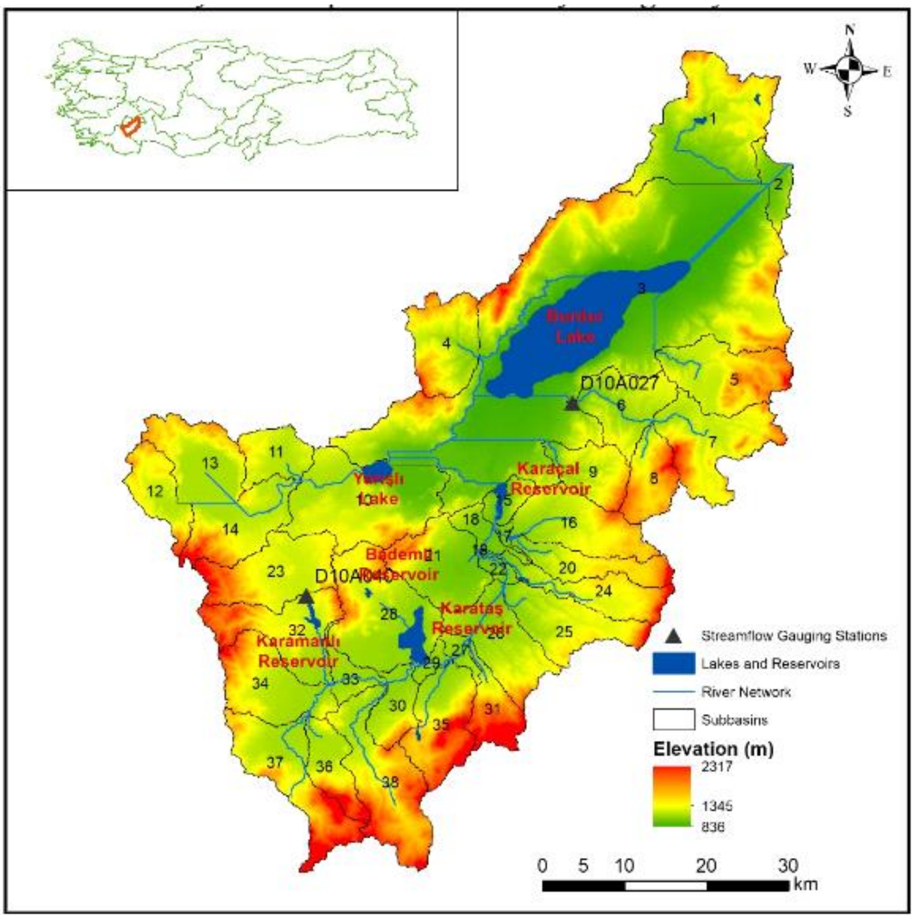

Figure 1. The location and hydrogeological characteristics of the Burdur Basin

2.2 SWAT model development, calibration and validation

For model calibration and validation, SUFI2 algorithm available in the SWAT-CUP software (Abbaspour, 2015) was used. Although the basin contains multiple streamflow gauging stations, only a few stations provided long-term and continuous data. The locations of these stations, namely D10A013 and D10A027, were shown in Figure 1. For calibration and validation, we also used data on reservoir volumes at Karataş and Karaçal reservoirs and water volumes in Burdur Lake (Figure 1). The ranges of parameters used in the calibration process were determined based on the basin's physical characteristics and prior studies in the watershed and surrounding areas. We used the data from 2016-2020 for calibration and data from 2021-2024 for validation. The model performance was evaluated based Nash-Sutcliffe Efficiency Coefficient (NSE), Coefficient of Determination (R^2), and Percent Bias (PBIAS).

2.3 Climate Projections

In this study, we obtained the daily climate projections data from the Turkish State Meteorological Service (MGM). MGM produced downscaled precipitation and air temperature data for the 2016–2098 period by using data from three Global Circulation Models, GFDL-ESM2M, HadGEM2-ES, and MPI-ESM-MR, well representing climate dynamics of Turkey based on two RCPs, RCP4.5 and RCP8.5. 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 increases until the twenty-first century. In order to increase the reliability of the simulations, bias correction with the quantile mapping method was applied for the climate data prediction period (2025-2098) using the observed data of Burdur meteorological station between 1975-2000 (Figure 2). Meteorological data series, which reflect the different climate scenarios, were run with SWAT model and effects on the Burdur Lake water volumes were evaluated.

3 RESULTS AND DISCUSSIONS

3.1 The performance of the SWAT model

The SWAT model consisted of 38 subbasins and 687 HRUs. The most critical analysis in the applied SWAT model is the evaluation of the calibration process. This analysis not only verifies the accuracy of the mathematical framework created for the basin, but also confirms that the relationships between the parameters are carried out properly. The performance metrics for all gauging stations and reservoirs are provided in Table 1. The comparison of predicted and observed water volumes at Burdur Lake was shown on Figure 2. In general, the simulated and observed values in model calibration and validation are compatible with each other. According to Moriasi et al. (2007), for a model to be considered satisfactory, NSE and R^2 values should generally be greater than 0.50. PBIAS should fall within ±25% for streamflow simulations to be satisfactory. The performance metrics provided satisfactory results based on NSE and R^2 at majority of the locations. However, all metrics were satisfactory based on the PBIAS value.

The performance of the SWAT model in the Burdur Lake Basin has been affected by a variety of factors. In this study, the uncertainties in the input data and data used for calibration/validation are among the most important factors that reduce the model performance. The low temporal and spatial resolution of the input data can also be evaluated in this context. For example, soil data set was obtained from the FAO/UNESCO map in Burdur Lake Basin, which may not adequately reflect the actual soil conditions. Finally, the differences between the period in which the model is calibrated and the validation can affect model performance (EPA., 2002). Changes occur in water management and land use over the years. It was not possible to adequately reflect this variability in the model.

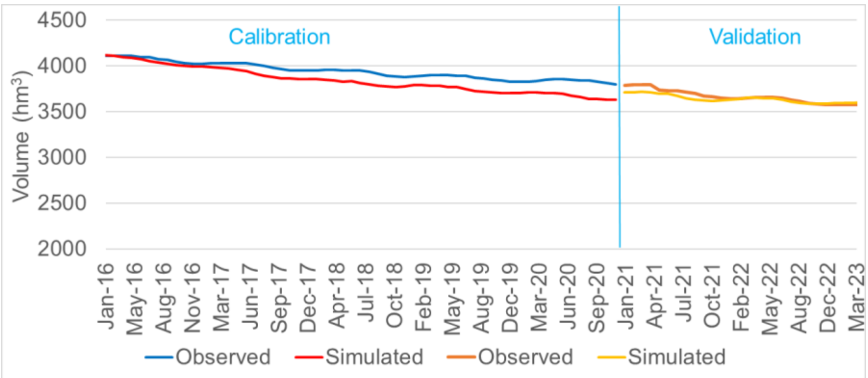

Figure 2. Simulated and observed water volumes at Burdur Lake during calibration and validation periods

Table 1. Statistical metrics for the calibration and validation periods

	Calibration			Validation		
Variable	R^2	NS	PBIAS	R^2	NS	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

3.2 Observed and Predicted Climate Characteristics

The average monthly precipitation, maximum temperature and minimum temperature data for the reference period (1975-2000) in the data produced by the GCMs were compared with the monitoring data obtained from the Burdur Central Meteorological Station (Figure 3, Table 2). The average annual precipitation for the observed and simulated data for the 1975-2000 period was 414 mm. Annual average maximum air temperature and minimum air temperature were 19.2 ºC and 7.3ºC, respectively. However, the values were variable through the years. The minimum annual precipitation in observed data was 281 mm and maximum annual precipitation was 571 mm during the 1975-2000 period. Based on GCM scenarios, minimum annual precipitation was between 206-244 and maximum annual precipitation was between 606-801 mm. These results suggest that, after bias correction, the GCMs reasonably reproduced the observed climatic patterns, although some variability existed in annual extremes.

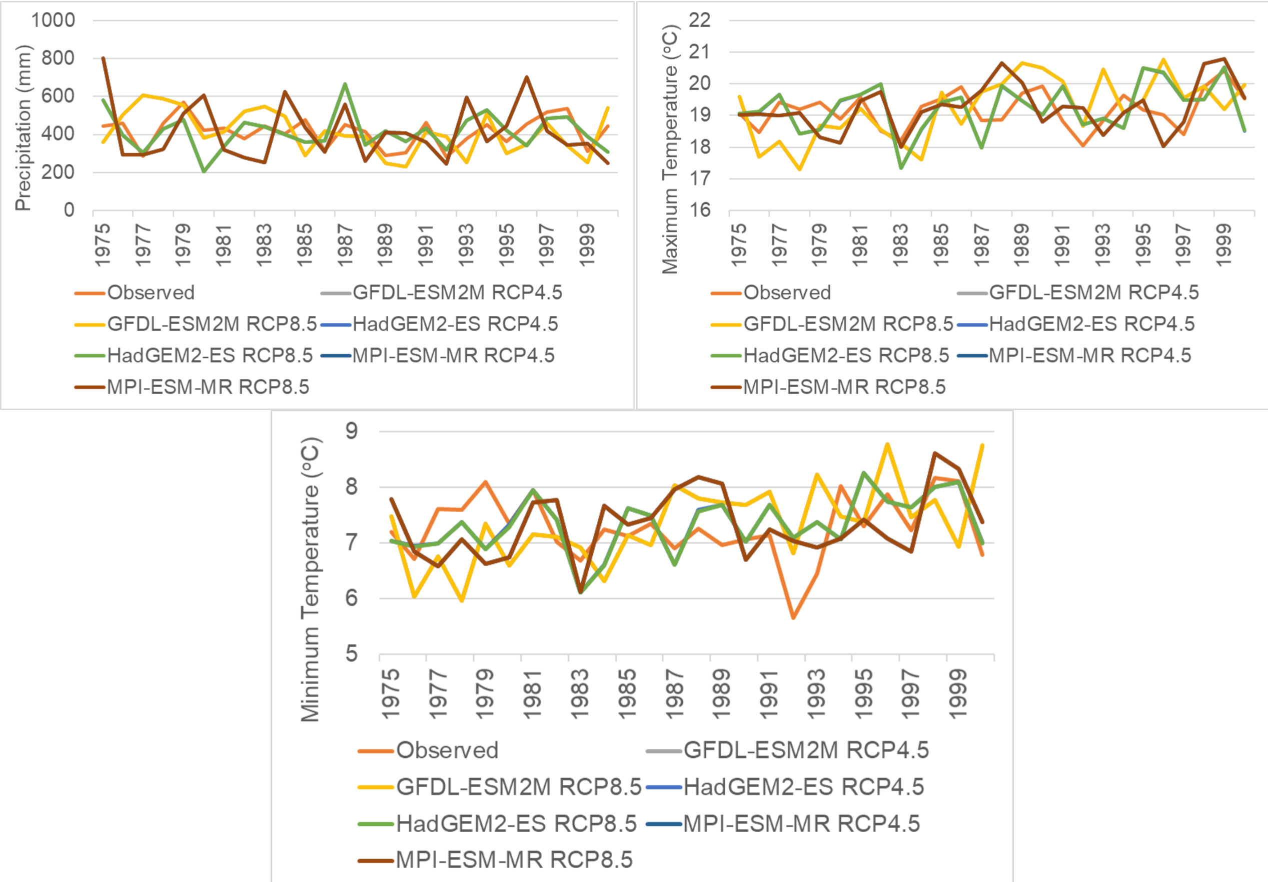

Figure 3. Simulated and observed precipitation, maximum temperature and minimum temperature for the reference period (1975-2000)

Table 2. Statistical characteristics of the simulated and observed precipitation, maximum temperature and minimum temperature for the reference period (1975-2000)

Variable	Statistics	Observed	GFDL-ESM2M RCP4.5	GFDL-ESM2M RCP8.5	HadGEM2-ES RCP4.5	HadGEM2-ES RCP4.5	MPI-ESM-MR	MPI-ESM-MR
Annual Precipitation (mm)	Mean	414	414	414	414	414	414	414
	Max.	571	606	606	667	667	801	801
	Min.	281	230	230	206	206	244	244
Annual Average	Mean	19.2	19.2	19.2	19.2	19.2	19.2	19.2
	Max.	20.4	20.8	20.8	20.5	20.5	20.8	20.8

Maximum Temperature (ºC)	Min.	18.0	17.3	17.3	17.3	17.3	18.0	18.0
Annual Average Minimum Temperature (ºC)	Mean	7.3	7.3	7.3	7.3	7.3	7.3	7.3
	Max	8.2	8.8	8.8	8.3	8.3	8.6	8.6
	Min.	5.6	6.0	6.0	6.1	6.1	6.1	6.1

3.3 Precipitation and Temperature Projections

The precipitation and temperature projections for the 2025-2098 period were evaluated under the RCP 4.5 and 8.5 scenarios based on three GCMs by comparing their values with those for the reference period (1975-2000) (Table 3). The observed mean annual precipitation for the 1975–2000 was 414 mm while GCM projections under the RCP4.5 scenario ranged between 358 mm and 393 mm. The projected mean precipitation values were lower under the RCP8.5 scenarios (332 mm to 358 mm). The observed maximum and minimum annual precipitation values were 571 mm and 281 mm, respectively. Projected maximums exceeded the historical maximum in most models, reaching up to 801 mm, indicating potential increases in extreme wet years. In contrast, projected minimums went down as low as 132 mm, significantly lower than the observed minimum, suggesting an increased risk of severe dry years. These results suggest that there is a decline both in average annual precipitation and in minimum annual precipitation during the 2025-2098 period compared to the historical reference. The observed mean annual maximum temperature was 19.2°C. Projections for future periods consistently showed higher values, ranging from 20.7°C (GFDL-ESM2M RCP4.5) to 23.2°C (MPI-ESM-MR RCP4.5), showing a warming climate. The projected annual maximum temperatures reached up to 25.6°C, compared to the historical maximum of 20.4°C. The projected minimum values (18.9–20.7°C) also exceeded the historical average. The observed mean annual minimum temperature was 7.3°C. Projected means ranged from 8.8°C to 11.0°C, showing again a rising temperatures.

Table 3. Statistical characteristics of the simulated precipitation, maximum temperature and minimum temperature e for the projection (2025-2098) period

Variable	Statistics	Reference period	GFDL-ESM2M RCP4.5	GFDL-ESM2M RCP8.5	HadGEM2-ES RCP4.5	HadGEM2-ES RCP4.5	MPI-ESM-MR	MPI-ESM-MR
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 (ºC)	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 (ºC)	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

3.4 Impacts of Climate Change on the Burdur Lake Water Volumes

Climatic scenarios were run with the SWAT model and changes in inflows to Burdur Lake and Burdur Lake water volumes were evaluated (Figure 6). GFDL-ESM2M model projects minor fluctuations with no dramatic long-term decline under RCP4.5 scenario. The water volumes start at 4000 hm^3 in 2016 and ends around 3960 hm^3 in 2098. Under the RCP8.5 scenario, water volumes drops especially after 2050, reaching to 2310 hm³ by 2098. HadGEM2-ES model shows steady decline under both scenarios. Under the RCP4.5 scenario the decline was particularly apparent after 2060s and water volumes are around 3960 hm³ in 2098. Under the RCP8.5 scenario, we see a sharp decline after 2070 and water volumes are 2710 hm^3 by 2098. MPI-ESM-MR model projected relatively stable water levels until 2098 compared to other two models under the RCP4.5 scenario. Water volumes were around 3960 hm³ in 2098. However, under the RCP4.5 scenario, this model simulated the highest decline among all models and water levels by the end of the century was 1960 hm³. With all models and scenarios, there is 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.

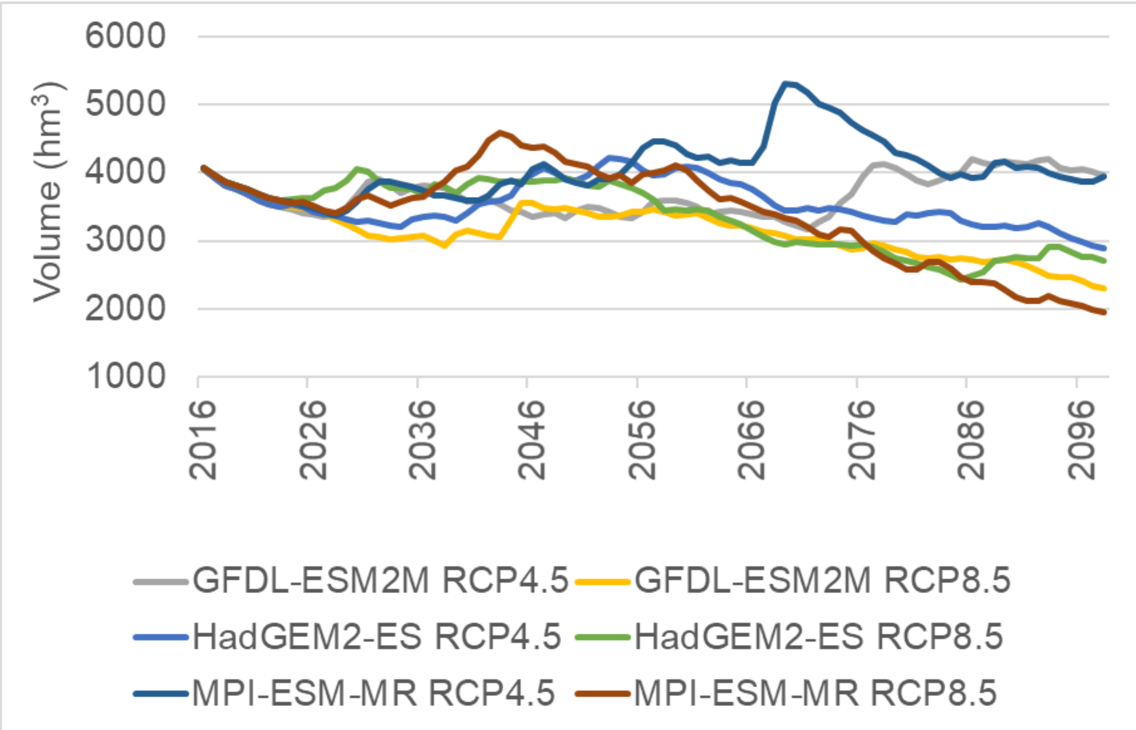

Figure 4. Simulated water volumes at Burdur Lake from 2025 to 2098

4 CONCLUSIONS

In this study, we estimated the possible effects of climate change on the basin hydrology in the Burdur Lake Basin by running climate projections data with SWAT. The projected changes between 2025-2098 were examined under the RCP4.5 and RCP8.5 scenarios based on the MPI-ESM-MR, HadGEM2-ES, and GFDL-ESM2M models. The projections indicate that climate change will significantly impact water volume, particularly under high-emission scenarios. The changed under moderate scenarios (RCP4.5) could be manageable, but business-as-usual pathways (RCP8.5) lead to potentially critical reductions in water availability by the end of the century. These findings emphasize the importance of climate mitigation and adaptive water resource management to preserve long-term water security.

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