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Climate Change Impacts on Precipitation Dynamics in the Southern Marmara Region of Turkey[A]

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Abstract: Understanding the dynamics of precipitation patterns is crucial for effective water management strategies, especially in regions vulnerable to the impacts of climate change. This study investigates the projected changes in annual and seasonal precipitation across the Southern Marmara Region of Turkey by comparing the averages of the reference period (1971-2000) with those of the future period (2061-2090). Employing multiple climate models (*GFDL, HADGEM*, and *MPI*) and Representative Concentration Pathways (*RCP4.5* and *RCP8.5*), the analysis includes Mann-Kendall trend tests and Sen's slope method to determine trends in precipitation patterns. Key findings reveal significant variability in precipitation projections among different models and scenarios, with implications for water resource management, agriculture, and ecosystem resilience in provinces such as Çanakkale, Balıkesir, Bursa, Bilecik, and Yalova. According to the annual rainfall change rates relative to the reference period, Balıkesir province stands out as the most resilient province against climate change with average rates of 8.81% and 7.09% under the HADGEM and MPI model simulations, respectively. Regarding seasonal variations, Bilecik province is expected to experience a significant decrease in rainfall, reaching up to -53.78% under the MPI RCP8.5 scenario. In terms of within-period changes in annual rainfall values, the strongest declining trend was identified with Z=-2.03 in Bilecik province under the MPI RCP8.5 scenario conditions by the Mann-Kendall test. On the other hand, for seasonal variations, Bursa province demonstrates the most robust decreasing trend under the GFDL RCP4.5 conditions (Z=-2.89). The study

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emphasizes the importance of considering spatially varying precipitation patterns and potential shifts in atmospheric circulation for sustainable water resource management amidst climate variability and change in the Southern Marmara region. These findings provide critical insights for policymakers and stakeholders involved in developing adaptive strategies to address the challenges posed by future climate scenarios.

Keywords: Precipitation, climate change, Marmara Region, climate models, Mann-Kendall test.

İklim Değişikliğinin Türkiye'nin Güney Marmara Bölgesi'ndeki Yağış Dinamikleri Üzerindeki Etkileri

Öz: Yağış dağılımının dinamiklerini anlamak, özellikle iklim değişikliğinin etkilerine duyarlı bölgelerde etkili su yönetimi stratejileri için hayati öneme sahiptir. Bu çalışma, referans dönem (1971-2000) yıllık ve sezonluk ortalamalarını gelecek dönem (2061-2090) ortalamaları ile karşılaştırarak Türkiye'nin Güney Marmara Bölgesi'ndeki yağışlarda öngörülen değişiklikleri incelemektedir. Farklı iklim modelleri (*GFDL*, *HADGEM* ve *MPI*) ve Temsili Konsantrasyon Senaryoları (*RCP4.5* ve *RCP8.5*) kullanılarak gerçekleştirilen analizler, yağış eğilimleri belirlemek için Mann-Kendall testi ve Sen'in eğim yöntemlerini içermektedir. Temel bulgular, Çanakkale, Balıkesir, Bursa, Bilecik ve Yalova illerinde su kaynakları yönetimi, tarım ve ekosistem dayanıklılığına ilişkin çıkarımlarla birlikte, farklı modeller ve senaryolar arasında yağış tahminlerinde önemli farklılıklar olduğunu ortaya koymaktadır. Referans dönemine göre yıllık yağış değişim oranlarına göre Balıkesir ili, HADGEM ve MPI model simülasyonlarında sırasıyla %8.81 ve %7.09 ortalamalarıyla iklim değişikliğine karşı en dayanıklı il olarak öne çıkmaktadır. Mevsimsel değişimler dikkate alındığında; MPI RCP8.5 senaryosuna göre Bilecik ilinde yağışlarda önemli bir düşüş yaşanarak, değişimin referans döneme göre -%53.78'e kadar ulaşması beklenmektedir. Mann-Kendall testi ile belirlenen yıllık yağış değerlerinde dönem içi değişimlerde en kuvvetli düşüş eğilimi MPI RCP8.5 senaryo koşullarında Z=-2.03 Bilecik ilinde ile tespit edilmiştir. Öte yandan, sezonluk değişimler açısından, GFDL RCP4.5 koşullarında en kuvvetli düşüş trendini Bursa ili göstermiştir (Z=-2.89). Çalışma, Güney Marmara Bölgesi'ndeki iklim değişkenliği ve bu değişim ortamında sürdürülebilir su kaynakları yönetimi için mekânsal olarak değişen yağış düzenlerinin ve atmosfer olaylarında potansiyel değişimlerin dikkate alınmasının önemini vurgulamaktadır. Bu bulgular, gelecekteki iklim senaryolarının ortaya çıkardığı zorlukların üstesinden gelmek için adaptasyon stratejileri geliştirmede rol olan karar vericiler ve paydaşlar için önemli bilgiler sağlamaktadır.

Anahtar Kelimeler: Yağış, iklim değişikliği, Marmara Bölgesi, iklim modelleri, Mann-Kendall testi.

Introduction

Rainfall, as a fundamental component of the regional climate system, plays a pivotal role in water availability and sustaining agriculture (Subramanian et al., 2023). The variability and distribution of rainfall have far-reaching implications, affecting from soil quality to government policies and planning. As a primary source of freshwater, rainfall sustains not only agricultural productivity but also plays a crucial role in supporting terrestrial and aquatic ecosystems. It provides essential hydration for crops, contributing directly to their growth and yield. Additionally, rainfall replenishes groundwater reserves and maintains the ecological balance necessary for the survival of various crop and animal species, including those crucial for soil fertility and natural pest control (McLaughlin and Kinzelbach, 2015). Rainfall, which holds crucial importance for ecosystems due to the mentioned effects, has been altered by urbanization, industrialization, land-use changes, and the effects of climate change, posing challenges for water resource management. Against this backdrop, delving into the distribution of rainfall becomes essential for devising informed strategies for adaptation, enhancing resilience, and fostering sustainable development in different regions. Given its crucial role, studies were extensively conducted on distribution and fluctuations of precipitation globally (New et al., 2001; Gemmer et al., 2004; Adler et al., 2017; Carvalho, 2020; Guo et al., 2020; Ekwueme and Agunwamba 2021; Verma et al., 2022; Berhail and Katipoğlu, 2023). Alongside global studies, the increasing temperatures within intricate climatic system of Turkey make it one of the countries most affected by climate change, underscoring the importance of examining precipitation patterns in Turkey (Yetik et al., 2024).

The drought events pose a mounting challenge in various regions worldwide, including Turkey (Serkendiz et al., 2023). Turkey falls within the Mediterranean macro-climate zone, characterized by sub-tropical lands along its western coasts (Türkeş and Deniz, 2011). Coastal regions are even more vulnerable to the impacts of current and projected climate change, with the mean temperature having increased by 0.85 °C over the past century (Solomon, 2007; Toros et al., 2019). The Southern Marmara region, comprising provinces of Bursa, Bilecik, Balıkesir, Çanakkale, and Yalova, serves as a transition zone between various climate zones and has a coastline along the Marmara Sea. It also shares some features of the Mediterranean climate belt. Known for its diverse landscapes ranging from fertile plains to rugged mountains, the Southern Marmara region plays a crucial role in the agricultural and economic sectors of the country (Koldemir, 2016). However, the region also faces challenges related to climate change, including fluctuations in rainfall patterns, and increasing aridity (Sevim et al., 2022).

Evaluations to determine the risks posed by future changes in rainfall on agriculture and water resources are crucial for fostering initiatives towards sustainable development in Turkey. Türkeş et al. (2020) investigated future precipitation changes in Turkey, utilizing regional climate model simulations to assess alterations in seasonal precipitation climatology, extreme weather conditions, and aridity conditions for the period of 2021–2050 compared to the reference period of 1971–2000. Another study by Danandeh Mehr and Kahya (2017) examined the impacts of climate change on catchment-scale extreme rainfall variability, focusing specifically on Rize Province, Turkey. Gorguner et al. (2019) assessed the impact of future climate change on precipitation and water resources in Gediz Basin (Turkey) by dynamically downscaling CMIP5 projections. Yilmaz (2015) investigated the effects of climate change on historical and future extreme rainfall in Antalya, Turkey. Nigussie and Altunkaynak (2019) investigated the impacts of climate change on the trends of extreme rainfall indices and maximum precipitation values at Olimpiyat Station, Istanbul, Turkey. As highlighted by Türkeş (1998), varied geographic characteristics of Turkey mean that different regions will experience climate change effects in distinct ways and to varying extents. Therefore, understanding the distribution and fluctuations of rainfall in the specific regions is critical for devising tailored adaptation and negativity mitigation strategies, ensuring effective responses to the localized challenges posed by climate change. In this study, the rainfall data of Southern Marmara Region of Turkey were examined for the reference (1971-2000) and future (2061-2090) periods. Trends of annual and seasonal (May-September) rainfall values were determined using Mann-Kendall Test and Sen Method.

Material and Method

Study Site

The study was carried out for five provinces of the Southern Marmara Region (Figure 1). The Southern Marmara region, situated in the northwest of Turkey, encompasses provinces of Çanakkale, Balıkesir, Bursa, Bilecik, and Yalova. This region exhibits diverse topographical features, ranging from mountainous terrain to coastal plains, which significantly influence its climate patterns and precipitation regimes (Sariş et al., 2010). Its proximity to the Aegean and Marmara Seas plays a crucial role in shaping local weather conditions, with maritime influences often moderating temperatures and contributing to precipitation variability throughout the year. Table 1 presents the geographical location characteristics of the stations and the average annual rainfall amounts obtained from the Turkish State Meteorological Service covering a long-term period (TSMS, 2024).

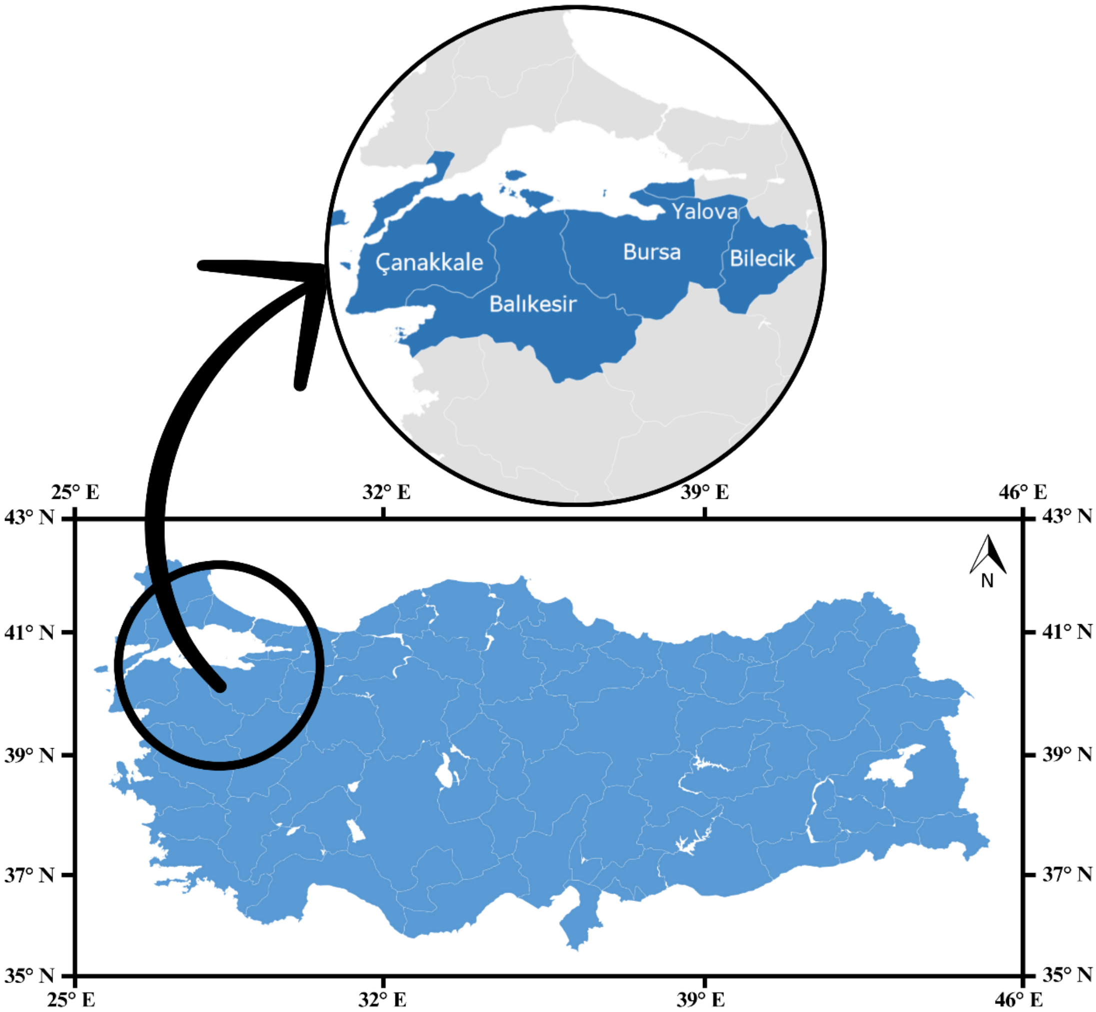

Figure 1. *Study site*

Table 1. The features of meteorological stations in the Southern Marmara Region 25

Station	Latitude	Longitude	Elevation (m)	Annual precipitation (mm)	Record period
Çanakkale	40.31	26.35	2	624.4	1929-2023
Balıkesir	40.35	28.05	70	675.6	1999-2023
Bursa	40.18	29.03	100	707.4	1928-2023
Yalova	40.55	29.27	30	754.6	1931-2023
Bilecik	40.19	30.00	500	459.6	1939-2023

Precipitation Data Set

The study utilized three distinct global climate models (*GCMs*) alongside two Representative Concentration Pathways (*RCPs*) to assess historical and projected precipitation patterns at selected meteorological stations. The chosen GCMs include HadGEM2-ES, MPI-ESM-MR, and GFDL-ESM2M, while the selected RCPs are RCP4.5

and RCP8.5. RCP4.5 represents a scenario with a higher likelihood of occurrence, whereas RCP8.5 is considered the most pessimistic scenario due to its anticipation of the highest global increases in temperatures and radiative forcing values (Javaherian et al., 2021; Khoirunisa, 2022). The datasets were created using the regional climate model (*RegCM4.3.4*) methodology by Akçakaya et al. (2015). This approach enables a comprehensive assessment of daily precipitation values, facilitating the determination of changes and trends in historical patterns and future projections. The base period used in the study spans from 1971 to 2000, serving as the reference for comparison, while future projections are made for the period 2061-2090.

Data Analysis

Two distinct methods were employed to assess precipitation pattern trends: the Mann-Kendall trend test and Sen's slope method. The Mann-Kendall trend test is a non-parametric statistical test used to detect trends in time-series data, evaluating whether a monotonic upward or downward trend exists over a specified period. The test statistic, denoted as *S*, is calculated as the sum of signs of differences between pairs of data points. The significance of the trend is determined by comparing the test statistic to a critical value obtained from the Kendall distribution (Kendall, 1948; Kendall, 1975). The statistics for the Mann-Kendall test (*S*) are provided below (Equation 1):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sgn(x_j - x_i) \quad (1)$$

In the Equation 1, the symbol "n" signifies the number of data points, while "X_j" and "Xi" denote the annual values in years "j" and "i", respectively, with "j" greater than "i". The expression Sign (X_j - X_i) represents the sign function, which assigns values of either 1, 0, or -1 based on the comparison between X_j and X_i. A positive value of S indicates a trend of increasing magnitude, while a negative value suggests a decreasing trend. However, to validate the significance of this phenomenon, a statistical analysis is required. The test procedure, utilizing the normal approximation test, is elaborated by Kendall (1975). This test assumes that the dataset does not contain numerous consecutive values. The variance (*S*) is computed using the following equation (Equation 2):

$$\text{Var (S)} = \frac{n(n - 1)(2n + 5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5)}{18} \quad (2)$$

In the Equation 2, n represents the number of data points, g denotes the count of zero differences between compared values, and tp signifies the number of data points. A standardized measure of test statistics (Z_{mk}) is calculated using the following equation (Equation 3):

$$Z_{mk} \begin{cases} (S-1)/\sqrt{(Var(S))} & S<0 \\ 0 & S=0 \\ (S+1)/\sqrt{(Var(S))} & S>0 \end{cases} \tag{3}$$

The standardized Z_{mk} values are determined to follow a normal distribution with mean 0 and variance 1, serving as a measure of trend significance.

In contrast, Sen's slope method, also known as the Sen-Theil slope estimator, estimates the magnitude and direction of the trend by calculating the median of the slopes of all possible pairs of data points (Van Belle and Hughes, 1984). This method is robust to outliers and does not assume normality in the data distribution. The slope, denoted as Q, is computed as the median of the differences between all pairs of data points (Sen, 1968). The slope of Sen is calculated as the mean of all pairwise slopes for any pair of points in the dataset. Each individual slope (m_{ij}) is estimated using the following equation (Equation 4):

$$m_{ij} = \frac{Y_j - Y_i}{j - i} \tag{4}$$

The Von Neumann Ratio test, introduced in Bartel (1982), was used to asses the changes within the precipitation dataset. This method contrasts the disparities in ranks between consecutive observations against the total variability of those ranks. The test statistic (N) is calculated as the ratio between the sum of squared rank differences and the sum of squared deviations from the mean rank. In cases where the sample size consists of 30 records (n), when the N value falls below 1.20 ($p<0.01$) and 1.42 ($p<0.05$), it indicates statistical significance levels of 1% and 5%, respectively, implying a notable shift in the time series.

Results and Discussion

The von Neumann test was utilized to assess the homogeneity of the precipitation dataset of stations across three distinct models and three different time periods (Table 2). The calculated N values consistently exceeded the predefined threshold for significance at the 1% and 5% levels, indicating the homogeneity of the dataset. This result underscores the stability of the underlying trend in the data across all examined models, time periods, and stations. Gürkan et al. (2024) stated that utilization of meteorological stations with continuous data for their assessments of the reference period (1971-2000) and future period (2023-2098). The presence of stations located in Çanakkale, Balıkesir, Bursa, Bilecik, and Yalova among those selected by the researchers was notable.

Table 2. Results of von Neumann Homogeneity Test for the stations across various models, periods

Model	Station	Seasonal						Annual					
		RF		GL_45		GL_85		RF		GL_45		GL_85	
		N	p	N	p	N	p	N	p	N	p	N	p
GFDL	Çanakkale	1.839	*0.331*	1.608	*0.136*	2.562	*0.950*	2.031	*0.541*	1.786	*0.272*	2.522	*0.934*
	Balıkesir	2.113	*0.625*	2.364	*0.848*	2.225	*0.728*	2.017	*0.515*	1.875	*0.364*	2.046	*0.545*
	Bursa	2.507	*0.921*	1.492	*0.080*	2.189	*0.696*	1.941	*0.436*	1.878	*0.369*	1.935	*0.428*
	Yalova	2.117	*0.629*	1.595	*0.133*	2.339	*0.823*	1.531	*0.102*	1.780	*0.276*	2.353	*0.843*
	Bilecik	2.461	*0.905*	1.458	*0.059*	2.532	*0.934*	1.708	*0.220*	2.041	*0.543*	1.998	*0.496*
HADGEM	Çanakkale	1.628	*0.153*	2.176	*0.676*	1.796	*0.284*	2.463	*0.904*	2.407	*0.871*	2.284	*0.794*
	Balıkesir	1.942	*0.441*	2.513	*0.943*	2.090	*0.571*	1.932	*0.424*	2.193	*0.705*	2.254	*0.761*
	Bursa	1.975	*0.475*	2.258	*0.764*	1.632	*0.154*	1.992	*0.487*	1.576	*0.120*	2.072	*0.578*
	Yalova	1.890	*0.390*	2.383	*0.864*	1.448	*0.060*	1.939	*0.440*	1.956	*0.456*	1.713	*0.216*
	Bilecik	1.883	*0.372*	2.104	*0.614*	1.947	*0.443*	1.677	*0.190*	1.591	*0.130*	1.883	*0.373*
MPI	Çanakkale	2.055	*0.547*	2.001	*0.495*	1.797	*0.294*	2.663	*0.973*	2.456	*0.894*	1.519	*0.092*
	Balıkesir	1.919	*0.393*	2.129	*0.623*	1.567	*0.113*	2.012	*0.508*	2.723	*0.996*	2.097	*0.609*
	Bursa	1.951	*0.436*	2.582	*0.952*	2.197	*0.693*	1.690	*0.192*	1.976	*0.478*	1.721	*0.227*
	Yalova	1.877	*0.362*	2.666	*0.974*	1.925	*0.406*	1.702	*0.208*	2.114	*0.634*	2.073	*0.584*
	Bilecik	2.074	*0.579*	1.937	*0.398*	2.339	*0.828*	1.917	*0.413*	2.228	*0.730*	1.715	*0.219*

The annual and seasonal precipitation results for different cities and different periods obtained from dataset of various models are presented in Table 3. The GFDL model generally predicts higher annual and seasonal precipitation levels compared to other models across the five cities. This may indicate a tendency towards overestimation of precipitation in the region by the GFDL model. However, it is important to note the variability within the different scenarios of model, as seen in the fluctuations of precipitation levels across seasons and cities. Koç (2001) conducted a comprehensive analysis of precipitation patterns within an extensive area encompassing the Marmara Region, shedding light on the presence of erratic precipitation phenomena. The findings revealed the diverse nature of precipitation behavior in the region, indicating that variations in precipitation levels occur not only across different seasons but also within different cities. The most significant change in the GFDL model was observed in the Yalova province, where the annual precipitation amount decreased from 877.7 mm to 753.1 mm. Bursa, Yalova, and Bilecik exhibit lower precipitation amounts under the GFDL RCP8.5 scenario compared to the RCP4.5 scenario, whereas Çanakkale and Balıkesir provinces experience higher precipitation under the RCP8.5 scenario.

Under the HADGEM model, there is significant variability in the projected precipitation levels across different cities and scenarios (Table 3). For instance, in Balıkesir, the model predicts higher precipitation amounts under future scenarios, indicating uncertainties in precipitation projections, while observed a seasonal precipitation increase from 190.3 mm to 259.0 mm. This discrepancy between the HADGEM model and the other two models, where precipitation decreases in the future, suggests the need for further investigation into the underlying mechanisms. The limiting factors utilized in the development of the models are considered as the fundamental reasons behind the discrepancies observed in the conducted simulations. The complexity in interpreting precipitation projections stems from the inherent discrepancies among different climate models, leading to uncertainties regarding the direction and magnitude of future precipitation changes (Agarwal et al., 2014). The utilization of multiple climate models in studies aims to better analyze these disparities, which is crucial for improving the accuracy and reliability of climate projections (Tebaldi and Knutti, 2007).

The MPI model presents a different perspective on precipitation projections, generally forecasting lower precipitation levels across the region compared to other models. For instance, in Bursa, the MPI model predicts relatively lower annual and seasonal precipitation levels compared to the GFDL and HADGEM models. When focusing on seasonal rainfall, decreases are observed across all provinces, with the highest differences between the RF and GL_RCP8.5 scenarios occurring in the provinces of Yalova (59.9 mm) and Bilecik (53.1 mm).

Table 3. The annual and seasonal precipitation values obtained from models for different scenarios

Model	Period	Çanakkale		Balıkesir		Bursa		Yalova		Bilecik	
		Annual	Seasonal	Annual	Seasonal	Annual	Seasonal	Annual	Seasonal	Annual	Seasonal
GFDL	RF	730.5	573.6	822.1	506.1	648.2	322.9	877.7	476.2	632.7	312.1
	GL_45	634.8	470.8	771.0	462.0	611.9	283.0	773.6	383.5	604.5	271.9
	GL_85	663.9	489.5	797.5	501.7	582.5	260.1	753.1	373.2	572.7	252.4
HADGEM	RF	855.4	351.0	764.1	190.3	630.3	175.2	842.1	222.1	628.0	185.9
	GL_45	878.4	378.4	790.3	224.9	607.5	176.8	821.6	205.3	639.4	189.4
	GL_85	844.2	355.8	872.6	258.0	645.3	204.1	836.4	243.6	625.4	206.3
MPI	RF	628.3	94.0	459.4	102.1	447.7	95.8	536.6	133.7	407.1	98.7
	GL_45	620.0	90.0	532.1	117.1	477.0	86.4	568.4	124.3	423.8	80.6
	GL_85	642.0	83.2	451.9	76.3	415.3	53.6	484.1	73.8	356.5	45.6

Figure 2 illustrates the annual and seasonal change rates relative to the Reference (RF) period, providing insights into the variations in precipitation trends across different models and scenarios. In the analysis of annual precipitation change rates relative to the RF period across different provinces and climate models, notable variations are noticed. Çanakkale demonstrates consistent decreases under the GFDL model for annual period in both GL_RCP4.5 and GL_RCP8.5 scenarios, with rates of -13.11% and -9.12%, respectively. Conversely, the HADGEM model shows mixed trends, with an increase of 2.69% under GL_RCP4.5 and a decrease of -1.31% under GL_RCP8.5 for annual period. Similarly, the MPI model presents contrasting results, indicating a decrease of -1.32% under GL_RCP4.5 and an increase of 2.18% under GL_RCP8.5 for annual. In Balıkesir, while the GFDL model suggests decreases in both scenarios, the MPI model projects increases, particularly notable with a significant increase of 15.82% under GL_RCP4.5. Bursa experiences decreases for RCP4.5 scenario under the GFDL and HADGEM models (-5.60% and -3.61%) but shows increases under the and MPI model (6.55%), indicating a complex pattern of precipitation changes. Yalova and Bilecik provinces exhibit significant similarities in annual precipitation changes across different models, with both provinces showing a decreasing trend proportionally under the RCP8.5 scenarios in all models. Specifically, change rates of Yalova for this scenario ranged between -0.68% and -14.19%, while for the Bilecik between -0.42% and -12.42%. In examining seasonal variations under future scenarios, notable fluctuations in percentage changes of rainfall are observed across the models and regions, compared to the reference period of 1971-2000 (*RF*) averages. Overall, the minimum and maximum changes are significant, with certain areas experiencing substantial shifts. For instance, in Çanakkale, under both RCP4.5 and RCP8.5 scenarios, the GFDL model shows a minimum increase of approximately 1.36% and a maximum decrease of about -17.92%. Conversely, in Balıkesir, the HADGEM model exhibits a maximum increase of roughly 18.15% and a maximum decrease of approximately -25.22% under RCP8.5, indicating considerable changes in precipitation relative to the reference period. Similarly, Bursa demonstrates noteworthy disparities, with the HADGEM model forecasting a decrease of around -43.99% in the scenario of RCP8.5. Yalova and Bilecik provinces, on the other hand, stand out as the provinces exhibiting maximum changes in the seasonal variations, with decreases of -44.80% (HADGEM RCP8.5) and -53.78% (MPI RCP8.5), respectively.

Sohoulande Djebou and Singh (2016) highlighted that climate change was expected to disrupt precipitation patterns, with significant implications for various aspects of water resources. In this sense, numerous studies have investigated future precipitation changes using different climate models worldwide (Kundu et al., 2014; Gao et al., 2020; Doulabian et al., 2021; Fan et al., 2021; Yaghoobzadeh, 2022). In the context of studies conducted in Turkey, Demircan et al. (2017) provided insights into the projected precipitation trends for the different regions of Turkey. Their findings, under the RCP4.5 scenario, suggest a significant decrease in summer precipitation, with anticipated reductions of up to 30%. On the other hand, under the RCP8.5 scenario, increased winter precipitation was indicated, particularly in northern Anatolia, alongside declines in spring precipitation across Turkey, including the Marmara region. Moreover, when summer rainfall was examined, coastal areas of the Marmara region showed no significant decrease in the HadGEM2-ES model, whereas decreases were observed in the MPI-ESM-MR and GFDL-ESM2M models. Bağçaci et al. (2021) analyzed precipitation changes over Turkey using CMIP6 database for climate, indicating a slight decrease in mean precipitation (-2.5%) and notable changes in extreme precipitation, with up to a 40% decrease in some regions. Seddiqe et al. (2023) examined the effects of climate change on streamflow in the Ayazma river basin, situated in the Marmara region of Turkey. Utilizing Regional Climate Model (*RCM*) outputs from CNRM-CM5/RCA4, EC-EARTH/RACMO22E, and NorESM1-M/HIRHAM5 under the RCP4.5 and RCP8.5 emission scenarios, they observed significant increases in precipitation projections, with positive anomalies ranging from 22 to 227 mm. The variability in the precipitation climate of the Marmara region was attributed to various factors.

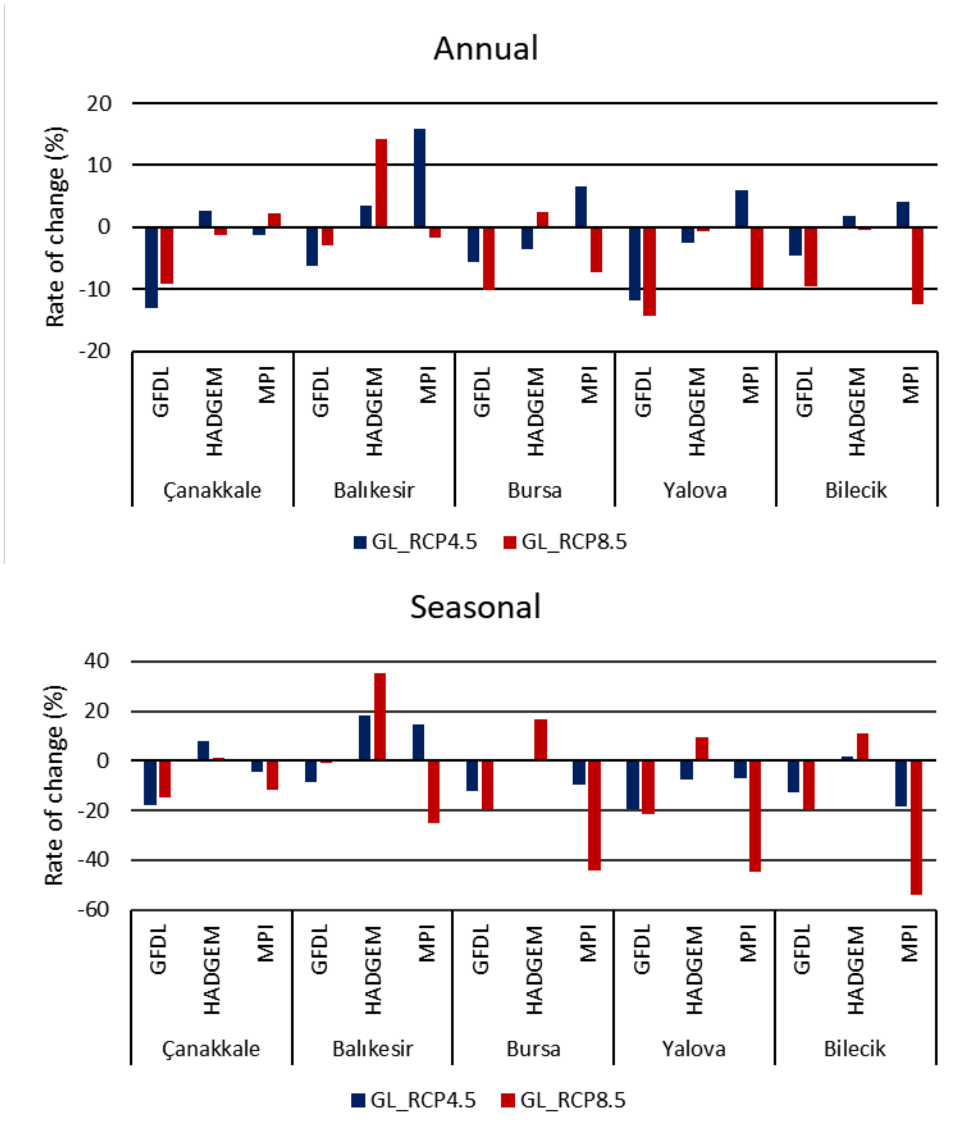

Figure 2. *Annual and seasonal precipitation change rates relative to the reference period*

The proximity of the Marmara region to the Black Sea and its complex topography contribute to this variability. Precipitation patterns are influenced by atmospheric circulation types, with northerly and easterly maritime trajectories playing a significant role in contributing to rainfall. However, stations farther away from the Black Sea, especially those in the western part of the region, experience rainfall associated with southerly components. This spatially heterogeneous response of precipitation to atmospheric circulation explains the complexity of the climate of region (Baltacı et al., 2015; Sirdaş et al., 2016).

The analysis of trends in annual precipitation data for the Southern Marmara Region is shown in Figure 3 , with significance levels at 1%, 5%, and 10%. The analysis conducted using the GFDL model revealed significant variations in annual precipitation trends across different cities under various RCP scenarios. During the RF period, all cities exhibited negative trends, with the sole statistically non-significant alteration detected in

Balıkesir (Z=-1.57). For both RCP scenarios, no significant trends were determined between the years 2061 and 2090. The results from the HADGEM model revealed upwards trends during the RF period, with a significant positive trend detected in Bilecik (Z=2.21, *α=0.05*). Furthermore, under the RCP8.5 scenario conditions, the model yielded results indicating adverse impacts on annual precipitation in the region, with a downward trend identified in all provinces except Bilecik. The MPI model stood out among all models as the one in which the adverse effects of climate change on annual precipitation distribution were most prominently observed. According to the model results, negative trends were identified for all provinces during the RF period, and these trends were significant for the provinces of Bursa (10%), Yalova (5%), and Bilecik (10%).

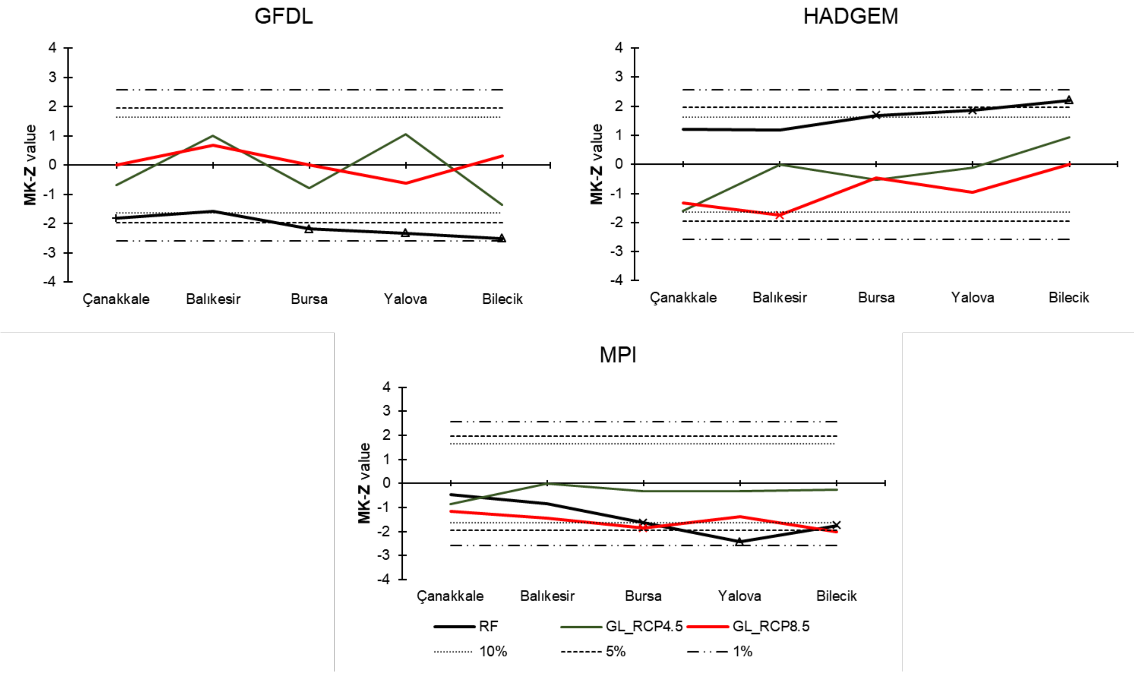

Figure 3. *Mann-Kendall test results of annual precipitation for different models and periods*

The analysis of trends in seasonal precipitation data for the Southern Marmara Region is shown in Figure 4, with significance levels at 1%, 5%, and 10%. Considering the seasonal analysis, it is pivotal to highlight the implications of these findings for agricultural irrigation, particularly in the context of water-intensive farming practices. In the seasonal results of the GFDL model, a negative change direction was observed for all provinces and scenarios. The strongest trend during the RF period was identified in Çanakkale with Z=-2.28 (*α=0.05*), while the province with the lowest Z value was Balıkesir (Z=-1.46). In the RCP4.5 scenario, a significant decrease of 1% was observed in Bursa, while significant decrease trends of 10% were found in Yalova and Bilecik provinces. In the RCP8.5 scenario, trends close to 0 were observed in Balıkesir and Bilecik provinces. The HADGEM model was identified as the model with the lowest frequency of intra-seasonal precipitation changes during the RF period. For the RCP4.5 scenario, no significant trends were observed, with the strongest trend identified in Bursa province with Z=-1.07. In the RCP8.5 scenario, intra-seasonal changes were quite pronounced, with significant decreasing trends of 5% identified in all provinces except Bilecik. Finally, the MPI model revealed negative trends for all provinces and scenarios. During the RF period, Bursa, Yalova, and Bilecik provinces exhibited the most severe trends, with Bilecik was emerged as the province expected to experience the most significant decrease in precipitation in both RCP scenarios in the future period (Figure 3). Given that variability in coastal regions is influenced not only by meteorological parameters but also by geological conditions, it is critical to examine temporal changes through pointwise Mann-Kendall testing (Xavier Junior et al., 2020). Demir and Kisi (2016) utilized the Mann-Kendall test method to analyze trends in annual total precipitation across provinces in the central Black Sea region. They found varying trends of increasing and decreasing annual total precipitations across the six provinces (Sinop, Samsun, Ordu, Corum, Amasya, and Tokat) within the region. Bağdatlı and Can (2019) conducted a study using the Mann-Kendall tests and reported significant increases in maximum precipitation trends during winter and autumn months in Nevşehir province and Ürgüp districts, while total precipitation exhibited a negative trend in spring and autumn seasons. Çiçek and Duman (2015) investigated seasonal and annual precipitation trends in Turkey, utilizing data from 1975 to 2008 from 83 meteorology stations and identified decreasing trends in all seasonal and annual precipitation. Nuri Balov and Altunkaynak (2019) investigated the impacts of climate change on precipitation Western Black Sea Basin, Turkey using historical and projected daily precipitation data from GFDL-ESM2M, HadGEM2-ES, and MPI-ESM-MR global circulation models under RCP4.5 and RCP8.5 scenarios. Trend analyses with the Mann-Kendall test during the reference period (1971–2000) revealed a strong increasing trend in indices in the eastern part of the basin, while non-significant trends were observed in the western part. For the future period (2020–2099) with the threat of climate change, the temporal patterns of precipitation are poised to undergo significant alterations, potentially leading to pronounced fluctuations in intra-seasonal rainfall dynamics (Trenberth, 2011).

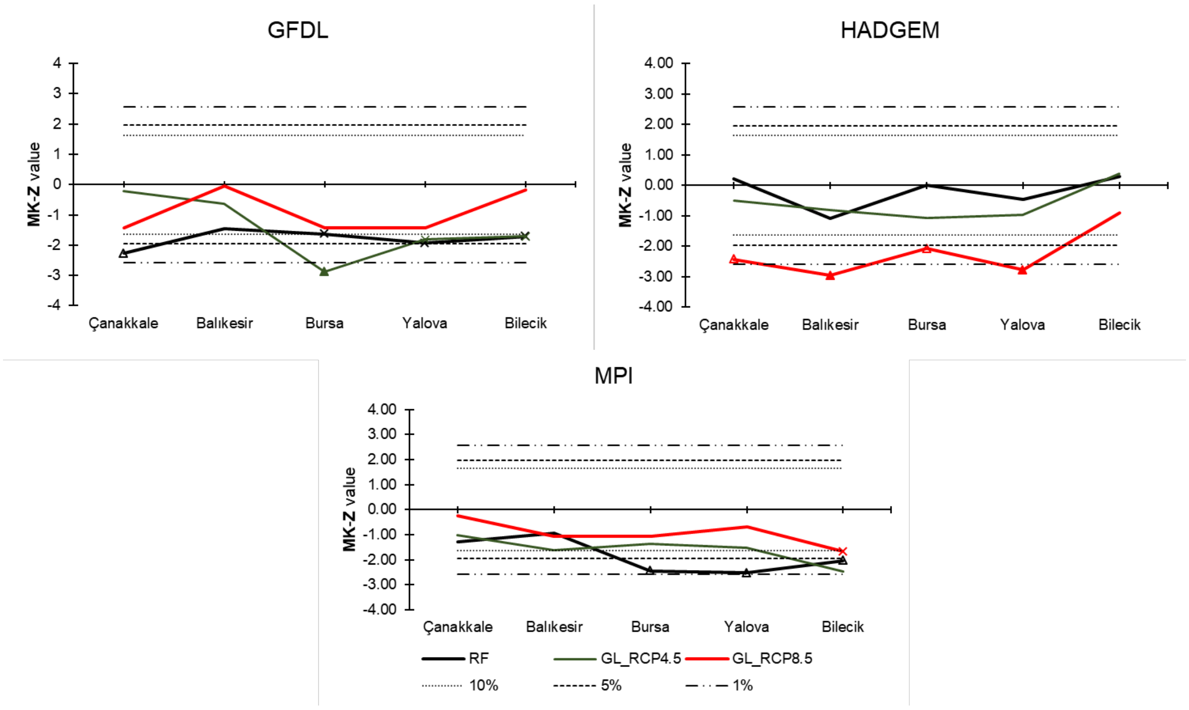

Figure 4. *Mann-Kendall test results of seasonal precipitation for different models and periods*

The analysis of the Sen's slope values (*Q*) revealed notable variations across different scenarios and provinces (Table 4). Among all scenarios, the highest Q value was recorded in Çanakkale under the HADGEM model RF scenario (8.239 mm year^{-1}) for annual precipitation, while the lowest Q value was observed in Çanakkale under the GFDL model RF scenario (-10.320 mm season^{-1}) for seasonal preciation. Additionally, in the GL_RCP4.5 scenario for annual precipitation, the highest Q value across all locations was identified in Balıkesir under the GFDL model (4.167 mm year^{-1}), whereas the lowest Q value was found in Çanakkale under the HADGEM model (-8.301 mm year^{-1}). Lastly in the GL_RCP8.5 scenario, the highest Q value was observed in Balıkesir under the GFDL model (1.916 mm year^{-1}), while the lowest Q value was recorded in Çanakkale under the HADGEM model (-8.804 mm year^{-1}) for annual precipitation. The analysis suggests that the western regions of the area are more vulnerable to climate change. Particularly, areas like Balıkesir and Çanakkale, situated in the western part of the Southern Marmara region, are closer to the sea and therefore more exposed to influences from the Aegean region. This proximity to the sea may enhance the impact of precipitation-related wind patterns and other climatic factors (Harley et al., 2006). Sharma et al. (2022) stated that among various meteorological parameters, precipitation exhibits the most variability over time and location. This variability highlights the diverse climatic responses even regions such as the Southern Marmara Region with relatively small surface areas, influenced by factors such as mountainous terrain and maritime effects.

Table 4. Sen's slope test results of the precipition values for different models and periods

Period	Model	Scenario	Çanakkale	Balıkesir	Bursa	Yalova	Bilecik
ANNUAL	GFDL	RF	-8.401*	-5.910	-6.807	-9.801	-6.056
		GL_RCP45	-1.771	4.167	-1.351	2.410	-2.923
		GL_RCP85	0.201	1.916	0.201	-1.414	0.740
	HADGEM	RF	8.239	4.881	5.362	6.988	5.309
		GL_RCP45	-8.301	0.159	-1.489	-0.92	3.448
		GL_RCP85	-8.804	-8.17	-2.076	-4.06	-0.26
	MPI	RF	-2.063	-2.523	-4.486	-7.234	-4.42
		GL_RCP45	-5.344	-0.06	-0.784	-1.194	-0.895
		GL_RCP85	-3.140	-5.445	-4.967	-3.810	-4.029
SEASONAL	GFDL	RF	-10.320	-5.636	-4.400	-7.971	-4.589
		GL_RCP45	-0.653	-2.260	-4.023	-3.586	-3.775
		GL_RCP85	-3.070	-0.085	-3.070	-4.920	-0.454
	HADGEM	RF	0.616	-1.742	-0.032	-0.976	0.580
		GL_RCP45	-1.229	-1.819	-1.829	-2.101	0.628
		GL_RCP85	-7.101	-7.193	-4.076	-7.859	-2.243
	MPI	RF	-1.600	-1.317	-3.112	-4.566	-1.890
		GL_RCP45	-2.200	-2.560	-1.581	-2.150	-1.971
		GL_RCP85	-0.438	-1.037	-0.806	-0.585	-0.801

*:Annual Q values are in mm year^{-1}, and seasonal values are in mm season^{-1}

Conclusion

Based on the extensive analysis of precipitation trends in the Southern Marmara Region of Turkey, several key findings emerge, shedding light on the implications for future climate scenarios and their impacts on various sectors, particularly agriculture and water resource management. The results indicate significant variability in projected precipitation levels across different climate models and scenarios, underscoring the complexity and uncertainty inherent in climate projections. Firstly, the analysis reveals substantial differences in annual and seasonal precipitation projections among the three climate models (*GFDL*, *HADGEM*, and *MPI*) under different Representative Concentration Pathways (*RCPs*). While the GFDL model generally predicts higher precipitation levels compared to the other models, particularly in the annual analysis, significant differences was determined within and across scenarios and provinces. This variability highlights the need for caution when interpreting model projections and emphasizes the importance of considering multiple models to capture the range of possible outcomes. Secondly, the study identifies contrasting trends in precipitation patterns between the historical reference period (1971-2000) and future projections (2061-2090). While some provinces exhibit consistent decreases or increases in precipitation over time, others show mixed trends, with significant intra-seasonal variability. These findings underscore the dynamic nature of precipitation patterns and the challenges associated with predicting future changes, especially in regions with complex topography and diverse climatic influences. Moreover, the results emphasize the vulnerability of coastal regions, such as the Southern Marmara Region, to the impacts of climate change, including shifts in precipitation patterns and increasing aridity. Comprehending these factors holds pivotal importance for crafting effective water management policies in the Southern Marmara Region. Foreseen alterations in future large-scale atmospheric circulation patterns could result in varied impacts on precipitation distribution throughout the region. Hence, water management strategies must consider the spatially diverse precipitation patterns and potential shifts in atmospheric circulation to guarantee the sustainability of water resources amidst climate variability and change.

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