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A Study on Precipitation Trends in Türkiye via Linear Regression Analysis and Non-Parametric Mann-Kendall Test

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Abstract

Climate change, a significant global issue, has recently become a pivotal area for many researchers. Climate is defined as the long-term average of meteorological parameters such as temperature, precipitation, wind speed, and air pressure of a region. Precipitation is an important climatic parameter that can be variable at the temporal and spatial scales. A half-century precipitation dataset was selected and analyzed to reveal the effects of global climate change on the rainfall amounts of Türkiye. Precipitation data of each geographical region have been analyzed with respect to annual and seasonal basis in the period of 1969-2018. For this purpose, the non-parametric Mann-Kendall trend test which is recommended by World Meteorological Organizations (WMO) and linear regression method have been implemented to each geographical region of Türkiye. As a result of analysis belonging to 85 meteorological stations, the presence of any increasing and decreasing linear trends in annual and seasonal precipitation series have been studied on a regional scale. While the Black Sea Region has the highest increase with 148 mm/50 years, the total annual precipitation in the Southeastern Anatolia Region has decreased by 3.2 mm/50 years. Another important finding of linear regression has been observed that increase in precipitation has occurred in the Black Sea Region in all seasons, as a consequence of seasonal analysis. To determine whether these trends are statistically significant, we used Mann-Kendall test results. The test proved the existence of an increasing trend at 99% significance level in the annual precipitation series of the Black Sea Region. A statistically significant increasing trend was also obtained for the autumn season of the Black Sea Region at a 95% confidence level.

Keywords: Precipitation, Linear regression, Mann-Kendall test, Trend analysis

Doğrusal Regresyon Analizi ve Parametrik Olmayan Mann-Kendall Testi ile Türkiye'deki Yağış Eğilimleri Üzerine Bir Araştırma

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Özet

Önemli bir küresel sorun olan iklim değişikliği, son dönemlerde pek çok araştırmacının odak noktası haline gelmiştir. İklim, bir bölgenin sıcaklık, yağış, rüzgâr hızı ve hava basıncı gibi meteorolojik parametrelerinin uzun vadeli ortalaması olarak tanımlanır. Yağış ise, zamansal ve mekânsal ölçekte sık

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değişiklik gösteren önemli bir iklim parametresidir. Bu çalışma kapsamında, küresel ölçekte yaşanan iklim değişikliğinin Türkiye üzerindeki etkilerini ortaya koymak için yarım asırlık yağış verileri seçilerek, analiz edilmiştir. Türkiye'nin coğrafi bölgelerine ait yağış değerleri 1969-2018 dönemi için yıllık ve mevsimsel olarak analiz edilmiştir. Bu amaçla, Dünya Meteoroloji Örgütü tarafından da meteorolojik verilerdeki trendlerin belirlenmesi için önerilen parametrik olmayan Mann-Kendall trend testi ve doğrusal regresyon yöntemi Türkiye'nin bölgelerine ait yağış verilerine uygulanmıştır. Gerçekleştirilen analizler neticesinde, Türkiye'de homojen olarak dağılan 85 meteoroloji istasyonuna ait bulgular bölgesel ölçekte yıllık ve mevsimsel yağış verilerinde doğrusal artma ve azalma eğilimlerinin varlığı ortaya koyulmuştur. Yıllık yağış miktarında en fazla artış 148 mm/50 yıl değeri ile Karadeniz Bölgesi'nde tespit edilirken, Güneydoğu Anadolu Bölgesi'nde yıllık yağış miktarı 3,2 mm/50 yıl azalma göstermiştir. Lineer regresyonun bir diğer önemli bulgusu, coğrafi bölgelere ait mevsim bazlı analizler neticesinde ortaya çıkan Karadeniz Bölgesi'nde tüm mevsimlerde gerçekleşen toplam yağış miktarlarında artan bir eğilimin olduğudur. Bu verilere ilave olarak, her bir bölge için parametrik olmayan Mann-Kendall testi uygulanması ile istatistiki açıdan önemli olan eğilimler çalışılmış ve anlamlı trendlerin yalnızca Karadeniz Bölgesi'nde olduğu tespit edilmiştir. Buna göre, 50 yıllık yağış serisinde gerçekleşen %99'luk önem düzeyinde bir artış eğiliminin varlığı gösterilmiştir. Bir diğer önemli tespit ise sonbahar mevsiminde Karadeniz Bölgesi'nde yaşanan %95 güvenilirlik seviyesinde bir artış eğiliminin varlığı olmuştur.

Anahtar kelimeler: Yağış, Lineer regresyon, Mann-Kendall test, Trend analizi

1. Introduction

Global warming, leading to a global surface temperature increase of 1.1°C above pre-industrial levels during the period from 2011 to 2020, has indisputably been brought about via human activities, primarily through the release of greenhouse gases (IPCC, 2023). It has been observed intense and quick changes in the atmosphere, cryosphere, ocean, and biosphere. Numerous weather and climate extremes are presently being influenced by human-induced climate changes all over the world. Consequently, this has engendered extensive detrimental repercussions and associated losses and harm to both ecosystems and human populations. Notably, susceptible communities, historically contributing minimally to ongoing climate transformations, are disproportionately impacted (IPCC, 2023).

In recent years, the certain recognition of human-induced climate change as a pressing issue, coupled with the experience of unprecedented impacts, has led many researchers to focus intensively on studies in this field (Karaca et al., 1995; Tayanç and Toros, 1997; Tayanç et al., 1997; Tayanç et al., 2009; Deniz et al., 2011; Unal et al., 2012; Gocic and Trajkovic, 2013; Toros et al., 2017; Yang et al., 2017; Sa'adi et al. 2019; Çelebioğlu et al. 2021).

Previously, Çelebioğlu et al. (2021) studied the temperature variabilities and trends in a 50-year time period of 1969-2018 in Türkiye. Temporal and spatial variability of temperature was studied by linear regression analysis and Mann-Kendall trend test. Temperature increase in this time period was found to be in the Eastern Anatolia Region with a value of 1.74°C/50 years. The regions with the highest seasonal temperature increases are estimated to be the Aegean Region (1.61°C) in autumn, Eastern Anatolia Region (2.37°C) in winter, Eastern Anatolia Region (1.84°C) in spring and Marmara Region in summer (2.79°C). Meanwhile, annual average temperature trends showed increasing trends at a 99% confidence level in most stations.

As a continuation of the above study, we evaluated the trends and variabilities of precipitation in Türkiye for the same 50-year time period of 1969-2018. To determine any existing trends in the precipitation series we used linear analyses and to find whether these

trends are statistically significant, we applied non-parametric Mann-Kendall trend. Therefore, the results of this study provide information about the recent climatic changes in Türkiye in terms of precipitation.

2. Material and Methods

The Turkish State Meteorological Service has provided precipitation data during the 1969-2018 period from 85 meteorological stations which are distributed uniformly across Türkiye, as illustrated in Figure 2.1. First of all, a quality control process has been applied to the dataset. The selected time period was divided into two parts to assess the any missing data in precipitation datasets across the stations. The first period was selected as the 50-year period between 1969-2018 years, whereas the second period was also the 20-year period during 1999-2018 years. For each station, if the data was missing for more than 10% of the first period, that station was excluded from the data set. Similarly, if the data was missing for more than 10% of the second period, the station was also disqualified. In addition, missing data at stations that met these criteria (ie, less than 10%) were completed by averaging the data from the same time of the previous year and the data from the same time of the following year. Annual and seasonal total precipitation data of each geographical region have been generated from the original daily precipitation values. Subsequently, data of each geographical region has been subjected to extensive analysis by Mann-Kendall trend test and linear regression methods to assess changes and trends in precipitation during the half century period of 1969-2018 on regional basis.

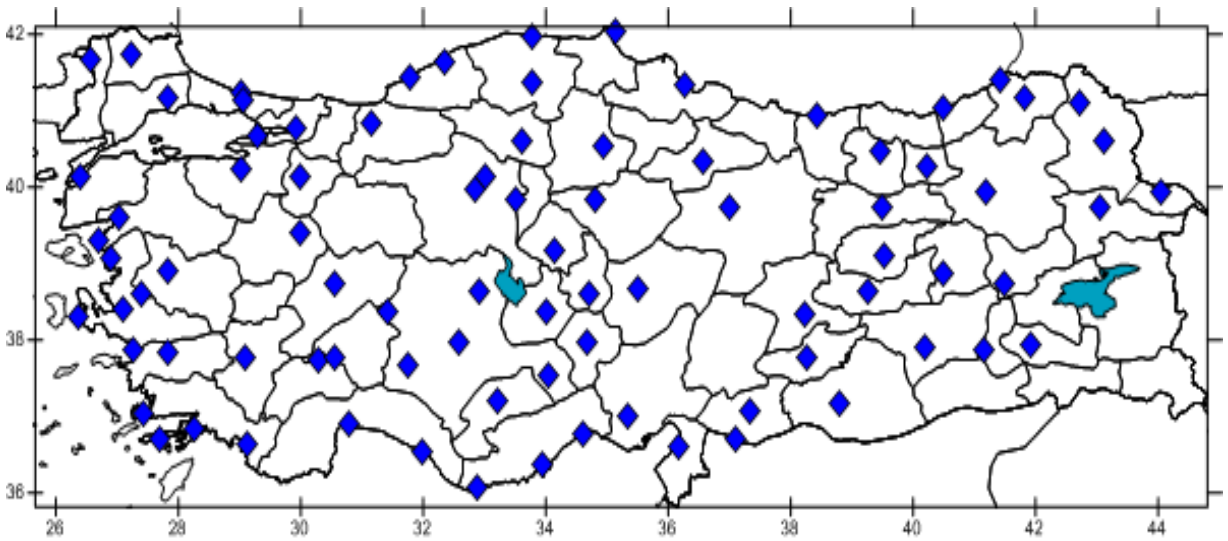

Figure 2.1. Spatial distribution of meteorological stations in Türkiye

World Meteorological Organization (WMO) recommended the use of Mann-Kendall test for climatic parameters (Rustum et al., 2017). The Mann-Kendall trend test, originally developed by Mann (Mann, 1945) and later by Kendall (Kendall, 1975), gained prevalent recognition with its application to detect significant trends within the time series like temperature, precipitation, streamflow.
The purpose of the Mann-Kendall test is to statistically assess if there is a monotonic upward or downward trend of the variable of interest over a time period. A monotonic upward or downward trend means that the variable consistently increases or decreases through time, but the trend may or may not be linear. The Mann-Kendall test can be used in place of a parametric linear regression analysis, which can be used to test if the slope of the estimated linear regression line is different from zero. The regression analysis requires that the residuals from the fitted regression line be

normally distributed; an assumption not required by the non-parametric Mann-Kendall test, that is, the test is a distribution-free test. Mann-Kendall test is best viewed as an exploratory analysis and is most appropriately used to identify stations where changes are significant or of large magnitude and to quantify these findings by many researchers (Agbo et al., 2021; Ye and Kameyama, 2021; Verma et al., 2022).

Non-parametric tests, such as the Mann-Kendall test, are preferred over parametric counterparts when dealing with datasets that deviate from normal distribution patterns (Brown et al., 1992; Dash and Hunt, 2007). Non-parametric Mann-Kendall test has been the most preferred method implemented to determine trends in climate variables such as precipitation and temperature (Partal and Kahya 2006; Martinez et al., 2012; Sanogo et al., 2023; Hussain et al., 2023).

In this study, both annual and seasonal 50-year precipitation values for each station and region have been analyzed by using linear regression and the Mann-Kendall test to identify climate trends. Thus, the study aims to examine the impact of global climate change on Türkiye in terms of precipitation.

3. Results and Discussion

Following annual analysis of the precipitation data belonging to each geographical region, it was found that precipitation has been increasing in each region, except for the Southeastern Anatolia Region. Results in Figure 3.1 reveal that the greatest increase in precipitation has been taking place in the Black Sea Region, with a value of 2.95 mm per year and a total of 148 mm for the specified period of 2069-2018. Meanwhile, the Southeastern Anatolia Region has experienced a decrease of 3.2 mm/50 years. Based on the linear equation, the projected increase of precipitation in the Black Sea Region is anticipated to cause an approximate increase of 300 mm in precipitation by the year 2070 since 1969. In contrast, a decline of 6.4 mm by 2070 can be foreseen for the Southeastern Anatolia Region. Based on climatic research, a decrease in precipitation is expected in areas along the Mediterranean coast and regions characterized by Mediterranean type of climate. Similar to our results, another study done by Bahadır (2011) found a precipitation increase of roughly 25-50 mm in stations located in the Black Sea climate zone. Additionally, Bahadır (2011) predicted precipitation decreases of roughly 2-100 mm in Continental and Mediterranean climate zone stations.

Tayanç et al. (2009) analyzed precipitation features of Eastern, Central and Southeastern

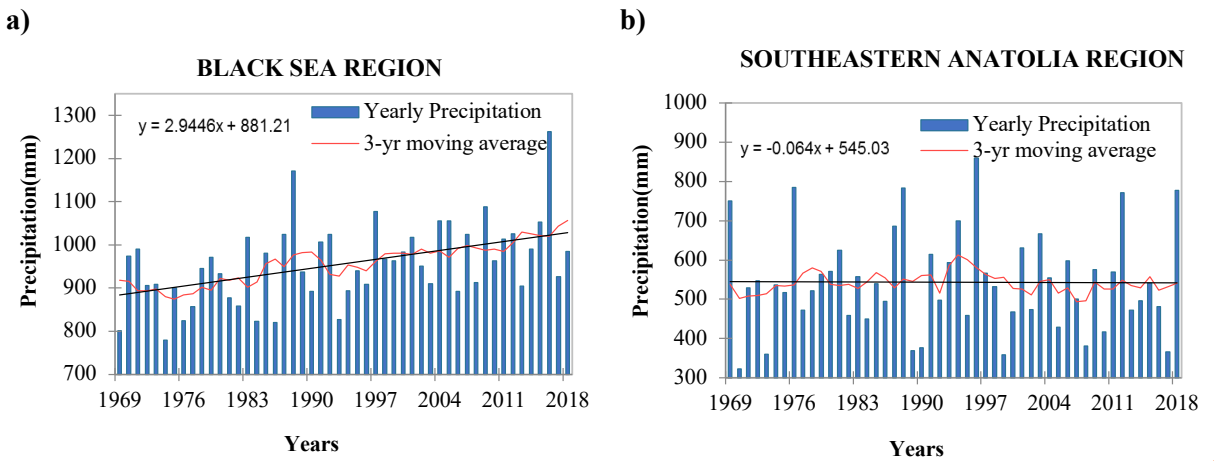

Figure 3.1. Regional annual precipitation variability

Anatolia Region and concluded that a drier climate has been observed in those 3 regions since the 1950s. Analysis of Central Anatolia Region shows that precipitation had decreased during the 1952-1973 period. The precipitation levels in the Southeastern Anatolia Region remained below the average values for an extended period from 1958 to 1976, with the exception of a few years in the late 1960s. No significant change was reported for the Eastern Anatolia Region until 1983 (Tayanç et al., 2009). In contrary, interesting results was obtained for the Mediterranean Region that precipitation was found to show an increasing trend (Tayanç et al., 2009).

Presence of increase in precipitation of autumn season has been detected among all geographical the regions. During the 50-year period, especially notable observations in Figure 3.2 for the autumn season include a 66 mm increase in the Black Sea Region and a 10.2 mm increase in the Eastern Anatolia Region. As per the linear regression analysis, precipitation levels in the Black Sea Region is expected to increase by 132 mm till 2070. Additionally, assessments suggest that precipitation patterns will undergo a 22 mm increase in Eastern Anatolia by 2070.

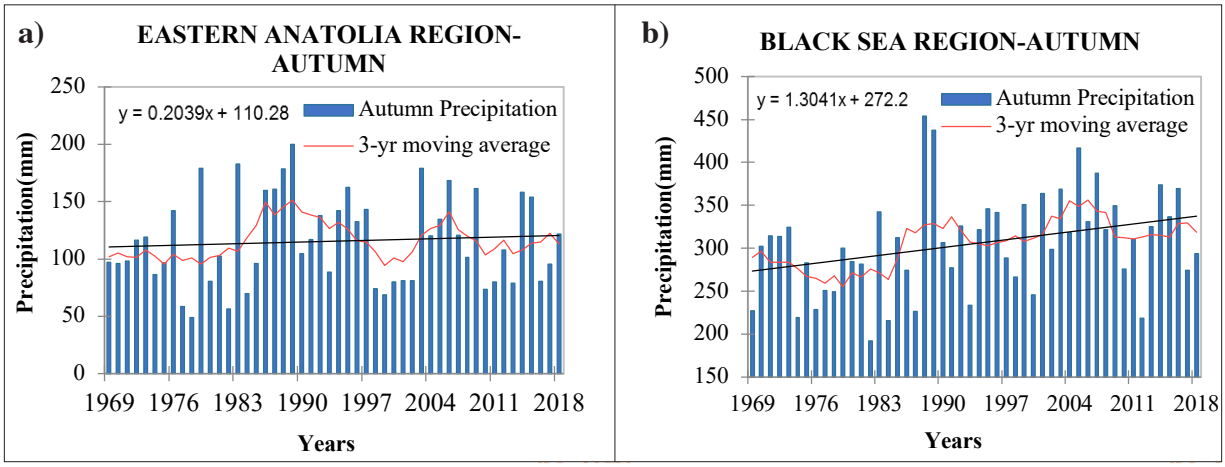

Figure 3.2. Autumn season precipitation variability

The winter precipitation mainly exhibits increasing trends across regions, apart from the Mediterranean and Aegean regions. Figure 3.3 represents a slight decrease of 5 mm/50 years in Aegean Region, experienced highest decline during this period. The highest value of increase has been also found out in the Black Sea Region with a value of 27 mm, in Figure 3.3. In contrast, while precipitation change is supposed to reach to 54 mm in Black Sea Region by 2070, a decrease with a value of 10 mm/100 years has been observed in the Aegean Region

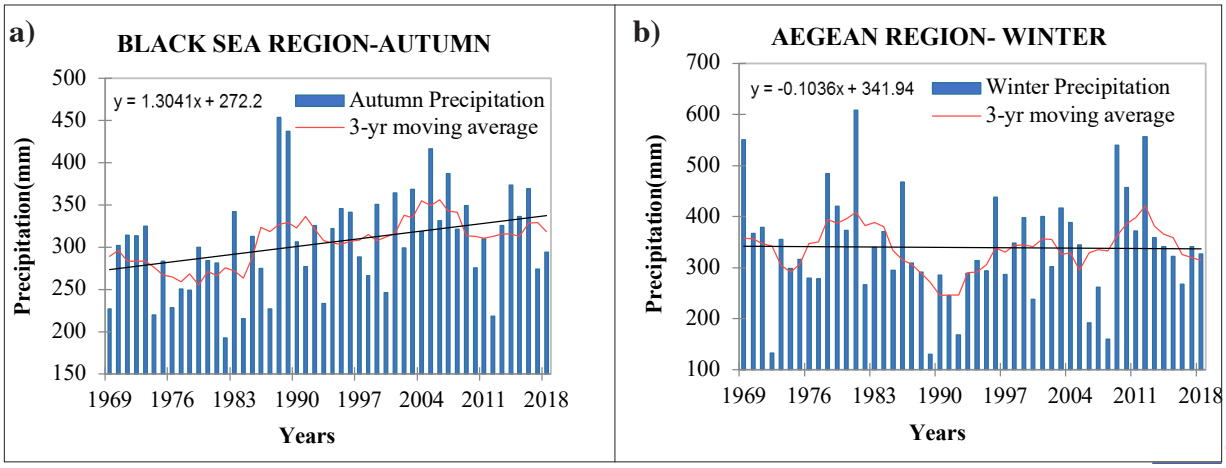

Figure 3.3. Winter season precipitation variability

Figure 3.4 illustrates a decrease of precipitation during spring in most regions, including Eastern Anatolia, Southeastern Anatolia over the span of five decades. Conversely, Aegean and Black Sea Region has experienced a rise in precipitation, in this period of time. Whereas the highest increase amount with 32.5 mm/50 years has been monitored in the Black Sea Region, Southeastern Anatolia Region has highest decrease amount with 55 mm/50 years. Most important future observations respectively indicate a rise with 65 mm/100 years in Black Sea Region and also a decline of 110 mm /100 years in Southeastern Anatolia Region.

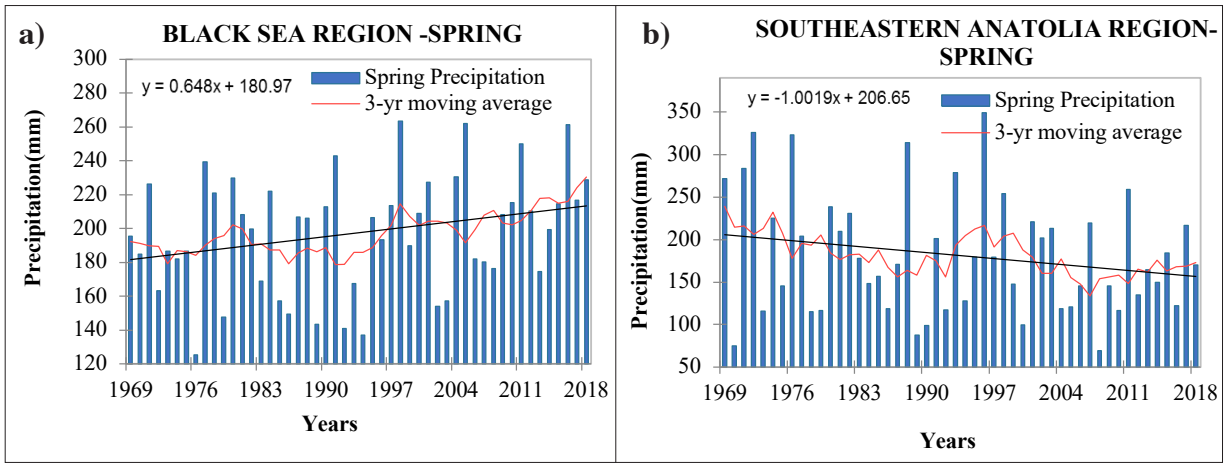

Figure 3.4. Spring season precipitation variability

The most remarkable analysis of summer season depicted in Figure 3.5 for Black Sea and Southeastern Region. As a consequence of analyzing summer season, the presence of increase has been stated in all regions. In the light of these findings, the highest summer precipitation increases with a value of 22.5 mm in Black Sea Region, the lowest increase has taken place in Southeastern Anatolia Region 3.75 mm in Southeastern Anatolia. Based on these findings, future predictions demonstrate further rises, with anticipated values of 45 mm/100 years in the Black Sea and 7.5 mm/100 years in Southeastern Anatolia Region.

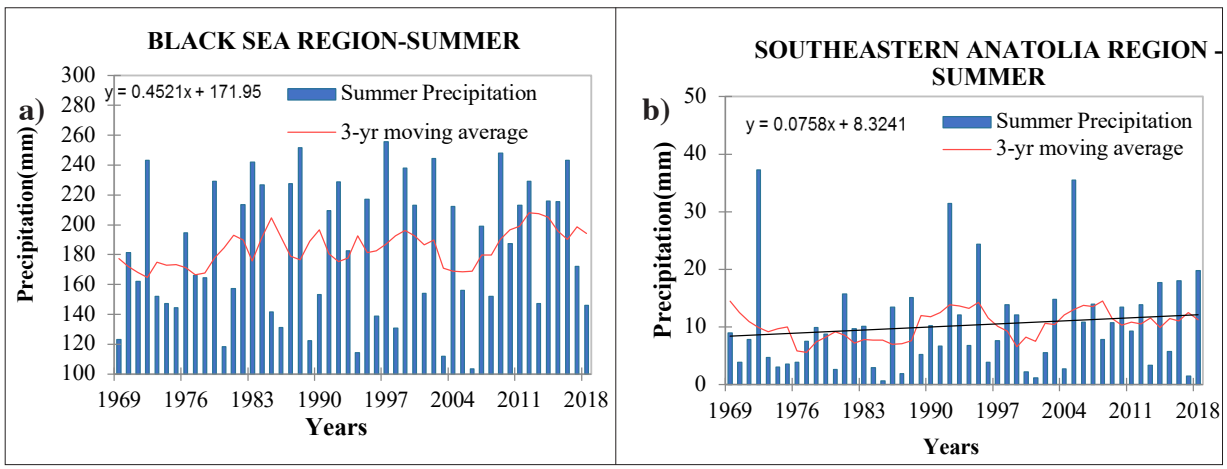

Figure 3.5. Summer season precipitation variability

Table 3.1 represents the summary of important results of linear regression belonging to regions. Future predictions of annual precipitation revealed increases in precipitation apart from Southeastern Anatolia Region. While highest increase has occurred in Black Sea Region, a slight decrease has been detected in Southeastern Anatolia Region. Increases in autumn and summer precipitation across the regions have been also detected. Furthermore, winter precipitation demonstrates an increase except for the Mediterranean and Aegean regions. A rise in spring precipitation is detected in only the Black Sea and Aegean regions

Table 3.1. Results of linear regression

Regions	Equation	Variability-Estimation
Black Sea-Annual	y=2.9446x+881.21	+148 mm/50 years +300 mm/100 years
Southeastern Anatolia - Annual	y= 0.064x+545.03	-3.2 mm/50 years -6.4 mm/100 years
Black Sea-Autumn	y=1.3041x+272.2	+66 mm/50 years + 132 mm/100 years
Eastern Anatolia-Autumn	y=0.2039x+110.28	+10.2 mm/ 50 years +22 mm/100 years
Black Sea-Winter	y=0.5405x+256.1	+27 mm/50 years +54 mm/100 years
Aegean-Winter	y=-0.1036x+341.94	-5 mm/50 years - 10 mm/100 years
Black Sea-Spring	y=0.648x+180.97	+32.5 mm/50 years +65 mm/100 years
Southeastern-Spring	y=-1.0019x+206.65	-55 mm/50 years -110 mm/100 years
Black Sea-Summer	y=0.4521+171.95	+22.5 mm/50 years +45 mm/100 years
Southeastern-Summer	y=0.0758x+8.3241	+3.75 mm/50 years +7.5 mm/100 years

Precipitation data produced using HadGEM2-ES according to the RCP 4.5 scenario demonstrates that there will be a decrease of around 20% except for the Coastal Aegean, Central Black Sea, and Northeastern Anatolia regions in the spring precipitation for the period of 2071-2099. There will be an increase of around 10% in winter precipitation, especially along the coastline. There will be a decrease of up to 40% in summer precipitation except for the Aegean, Marmara and Black Sea coasts. It is noticeable that there will be decreases in autumn precipitation almost all over the country in the 2071-2099 (URL-1).

Another set of precipitation data produced by using HadGEM2-ES according to the RCP 8.5 scenario indicate that, there will be decreases of around 20% in regions during the spring months, except for the Coastal Aegean, the western part of the Central Black Sea and the Eastern Black Sea. Winter precipitation is expected to decrease in the Central and Eastern Mediterranean Region as well as the Southeastern Anatolia Region, while increases are anticipated in other areas, particularly along the Central and Eastern Black Sea coasts. In addition, while increases in summer precipitation are expected in the Marmara and Western Black Sea regions, it is noteworthy that there will be decreases in precipitation, especially in the Mediterranean and Eastern Anatolia regions. It is noteworthy that in the autumn, there will be decreases of up to 40% and sometimes up to 50% all over the country except the Marmara coast. for the period of 2071-2099 (URL-1).

While our linear regression result predicts an increase in autumn precipitation across all regions, the Turkish State Meteorological Service report (URL-1) expects decreases in almost the entire country according to the RCP 4.5 scenario HadGEM2-ES for the period 2071-2099. Additionally, according to the linear regression applied in this study, an

increase in summer precipitation is anticipated in all regions; however, the model results indicate decreases in summer precipitation except for the Aegean, Marmara, and Black Sea coasts. Furthermore, while the linear trend shows decreases in spring precipitation in most regions, the model result for spring precipitation is parallel to these findings. Whereas the RCP 4.5 scenario HadGEM2-ES result demonstrates an increase in winter precipitation in coastal regions, the linear regression indicates an increase except for the Aegean and Mediterranean regions.

According to RCP8.5/ HadGEM2-ES results, it is stated that there is a decrease in the whole country apart from Marmara coasts in the autumn, while linear regression result indicates an increase in all regions in the autumn season. Whereas result of model presents an increase in the Marmara and Western Black Sea in summer precipitation, linear regression proves the existence of increase in all regions. According to our future estimation, the decrease in precipitation in most regions is parallel to the decrease in precipitation in the spring precipitation in the RCP 8.5/ HadGEM2-ES. In addition, presence of increase is determined by linear regression in the Black Sea Region in winter precipitation, Turkish State Meteorological Service also predicts an increase especially in the Central and Eastern Black Sea coasts.

Statistically significant trend has not been mostly observed across Türkiye by implementing non-parametric Mann-Kendall trend test to annual precipitation dataset, as seen in Figure 3.6. However, increasing trends which are both at 95% and 99% confidence level have been mainly detected in stations in the north of Eastern Anatolia, central and eastern parts of the Black Sea Region. In the annual precipitation data sets for the Aegean and Mediterranean coasts, no statistically significant trends were identified. However, a notable exception is the presence of a strong increasing trend at the station located in Hatay, observed at the 99% confidence interval. Furthermore, the annual precipitation data for stations situated in the interior parts of the Aegean and Mediterranean regions also revealed no statistically significant trends. Similarly, the majority of stations in the Marmara and Central Anatolia Regions exhibited no statistically significant trends in their annual precipitation data.

Statistically insignificant increasing trends in most regions have been revealed as a result of seasonal and annual analysis. Only annual precipitation of Black Sea Region indicates an increasing trend at the 99% confidence level among the seasonal analyses. Moreover, autumn precipitation in a half century over Black Sea Region has increasing trend at the 95% confidence interval.

Some researchers also determined significant increasing trends at some stations in the Black Sea and north of Eastern Anatolia Region. They mentioned the existence of a decreasing trend in precipitation in the Mediterranean, Mediterranean Transition Climate and Continental Mediterranean Climate Zone. No precipitation trend had been reported in Marmara and Central Anatolia Regions (Demir et al., 2008). Like our findings, increasing trends in annual precipitation all through the Black Sea Region have been found by other researchers (Tokgöz et al., 2020).

4. Conclusions

Annual and seasonal precipitation values for each geographical region of Türkiye have been analyzed by using data collected from 85 meteorological stations for the period of 1969-2018. Time series of precipitation data for each station has been interpreted using linear regression analysis and Mann-Kendall trend test. The annual results of the linear regression analysis align with the findings of Mann-Kendall trend test.

Increasing linear trends in the annual total precipitation series of every region, except for the Southeastern Anatolia Region have been noted. Notably, a pronounced increasing trend has been identified in the precipitation series of the Black Sea region. While Black Sea Region has the highest increase in annual precipitation with a trend of 148 mm/50 years and significant at 99% confidence level, the annual precipitation of Southeastern Anatolia Region has

decreased by a trend of 3.2 mm/50 years that is not significant at 95% level. 95% significant increasing precipitation trend has also been obtained for the autumn season in the Black Sea Region. While there are increasing trends in winter, spring, and summer precipitation values in most regions, majority of them are found to insignificant. Results of these analyses have provided insight into the changes and trends in the precipitation series of Türkiye over the past half-century.

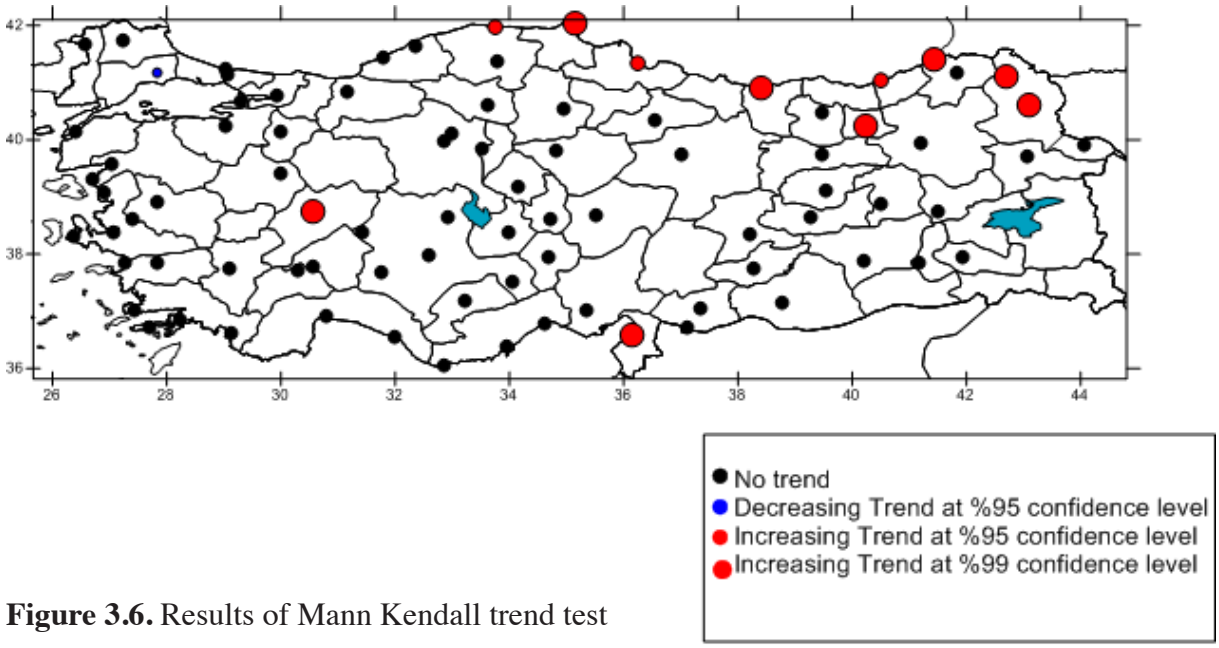

Figure 3.6. Results of Mann Kendall trend test

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