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Analysing the impact of climate change on evapotranspiration in a climate-sensitive region: Example of Central Anatolia (Türkiye)

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Abstract: Evapotranspiration (ET) is one of the main components of the hydrological cycle and plays a crucial role for water resources. It is sensitive to climate change, and therefore, estimating ET under changing climatic conditions is essential in comprehending hydrological processes, particularly in agricultural water management. In this study, the impact of climate change on ET in the Central Anatolia region of Türkiye was assessed. For this purpose, RCP4.5 and RCP8.5 climate change scenarios based on two Earth System Models, HadGEM2-ES and MPI-ESM-MR, were employed for three future time periods: 2025–2049, 2050–2074, and 2075–2098. As a baseline period for comparison, the time interval spanning 1980–2000 was considered. ET values were computed by using the Penman-Monteith equation, recommended by the Food and Agriculture Organization, along with five widely utilized methods. The study revealed a consistent increase in ET depending on the employed methods for the future period in response to climate change. The average of the ET amounts for the region was determined as 1089 mm for the reference period 1980–2000. As the average of the six methods utilized, amounts estimated by HadGEM RCP4.5, HadGEM RCP8.5, MPI RCP4.5, and MPI RCP8.5 models for the future period were obtained as 1 199, 1 285, 1 166, and 1 248 mm, respectively. Considering the results, it is found that the ET amount in the Central Anatolia region of Türkiye will increase by up to 11% by the end of this century under the optimistic RCP 4.5 scenario and by up to 19% under the extreme RCP 8.5 scenario. These findings regarding increased evapotranspiration play a significant role in water resource management and agricultural production planning in the region, holding crucial implications for sustainable agriculture.

Keywords: agricultural planning; climate change scenarios; evaporation; water management; water resources

Evapotranspiration (ET) not only is a fundamental parameter of the energy budget in the earth-atmosphere system but also plays an essential role in water resources (Wang et al. 2017). It is one of the main components of the hydrological cycle (Valiantzas 2006; Abdullahia & Elkiran 2017) and involves the combination of processes such as evaporation from the soil, interception of precipitation by vegetation, and water transpiration by vegetation (Singh 1988; Kişi 2006). The precise estimation of ET is essential for various fields and inquiries such as the analysis of hydrological water balance, the strategic planning and management of water resources, and the planning of regional agricultural production systems (Valiantzas 2006). Especially, in regions characterized by limited water resources, the determination of ET

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assumes a critical role in the strategic formulation and control of water resources (Kişi 2006).

Climate change has a significant impact on Earth's systems, particularly regarding global warming (Nistor et al. 2019). Especially in recent decades, changes in temperatures have led to noticeable shifts in the hydrological cycle (IPCC 2007; Sperna et al. 2012). These observed changes in the hydrological cycle have, in turn, resulted in a variety of adverse impacts on ecosystems, surface waters, groundwater, and agricultural lands, all attributable to the influence of climate change (Nistor et al. 2019). Furthermore, as a reflection of changes in the hydrological cycle, the variability of the impact on precipitation, ET, and runoff by geographical region has also emerged as a widely witnessed phenomenon (Abtew & Melesse 2013).

The combination of climate change and water scarcity poses a threat to food security and sustainable development in arid regions (Kheir et al. 2021). As a general trend, regions already facing water scarcity are likely to experience increased aridity and higher temperatures (Turral et al. 2011; Ebrahimpour et al. 2014). Türkiye, located at the crossroads of Europe and Asia and also influenced by the Mediterranean climate zone, is one of those countries that experiences and is greatly affected by the impacts of climate change. Water management and planning are of great importance, especially in Türkiye, where the agricultural sector has a significant share in economic income and 70–75% of the water demand stems from the agricultural sector (Azlak & Şaylan 2019). In this context, in water-scarce Türkiye, where the agricultural sector is the major consumer of water, enhancing the productivity of the agricultural sector and optimizing water resources through the knowledge of ET are critical aspects for mitigating the impacts of climate change.

ET is a multifaceted and complicated process arising from the intricate interplay of several climatological elements, namely temperature, solar radiation, wind velocity, duration of sunshine, and humidity (Abdullahia & Elkiran 2017). The assessment of ET can be achieved through the utilization of instruments or through calculations based on ET equations (Abdullahia & Elkiran 2017). Since direct measurement of ET is challenging (Johnson & Sharma 2007), various methods have been suggested, both theoretical and empirical, to measure ET (Kişi 2006; Johnson & Sharma 2007). Among them, the Penman-Monteith (PM) equation, as documented by Allen et al. (1998), is widely acknowledged for its efficacy in estimating ET under diverse climatic circumstances. Additionally, the United Nations Food and Agriculture Organization (FAO) has endorsed the PM approach as the standard benchmark for calculating reference ET utilizing meteorological data (Stöckle et al. 2004).

Considering its importance in water resources and agricultural planning, several studies have been conducted in Türkiye focusing on ET. One of the important frameworks of these studies is the examination of the relationships between real measurements and empirical methods. In this context, a study was conducted in the Konya province. The actual ET amount determined by gravimetric and meteorological measurements for the grass was compared with the ET amount calculated with the PM method (Şahin & Kara 2005). As a result, it was determined that the values calculated by the PM method closely approximated the real ET values. Besides, another study incorporating ET was conducted at the Atatürk Soil Water and Agricultural Meteorology Research Institute (Akataş et al. 2016). With the study, it was aimed to identify the most suitable empirical ET calculation methods that align with actual measurements. In this scope, the ET values calculated by 18 different empirical methods were compared with the actual amount of ET measured by the Bowen Ratio Energy Balance (BREB) method, which is a microclimatic approach. As a result of the study, it was concluded that radiation-based methods offer the closest estimates to real measurements and that Irmak (IR), Jensen-Haise (JH), Priestly Taylor (PT), and PM methods give the most favourable results. These considerations were taken into account in selecting the methods for this study.

Beyond the comparison between real and estimated values, several comparative studies have also been carried out between empirical methods. In this scope, a study was conducted by Kişi (2014), using meteorological station data from four provinces under the influence of the Mediterranean climate zone in Türkiye. Different empirical methods were compared, and taking the PM method as a reference, estimations of the other methods were evaluated in the study. Better correlation and the closest amounts to the PM method were estimated with the Hargraves and Samani (HS), Copais, Valiantzas and IR methods. Furthermore, similar studies were conducted in Türkiye for different locations by Şaylan et al. (2011) and Azlak and Şaylan (2019), and similar results respectively were found by Şaylan et al.

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(2011) for Makking and HS methods and by Azlak and Şaylan (2019) for Jones and Ritchie (1990) (JR), JH, and HS methods. In addition to these studies, another research on ET was conducted by Koç et al. (2022) on K_c coefficients. K_c values are important to estimate actual ET in agricultural applications. In this regard, K_c values were calculated for maize through actual lysimeter-based measurements and compared with FAO's suggested values. As a result of the study conducted, it was determined that the amount of ET obtained by actual measurements was 30% more than the amount of ET estimated by using the K_c value recommended by FAO. Moreover, besides this study, a study was conducted by Dadaşer-Çelik et al. (2016) to determine trends in ET values. In the study covering 77 stations across Türkiye, a trend analysis of ET values was made from 1975 to 2006. As a result, significant increasing trends in ET values were detected especially in the stations located in the central, southern, and south-eastern regions of Türkiye, which are sensitive to climate change and under the influence of the Mediterranean climate zone.

Under the reality of climate change and the above-given framework, this study aimed to investigate the impacts of climate change on ET in Türkiye. In line with this objective, ET was estimated by using the PM method and 5 commonly used methods for Aksaray, Karaman, Konya (11 stations), and Niğde provinces located in the Central Anatolia region of Türkiye, where the effects of climate change are significantly observed. For the future period, an analysis was conducted for the close (2025–2049), middle (2050–2074), and the end (2075–2099) part of the running century. Depending on the RCP4.5 and RCP8.5 scenarios, possible changes in the amount of ET were determined according to the reference period of 1980–2000.

MATERIAL AND METHODS

Study area. The study focuses on the Central Anatolia region of Türkiye, characterized by a climate with dry and hot summers, cold and snowy winters, and limited rainfall (Figure 1). Konya province was the focal area of investigation for this study with 11 meteorological stations. In addition to Konya, Aksaray, Karaman, and Niğde provinces in the region are the other provinces where analysis was conducted. With a vast land area covering 38 873 km², Konya holds the distinction of being the largest province in Türkiye, and a significant portion of its land is dedicated to agricultural use. Intensive agriculture is one of the primary contributors to the region's water demand. According to the time frame spanning from 1991 to 2020 (climate; 30 years), information on climatic records for Aksaray, Karaman, Konya, and Niğde provinces is given in the Table 1 (MGM 2023).

Meteorological data. Meteorological data from the 14 stations present in the region were used to conduct analysis. As a baseline period, the period spanning from January 1980 to December 2000 was used. For this period, daily time series of air pressure (hPa); relative humidity (%); wind speed (m/s); actual sunshine duration (h); and maximum, minimum, and average temperature (°C) were obtained from the National Meteorological Service. Since the data for the determined reference period is not available for global solar radiation (MJ/m^{2}day), data spanning from 2009 to 2015 period were obtained, and relevant analysis were carried out by using available data. Unit conversions were made where necessary for meteorological variables and analyses were made with standard units.

Model data. In the study, model output data generated by using the RegCM4.3 regional climate

Figure 1. Study area and the meteorological stations

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model was used. The initial and boundary conditions for these data were derived from two global Earth System Models, namely HadGEM2-ES (HD) and MPI-ESM-MR (MPI), available in the CMIP5 database. The HD model, developed by The Met Office Hadley Centre, is a combined model that includes atmospheric and oceanic global circulation models. Several sub-models have been integrated into the model to better represent the carbon cycle via land, atmosphere, and oceans, as well as to enhance the physical representation of the climate system with sub-model schemes such as hydrology (Collins et al. 2011). The MPI model, on the other hand, combines atmospheric, oceanic, terrestrial biosphere, and ocean biogeochemistry models to study how energy, momentum, water, and carbon interact within the Earth's system. It was developed by the Max Planck Institute for Meteorology and offers three configurations with varying resolutions and vertical levels to enhance modelling accuracy. Both models have been extensively used in multiple studies investigating climate change impacts.

In the study, the used model data are the data produced based on the RCP4.5 and RCP8.5 (Representative Concentration Pathways) scenarios for the future period. From these two scenarios; while RCP4.5 represents ~4.5 W/m^2 radiative forcing and the decline in greenhouse gasses from the mid-century, RCP8.5 represents > 8.5 W/m^2 radiative forcing and continuous rise in greenhouse gases until 2100 (Demircan et al. 2017). For the analysis, daily model data obtained from 10 × 10 km grids representing the 14 meteorological stations have been employed (Table 2). As a baseline period, the period spanning from January 1980 to December 2000 was used, which aligns with the station data. To analyse the impacts of climate change, model data for the period from 2025 to 2098 were considered.

Climate models produce outputs that are coarse in resolution and can be locally biased in nature. As a result, it is necessary to take corrective measures to address systematic inaccuracies resulting from the physics and parameterization schemes employed within these models (Ning et al. 2015; Werner & Cannon 2016; Zhang et al. 2019). This can be done through bias correction of the daily data outputs, which involves aligning the model outputs with actual measurements to rectify possible errors (Zhang et al. 2019). In this regard, in this study, actual data from the 14 meteorological stations were

Table 1. Long term (1991–2020) average of climatological variables

	Aksaray				Konya				Karaman				Niğde			
	monthly		annual		monthly		annual		monthly		annual		monthly		annual	
	min	max	avg	total	min	max	avg	total	min	max	avg	total	min	max	avg	total
T_{mean} (°C)	0.9	24.5	12.8		–0.3	24.1	11.9		0.0	23.2	11.7		0.7	24.0	12.4	
T_{max} (°C)	5.8	31.3	19.1		4.6	31.0	18.3		5.3	30.3	18.2		5.6	31.7	19.1	
T_{min} (°C)	–3.0	17.1	6.8		–3.9	17.2	6.0		–4.1	15.8	5.8		–3.4	16.0	6.0	
RH (%)	33.8	81.5	57.9		62.2	83.5	75.1		36.4	84.0	62.3		35.6	79.6	60.8	
Sunshine duration (h)	3.0	11.9	7.3		3.3	11.1	7.4		3.6	11.1	7.3		3.2	12.5	7.7	
No. of rainy days	1.5	10.9		89.6	1.9	11.2		85.9	1.9	12.2		92.4	1.3	10.3		75.7
Total precipitation (mm)	6.2	44.8		349.4	6.5	45.6		325.3	5.5	43.4		349.9	6.7	48.8		335.3
Max and min (all record time)																
T_{max} (°C)	40.0				40.6				38.5				40.4			
T_{min} (°C)	–29.0				–28.2				–25.6				–28.0			
Maximum daily wind speed (m/sn)	46.0				32.4				38.3				39.4			
Maximum daily precipitation (mm)	65.8				60.3				54.5				68.0			
Record period	1929–2023				1929–2023				1935–2023				1951–2023			

Min – minimum of the variables; max – maximum of the variables; avg – average of the variables; T_{max} – maximum temperature; T_{mean} – mean temperature; T_{min} – minimum temperature; RH – relative humidity

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Table 2. Coordinates of stations and corresponding model data grids

Province/station name		Station		Model grid	
		latitude	longitude	latitude	longitude
Aksaray		38.371	33.999	38.331	34.044
Karaman		37.193	33.220	37.168	33.233
	Akşehir	38.369	31.430	38.358	31.480
	Beyşehir	37.678	31.746	37.698	31.763
	Cihanbeyli	38.651	32.922	38.691	32.931
	Çumra	37.566	32.790	37.538	32.737
	Ereğli	37.526	34.049	37.566	34.063
Konya	Hadim	36.989	32.456	36.955	32.404
	Ilgın	38.276	31.894	38.276	31.851
	Karapınar	37.716	33.526	37.749	33.575
	Konya Havalimanı	37.984	32.574	38.012	32.595
	Kulu	39.079	33.066	39.077	33.039
	Yunak	38.821	31.726	38.845	31.695
Niğde		37.959	34.680	37.956	34.660

compared with model reference data sets obtained from corresponding grids. Monthly "correction differences" and "correction coefficients" were derived from the comparison analysis on a meteorological variable basis to rectify the deviation of model data from station data. These correction differences and coefficients were then applied to the model's reference and future period data set to perform a bias correction process.

Evapotranspiration estimation methods

Six commonly employed methods for ET calculations were selected for the study and equations pertaining to the methods employed in the study are presented below.

The calculation of all required data to estimate ET followed the methods and procedures given in Chapter-3 of FAO-56 (Allen et al. 1998).

Penman-Monteith method (PM). The PM is a combination method that relies on radiation, air temperature, humidity, and wind speed data. It has been recommended as the single standard method for defining and calculating reference ET (Allen et al. 1998). It was considered as a reference method in comparisons in this study, as well. The PM FAO-56 equation is given below (Allen et al. 1998):

$$\mathrm{ET}_0 = \frac{0.408(R_n - G) + \gamma \dfrac{900}{T_{avg} + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where:
ET_0 – evapotranspiration (mm/day);
R_n – net radiation (MJ/m^{2}day);
G – soil heat flux density (MJ/m^{2}day);
γ – psychrometric constant (kPa/°C);
T_{avg} – daily average air temperature (°C);
u_2 – wind speed measured at 2 m above the ground (m/s);
e_s – saturated vapour pressure (kPa);
e_a – actual vapor pressure (kPa);
Δ – slope of saturation vapour pressure curve (kPa/°C).

Jensen-Haise method (JH). Another method employed in this study, known as the Jensen-Haise method (Equation 2), is one of the radiation-based methods and was developed in 1963. The equation of the method is given below.

$$\mathrm{ET}_0 = C_T \frac{(T_{avg} - T_x) R_s}{\lambda} \quad (2)$$

where:
C_T – the temperature constant (0.025 °C);
T_x – constant (–3);
R_s – daily total global solar radiation (MJ/m^{2}day);
λ – latent heat (MJ/kg).

Hargreaves-Samani method (HS). Hargreaves and Samani (1982, 1985) developed a set of equations based on temperature and radiation to calculate reference ET (for grass), building upon the Hargreaves method (1975). In this study, the follow-

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ing equation they formulated in 1985 was utilized (Equation 3).

$$ET_0 = 0.023 \times 0.408 R_a \left(\frac{T_{max} + T_{min}}{2} + 17.8 \right) \left(T_{max} - T_{min} \right)^{0.5} \quad (3)$$

where:

R_a – extraterrestrial radiation (MJ/m^{2}day);

T_{max} – maximum temperature (°C);

T_{min} – minimum temperature (°C).

Priestley-Taylor method (PT). Another equation used in the study is the Priestley-Taylor method (Equation 4), which was developed in 1972 and represents a simplified version of the Penman method.

$$ET_0 = \alpha \frac{\Delta}{\Delta + \gamma} \frac{R_n}{\lambda} \quad (4)$$

where:

α – calibration constant, considered as 1.26 for this study.

Jones-Ritchie method (JR). The Jones-Ritchie method is based on the equation developed by Ritchie (1972) and it was formulated in 1990 (Equation 5).

$$ET_0 = \alpha_1 \left[3.87x10^{-3} R_s \left(0.6 T_{max} + 0.4 T_{min} + 29 \right) \right] \quad (5)$$

where:

α_1 – coefficient that varies as follows:

$\alpha_1 = 0.1 \exp [0.18 (T_{max} + 20)]$ when $T_{max} \leq 5$ °C;

$\alpha_1 = 1.1$ when $5 < T_{max} < 35$ °C;

$\alpha_1 = 1.1 + 0.05 (T_{max} - 35)$ when $T_{max} \geq 35$ °C.

Irmak method (IR). It was developed by Irmak et al. (2003) for calculating reference ET and it is based on radiation and temperature (Equation 6).

$$ET_0 = -0.611 + 0.149 R_s + 0.079 T_a \quad (6)$$

RESULTS

Analysis of data set. In the study, the status of data sets affecting ET values, including maximum, minimum, and average temperature, relative humidity, and radiation, was examined. As a result of the analyses made within the framework of the RCP4.5 and RCP8.5 scenarios of the HD and MPI models, an increase in temperature and radiation values was observed, while a decrease in relative humidity values was obtained. Changes in relevant meteorological variables are given in Table 3 as the average of 14 stations.

Evaluation of evapotranspiration. The ET calculations based on PM and five other equations were performed for the reference and future periods within the framework of RCP4.5 and RCP8.5 scenarios of the HD and MPI models. The results for the maximum and minimum values of the long-term annual total ET for the 14 stations within the framework of two models, two scenarios, and six methods used in the study are presented in Table 4.

Based on the analysis results, it has been determined that the rate of ET will increase in the future. All models and scenarios showed a consistent increase

Table 3. Changes in meteorological variables compared to the reference period

Meteorological variable/model scenario		2025–2049		2050–2074		2075–2098	
		HD	MPI	HD	MPI	HD	MPI
RH change (%)	RCP 4.5	–1.7	–0.7	–1.9	–0.5	–1.9	–1.0
	RCP 8.5	–1.2	–0.5	–2.7	–3.2	–3.1	–3.3
T_{max} change (°C)	RCP 4.5	2.2	1.2	2.7	1.6	3.2	2.1
	RCP 8.5	2.2	1.3	3.9	2.9	5.4	4.2
T_{min} change (°C)	RCP 4.5	1.9	1.0	2.5	1.5	2.9	1.9
	RCP 8.5	2.1	1.2	3.5	2.4	5.1	3.7
T_{avg} change (°C)	RCP 4.5	2.0	1.1	2.6	1.5	3.0	1.9
	RCP 8.5	2.1	1.3	3.6	2.7	5.2	3.9
Global solar radiation change (%)	RCP 4.5	1.7	1.1	1.6	1.0	1.7	1.2
	RCP 8.5	0.8	0.0	1.9	1.6	2.0	1.6

The values in the table show the changes in long-term annual averages of the meteorological variables for the relevant period; change in the global solar radiation refers to the percentage change in amounts (as MJ/m^2 day); RH – relative humidity; T_{max} – maximum temperature; T_{avg} – average temperature; T_{min} – minimum temperature; HD – HadGEM2-ES climate change model; MPI – MPI-ESM-MR climate change model; RCP4.5 and RCP8.5 – representative concentration pathway 4.5 and 8.5 scenarios

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Table 4. The estimation range differences between the methods for the long-term annual total evapotranspiration (ET) values (in mm)

Provinces/stations		1980–2000		2025–2049		2050–2074		2075–2098	
		max	min	max	min	max	min	max	min
Aksaray		1 331	981	1 351	1 025	1 423	1 034	1 517	1 046
Karaman		1 399	1 010	1 410	1 057	1 460	1 071	1 482	1 082
	Akşehir	1 325	952	1 321	985	1 342	1 002	1 383	1 011
	Beyşehir	1 389	**860**	1 399	**912**	1 422	**917**	1 440	**933**
	Cihanbeyli	1 321	942	1 326	981	1 411	992	1 508	1 001
	Cumra	1 372	918	1 371	962	1 422	967	1 455	990
	Eregli	1 374	1 010	1 387	1 049	1 445	1 062	1 487	1 073
Konya	Hadim	**1 494**	958	**1 457**	1 007	**1 477**	1 022	1 458	1 043
	Ilgın	1 350	955	1 350	1 009	1 391	1 013	1 410	1 038
	Karapınar	1 262	920	1 296	950	1 369	961	1 428	970
	Konya HL	1 263	910	1 259	940	1 299	950	1 330	958
	Kulu	1 349	935	1 352	968	1 389	976	1 384	986
	Yunak	1 380	951	1 371	989	1 470	998	**1 563**	1 007
Niğde		1 393	960	1 376	993	1 417	1 005	1 467	1 017
Average		1 357	947	1 359	988	1 410	998	1 451	1 011

The table shows the maximum and minimum annual total ET values obtained from all callculations for the period (there are 24 ET series showing annual total ET values for each station; under the combination of two models (HD and MPI), two scenarios (RCP4.5 and RCP8.5), and six methods used); max – maximum of the annul ET values; min– minimum of the annul ET values; HD – HadGEM2-ES climate change model; MPI – MPI-ESM-MR climate change model; RCP4.5 and RCP8.5 – representative concentration pathway 4.5 and 8.5 scenarios; bold – the maximum (for max columns) and the minimum (for min columns) values of the estimation results given in the columns

towards the end of the century. Among the 2 models and 2 scenarios used, the MPI model estimated the least increase under the RCP4.5 scenario, while the HD model predicted the highest increase under the RCP8.5 scenario. Furthermore, as expected, the pessimistic scenario RCP8.5 predicted higher ET values

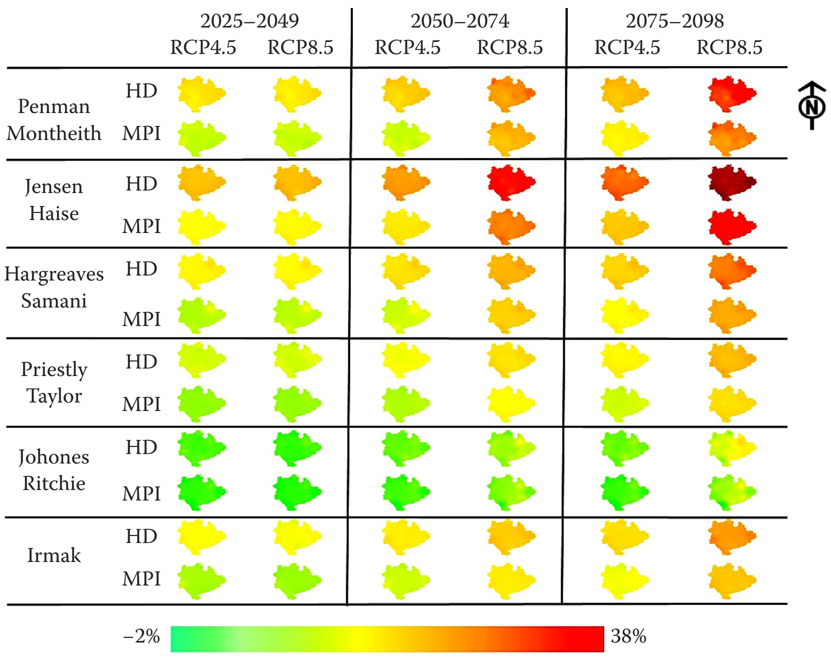

Figure 2. Spatio-temporal variation of percentage increase of annual total evapotranspiration (ET) obtained by six methods

RCP4.5 and RCP8.5 – representative concentration pathway 4.5 and 8.5 scenarios; HD_RCP_4.5 – RCP4.5 scenario of HadGEM2-ES model; HD_RCP_8.5 – RCP8.5 scenario of HadGEM2-ES model; MPI_RCP_4.5 – RCP4.5 scenario of MPI-ESM-MR model; MPI_RCP_4.5 – RCP8.5 scenario of MPI-ESM-MR model

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than RCP4.5 in both models. The map displaying the spatio-temporal change of the long-term average of the annual total ET amounts for the six methods employed (Figure 2) are given below.

When examining the state of ET values with respect to the methods, it has been observed that the JR method provides higher annual total ET values compared to the other methods. On the other hand, the PT and IR methods were found to yield lower annual total ET values. The PM method was determined to estimate a value close to the average of the six methods, and it was also established that the PT method provides ET values like those of the PM method (Figure 3).

In the study, the Sen's slope test, recommended by the World Meteorological Organization (WMO 2018) as a part of trend detection in hydro-meteorological data, and the Mann-Kendall test were applied to the annual total ET values. Within the scope of the Mann-Kendall test, S and Z values were calculated with a 0.05 level of significance ($\alpha < 0.05$). As a result of the tests performed, it was determined that there was a positive ET increasing trend in all models (HD and MPI), scenarios (RCP4.5 and RCP8.5), and methods (PM, JH, HS, PT, JR, and IR), except the ET values calculated with the JR method within the scope of the MPI model and RCP4.5 scenario.

Upon closer examination of the monthly ET values, it was observed that the PM and PT methods gave higher values during the summer period (June-August) compared to other methods. Additionally, it was also determined that the JR method calculated higher ET values during the winter period (December-March). The long-term average of monthly total ET amounts on a provincial basis for the reference period of 1980–2000 are provided in Figure 4.

Additionally, the relationship between the five methods used and the PM standard method was also investigated. The examination revealed that the JR method yields low correlation values with the PM standard method, while the other methods exhibit high correlation values (Table 5).

As the main objective of the study, model results for the reference period of 1980–2000 were com-

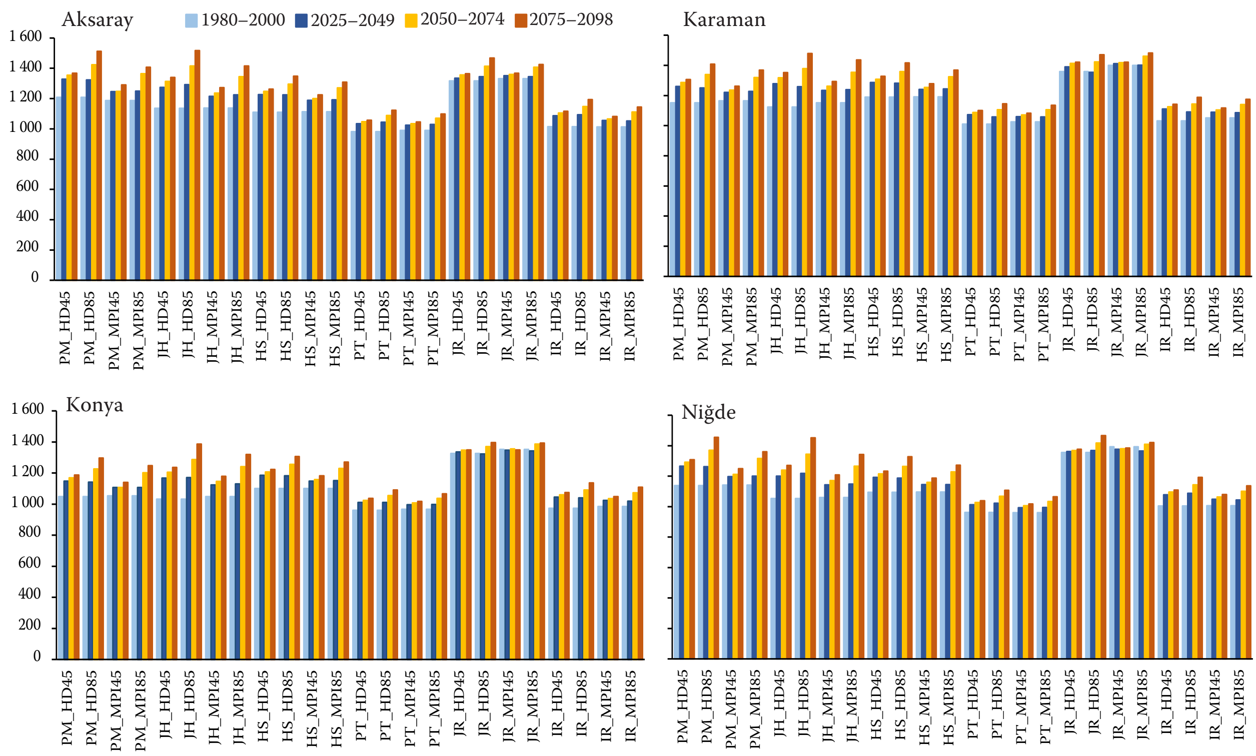

Figure 3. Long-term average of annual total evapotranspiration (ET) in the provinces (in mm)

PM – Penman-Monteith ET method; JS – Jensen-Haise ET method; HS – Hargreaves-Samani ET method; PT – Priestley-Taylor ET method; JR – Jones-Ritchie ET method; IR – Irmak ET method; RCP4.5 and RCP8.5 – representative concentration pathway 4.5 and 8.5 scenarios; HD45 RCP4.5 scenario of HadGEM2-ES model; HD85 – RCP8.5 scenario of HadGEM2-ES model; MPI45 – RCP4.5 scenario of MPI-ESM-MR model; MPI85 –RCP8.5 scenario of MPI-ESM-MR model

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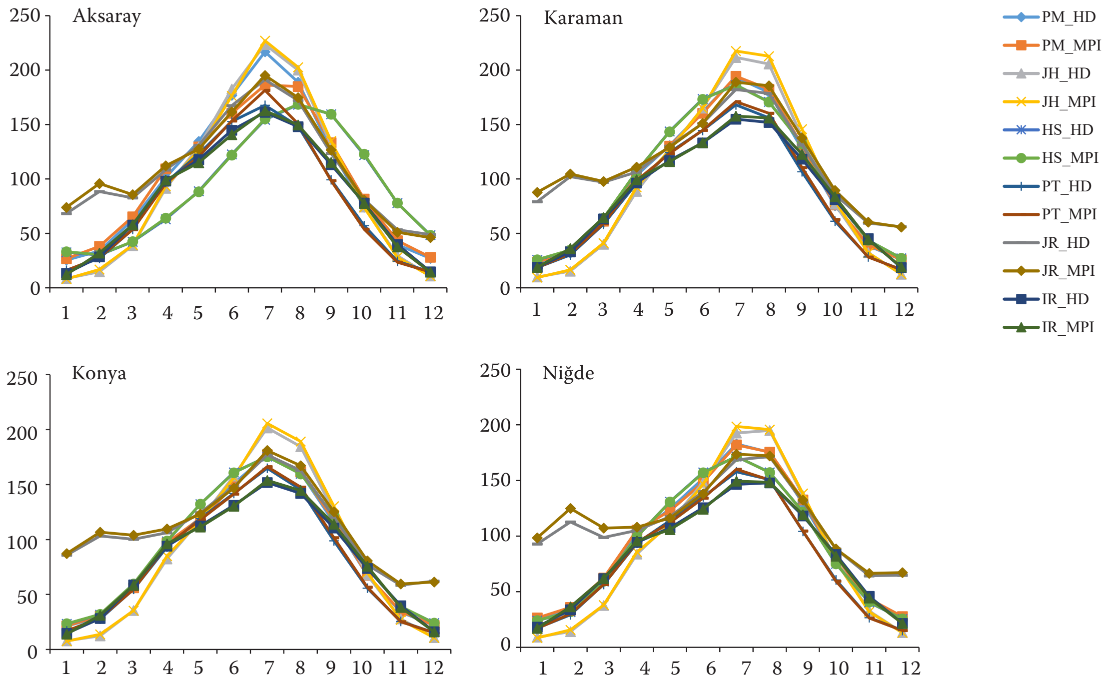

Figure 4. Long-term monthly average of evapotranspiration (ET) for the reference period 1980-2000 in the provinces (in mm) PM – Penman-Monteith ET method; JS – Jensen-Haise ET method; HS – Hargreaves-Samani ET method; PT – Priestley-Taylor ET method; JR – Jones-Ritchie ET method; IR – Irmak ET method; HD – HadGEM2-ES model; MPI – MPI-ESM-MR model

pared with the model results for future periods, spanning 2025–2049, 2050–2075, and 2075–2098. The comparative analysis showed that all employed methods projected an increase in ET amount for future periods, apart from a slight decrease of less than 1% obtained under the JR method for the fu-

Table 5. Correlation between the PM method and the other five methods employed

Stations	HD-Model					MPI-Model				
	PM-JH	PM-HS	PM-PT	PM-JR	PM-IR	PM-JH	PM-HS	PM-PT	PM-JR	PM-IR
Aksaray	0.95	0.75	0.92	0.71	0.93	0.93	0.76	0.88	0.67	0.91
Akşehir	0.96	0.96	0.95	0.57	0.95	0.96	0.96	0.94	0.55	0.95
Beyşehir	0.97	0.97	0.98	0.54	0.97	0.97	0.97	0.98	0.54	0.97
Cihanbeyli	0.95	0.95	0.92	0.61	0.93	0.95	0.95	0.92	0.63	0.93
Çumra	0.97	0.98	0.98	0.61	0.97	0.97	0.97	0.98	0.61	0.97
Ereğli	0.95	0.95	0.93	0.59	0.94	0.95	0.95	0.91	0.61	0.93
Hadim	0.96	0.96	0.94	0.49	0.95	0.96	0.95	0.92	0.40	0.94
Ilgın	0.97	0.97	0.96	0.60	0.96	0.97	0.97	0.96	0.58	0.96
Karaman	0.96	0.95	0.95	0.61	0.95	0.95	0.95	0.94	0.61	0.94
Karapınar	0.95	0.94	0.91	0.54	0.92	0.94	0.94	0.90	0.54	0.92
Konya HL	0.97	0.96	0.95	0.56	0.95	0.96	0.96	0.95	0.56	0.95
Kulu	0.96	0.96	0.94	0.56	0.95	0.96	0.96	0.94	0.56	0.95
Niğde	0.94	0.94	0.91	0.49	0.93	0.93	0.92	0.88	0.43	0.92
Yunak	0.95	0.95	0.91	0.51	0.93	0.95	0.95	0.90	0.49	0.93

PM – Penman-Monteith evapotranspiration (ET) method; JS – Jensen-Haise ET method; HS – Hargreaves-Samani ET method; PT – Priestley-Taylor ET method; JR – Jones-Ritchie ET method; IR – Irmak ET method; HD – HadGEM2-ES model; MPI – MPI-ESM-MR model ture period 2025–2049. Considering the framework of two climate change models, two scenarios, and six ET methods; it was determined that there will be an increase in ET amount compared to the 1980–2000 reference period. The magnitudes of these increases are provided in Table 6.

CONCLUSION AND DISCUSSION

The aim of the study is to examine the impact of climate change on ET in the Central Anatolia region of Türkiye. In this scope, six widely utilized methods were employed to calculate ET using various inputs and constants. ET values for the Aksaray, Karaman, Konya, and Niğde provinces in the Central Anatolia region of Türkiye were computed for both past and future periods. The calculations were performed using data generated under the RCP 4.5 and RCP 8.5 scenarios of the HD and MPI models.

To make calculations, first, the data was examined. In this context, data obtained from the HD model and the MPI model were analysed. With the models, it was determined that there is an increase in both temperature values and radiation values in the region. On the other hand, a decrease in relative humidity values was observed due to temperature and radiation. In the analysis studies carried out for climate change models in Türkiye, it has been determined that the HD model is more biased in terms of temperature increase than the MPI model (SYGM 2016) due to the climate and earth system model it consisted of. Here, with the analysis conducted, similar results were also determined and higher values for temperatures and radiation were obtained by the HD model than MPI. In addition to data analysis, a comparison study of data for the reference period was carried out. In this scope, model data were compared with actual measurement values for the reference period. As a result of the analysis, it was determined that in general while lower values were obtained for pressure within the scope of the data obtained with the model, higher values were obtained for humidity, sunshine duration, temperature, precipitation, and radiation.

Subsequently, after data examination, an analysis was conducted to determine the potential impacts of climate change on ET amount in the Central Anatolia region of Türkiye. The comparative analysis revealed that, apart from the decrease indicated by the JR method for the 2025–2049 period, all methods and scenarios estimated an increase in the ET amount for the future period. Trend analysis was performed on the ET series and positive increasing trends were determined. Particularly, the PM standard method was found to exhibit an increase in ET amount exceeding 10% from 2050 onward. Considering the average of the

Table 6. Percentage change in the annual total evapotranspiration (ET) amount for the future period

Methods/model		2025–2049		2050–2074		2075–2098	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Penman-Monteith	HD	9.7	9.1	11.7	17.1	13.4	23.8
	MPI	5.0	5.1	5.3	14.1	8.3	18.3
Jensen-Haise	HD	13.2	13.6	16.8	24.7	19.8	34.3
	MPI	7.3	7.8	9.4	18.4	12.5	25.7
Hargreaves-Samani	HD	8.1	7.8	10.1	14.4	11.6	19.2
	MPI	4.4	4.8	5.4	11.8	7.6	15.6
Priestly-Taylor	HD	5.5	5.5	6.8	10.0	8.1	13.7
	MPI	3.2	3.3	4.2	7.4	5.3	10.4
Jones-Ritchie	HD	0.9	0.0	1.8	3.8	2.1	6.1
	MPI	–0.2	–0.6	0.4	2.8	0.1	3.5
Irmak	HD	7.3	6.9	8.9	12.2	10.3	16.8
	MPI	4.0	3.5	5.2	9.0	6.6	12.7
Average	HD	7.5	7.1	9.3	13.7	10.9	19.0
	MPI	3.9	4.0	5.0	10.6	6.7	14.4

Table shows the average of 14 locations investigated; RCP4.5 and RCP8.5 – representative concentration pathway 4.5 and 8.5 scenarios; HD – HadGEM2-ES model; MPI – MPI-ESM-MR model

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six methods employed, according to the RCP4.5 and RCP8.5 scenarios of the HD model, it was determined that the increase in ET will be respectively; 7.5% and 7.1% for the period 2025–2049, 9.3% and 13.7% for the period 2050–2074, and finally 10.9% to 19% for the period 2075–2098. On the other hand, depending on the RCP4.5 and RCP8.5 scenarios of the MPI model, the increase in ET was estimated as respectively; 3.9% and 4% for the period 2025–2049, 5% and 10.6% for the period 2050–2074, and finally 6.7% to 14.4% for the period 2075–2098.

In conclusion, as a result of the study, it is determined that the ET amount in Türkiye's Central Anatolia region will increase by up to 11% by the end of this century under the optimistic RCP 4.5 scenario, and by up to 20% under the extreme RCP 8.5 scenario.

Central Anatolia is a region that is under the influence of the Mediterranean climate zone but has a drier characteristic due to its continental structure. Climate change studies have revealed that the Central Anatolia region, along with other regions under the influence of the Mediterranean climate zone, is one of the most sensitive regions of Türkiye that will be affected by climate change. The results obtained from this study support this consideration. Due to the location of the region, it is possible that the effects of climate change in the region are parallel to the studies carried out in other Mediterranean zone countries.

In examinations conducted, it has been determined that the findings obtained from this study exhibit consistency with research in countries situated within the Mediterranean climate zone. For instance, a study conducted in Greece revealed an estimated increase in evapotranspiration (ET) levels ranging between 6–10% for the period of 2020–2050 compared to the reference period (Nastos et al. 2015). Another study conducted for northern Greece indicated an approximate 10% rise in ET levels during the 2040–2060 period and an increase exceeding 20% for the 2080 to 2100 period (Koukouli et al. 2019). North African countries, positioned as among the most vulnerable regions to climate change within the Mediterranean zone, were also subject to a study involving 22 North African and Middle Eastern countries (Terink et al. 2013). With the study, it is revealed that there will be ET increases of over 20% on average in the period between 2030 and 2050 for these 22 countries. Similar outcomes were derived from the research conducted in Western Mediterranean countries. In the study conducted by Moutahir and Bellot (2016) for the southeast of Spain, it was estimated that the evapotranspiration (ET) in the southeast of Spain would increase by around 10% under the RCP4.5 scenario. Furthermore, in the scope of the study, it was also determined that the increase would exceed 20% under the RCP8.5 scenario. In another study covering Spain, Portugal, Morocco, and Algeria, it was estimated approximately a 10% increase in ET levels by 2050 (Saadi et al. 2015). Similarly, a study carried out for the Po Basin in Italy by Bocchiola (2015) indicated an increase of around 10% in ET values. Within the scope of another study conducted in France, similar results were found, as well (Habets et al. 2013). Beyond these studies, a comparable study was conducted in Iran, located within the latitude degrees of the Mediterranean region. In the study, it was determined that according to the RCP4.5 scenario, there would be a 4–5% increase in ET levels by 2040 and an increase of around 15% by the end of the century. According to the RCP8.5 scenario, the increase was estimated to be around 20% (Fallah-Ghalhari & Shakeri 2023).

Studies, conducted in countries within the Mediterranean region and characterized by Mediterranean climates, have established an increase in evapotranspiration (ET) values. The observed increments in these studies range around 5–10% for the optimistic scenarios of RCP2.6 and RCP4.5 while approaching and exceeding 20% for RCP8.5, which represents a more extreme scenario. It has also been inferred from the studies that the ratio of increase in North African countries is expected to be higher. Similar outcomes to those observed in Mediterranean countries were obtained in this study, as well. Moreover, in Türkiye, Azlak and Şaylan (2019) conducted a study specifically for the Thrace region. Under the A1B scenario, an older climate change scenario corresponding to the RCP6, the study projected an approximate 10% increase in ET amounts by the year 2040. In this context, this study gave consistent results with the previous study.

The region's significance in terms of agricultural production, characterized by both heterogeneity and diversity, has led to an increasing importance of studies concerning the impacts of climate change on agricultural production and water resources in the region. Consequently, research on the effects of climate change on agricultural production, and hence on evapotranspiration (ET), has been gaining significance. Given the region's importance in agricultural

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production and diversity, coupled with limited water resources and high susceptibility to climate change, studies that contribute to agricultural planning and water resource management have become crucial priorities for the region. Considering the numerous studies on ET, managing water resources and sustainably planning agricultural production is essential for food security, socioeconomic development, and ecological sustainability in the region. However, it is equally important to focus on determining the impacts of climate change on agricultural products produced in the region. Such research is essential for accurate and sustainable planning and ensuring sustainability in agricultural production and water management.

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