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The Statistical Methods for Precipitation Prediction with Trend Analysis

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Abstract: This study investigates the condensation of water vapor in the atmosphere, precipitating to the ground in either solid or liquid form. This meteorological variable exhibits temporal and spatial variations influenced by climate change and other factors. To better analyze the effects of climate change on precipitation, the Konya Closed Basin was selected as the research area. Key parameters and datasets critical for various sectors and activities—from hydraulic structure design to irrigation planning—were identified. Seasonal and annual precipitation trend analyses were conducted for the provinces of Aksaray, Ankara, Isparta, Mersin, and Nevşehir using statistical methods, including the Mann-Kendall test, Spearman's Rho, and the Innovative Şen Test, with the aid of XLSTAT software. The results revealed negative precipitation trends in Aksaray, Ankara, and Nevşehir, while positive trends were observed in Isparta and Mersin. Additionally, complementary data were collected from the Muş Meteorology Provincial Directorate to support the findings.

Keywords: Precipitation, Trend analysis, Mann-Kendall, Spearman Rho, Innovative Şen Test.

Trend Analizi ile Yağış Tahmini için İstatistiksel Yöntemler

Öz: Bu çalışmada atmosferdeki su buharının yoğunlaşması ve daha sonra katı veya sıvı formda yere çökmesi araştırılmıştır. Bu meteorolojik değişken, iklim değişikliği ve diğer faktörlerden etkilenen zamansal ve mekansal değişimler göstermektedir. İklim değişikliğinin yağış üzerindeki etkilerini daha iyi analiz edebilmek için Konya Kapalı Havzası araştırma alanı olarak seçilmiştir. Hidrolik yapı tasarımından sulama planlamasına kadar çeşitli sektörler ve faaliyetler için kritik öneme sahip anahtar parametreler ve veri kümeleri belirlenmiştir. Mann-Kendall testi, Spearman's Rho ve Yenilikçi Şen Testi gibi istatistiksel yöntemler kullanılarak Aksaray, Ankara, Isparta, Mersin ve Nevşehir illeri için mevsimsel ve yıllık yağış eğilimi analizleri XLSTAT yazılımının yardımıyla gerçekleştirilmiştir. Sonuçlar Aksaray, Ankara ve Nevşehir'de olumsuz yağış eğilimleri ortaya koyarken, Isparta ve Mersin'de olumlu eğilimler gözlenmiştir. Ayrıca bulguları desteklemek için Muş Meteoroloji İl Müdürlüğü'nden tamamlayıcı veriler toplanmıştır.

Anahtar kelimeler: Yağış, Trend analizi, Mann-Kendall, Spearman Rho, Yenilikçi Şen testi.

1. Introduction

In the existing literature, various methods have been employed for precipitation forecasting, ranging from traditional statistical approaches to advanced artificial intelligence techniques. In recent years, rapid advancements in technology and the increased standard of living have driven a significant rise in the consumption of fossil fuels. This surge in fossil fuel usage has, in turn, led to a substantial increase in greenhouse gas emissions, which profoundly impact almost all meteorological variables. The effects of these gases, which intensify global warming, vary across regions and basins, with their most pronounced influences observed on temperature and precipitation patterns [1]. Precipitation has emerged as a critical area of research among these meteorological variables due to its direct and widespread implications for environmental systems and human activities.

Changing climate conditions have introduced significant temporal and spatial variations in precipitation. Excessive precipitation can result in severe hydrological events such as floods and inundations, while insufficient precipitation may lead to prolonged droughts, with devastating consequences for agriculture, water supply, and ecosystems. Furthermore, technological advancements and the expansion of urban areas have adversely affected the efficiency of precipitation utilization. Increased technological development has escalated water consumption, while urbanization has accelerated surface runoff rates, reducing the capacity for natural water retention and storage in the environment [2,3].

Given that climate change is a primary driver of variability in precipitation patterns, understanding its potential impact is paramount for the sustainable planning and management of water resources. Statistical trend

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analysis is a critical tool for this purpose, enabling researchers to identify temporal patterns of increase or decrease in precipitation within a time series [4,5]. These analyses are crucial for addressing practical needs in sectors such as agriculture, irrigation, energy production, and the design of hydraulic structures. By detecting trends in precipitation, it becomes possible to develop strategies for mitigating risks associated with both excessive and insufficient rainfall.

Among the various statistical methods available, the Mann-Kendall test has proven to be particularly effective due to its non-parametric nature and its robust application to hydrometeorological time series [6]. This test, along with other techniques such as Spearman's Rho and the Innovative Şen Test, has been extensively utilized in the literature for identifying trends in precipitation data. Additionally, recent advancements have expanded the scope of precipitation forecasting to include artificial intelligence methods, offering new opportunities for more accurate and comprehensive analyses.

Partal and Kahya analyzed Türkiye's precipitation using the Mann-Kendall test, a statistical method and identified a decreasing trend along certain coastal areas of the Black Sea region [7]. Lefadani et al., employed ANN, ANFIS, and MIKE11/NAM models to forecast precipitation in Iran's Eskandari basin. Their study concluded that the results predicted by the ANFIS and ANN models were more accurate than those predicted by the MIKE11/NAM model [8]. Patel and Parekh utilized the ANFIS method to predict monthly monsoon precipitation at the Gandhinagar station. They developed a hybrid model with seven membership functions, incorporating wind speed, temperature, and relative humidity as three input variables, and reported highly successful results [9]. Sojitra also used the ANFIS method to create two datasets for developing predictive models based on 35 years of rainfall data from Udaipur City. In addition to considering variables such as average temperature, evaporation, and humidity, the authors achieved successful outcomes using Generalized Bell and Gaussian membership functions [10]. Öztopal and Şen employed both the Innovative Şen and Mann-Kendall methods to analyze trends in temperature and precipitation data from 16 meteorological stations across the Black Sea Region. Their study revealed that the Mann-Kendall method identified an increasing trend in precipitation and temperature at seven of the stations. In contrast, the Innovative Şen method indicated an upward trend in both temperature and precipitation at all stations, with the trends being largely consistent across the two methods. This demonstrated that the Innovative Şen method provided a more comprehensive view of the regional climatic shifts, aligning with the increasing trend observed across the majority of the study stations [11, 12]. Similarly, Coşkun conducted a trend analysis of seasonal and annual precipitation data from seven stations within the Van Lake closed basin, utilizing the Mann-Kendall, Spearman's Rho, and Innovative Şen methods. The analysis revealed a general decreasing trend in precipitation across the entire basin, suggesting that the region may be experiencing a long-term reduction in rainfall. This finding highlights the need for further investigations into the implications of reduced precipitation on water resources and agriculture in the Van Lake basin [13]. Aydın and Öz also focused on the Van Lake basin, analyzing trends in both temperature and precipitation data using the Innovative Şen, Mann-Kendall, and Spearman-Rho methods. Their findings indicated a clear decreasing trend in precipitation in the Erciş and Ahlat districts, while no significant trend was identified in other districts. In contrast, the temperature data revealed an absence of trends in the Erciş and Ahlat districts, but an increasing trend was observed across all other districts. These findings point to regional variability in precipitation trends within the Van Lake basin and suggest that localized climate patterns may be influencing the observed temperature and precipitation trends [14]. Yaman et al., investigated the relationship between precipitation and runoff using artificial intelligence techniques such as ANFIS and GEP. The models' performance was measured using Root Mean Square Error (RMSE), the coefficient of determination (R^2), and other statistical criteria. The study found that the predictions made by the GEP and ANFIS methods were closely aligned [15].

In this study, the seasonal and annual total precipitation data of the Konya Closed Basin were analyzed for trends using Spearman's Rho, Mann-Kendall, and Innovative Şen methods. The research focuses on the Konya Closed Basin, with trend analyses conducted on monthly total precipitation data from the provinces of Aksaray, Ankara, Isparta, Mersin and Nevşehir. While existing studies have established that temperature trends across the country exhibit a consistent increase, precipitation trends show significant spatial variability, either increasing or decreasing depending on the specific basin or region. This study offers a focused analysis of precipitation trends in a geographically unique closed basin, contributing to the understanding of localized hydrometeorological responses to climate change.

2. Method

2.1. The Spearman-Rho Test

It is a non-parametric statistical method. The test requires that the data be arranged in either ascending or descending order. The rank statistic value, $R(x_i)$, is determined by sorting the data set in ascending order, and the Spearman-Rho test statistic value, r_s, is calculated using the following Equation 1. [16, 17].

$$r_s = 1 - 6[\sum_{i=1}^{n}(R\,(x_i) - i)^2]/(n^3 - n) \quad (1)$$

For the data set under evaluation, when the analyzed r_s distribution approaches a normal distribution with n>30, the calculated Z values are compared with $Z_{\alpha/2}$ (1.96) obtained from normal distribution tables at a 95% significance level. The Z value explains the test statistic r_s and is calculated using Equation 1,2. If the calculated Z value is greater than $Z_{\alpha/2}$ (1.96), it indicates the presence of a trend. If the r_s value is positive, it signifies an increasing trend, whereas a negative value indicates a decreasing trend [17].

$$Z = r_s\sqrt{n-1} \quad (2)$$

2.2. The Mann-Kendall Test

This method is one of the statistical techniques used to detect parametric analyses and is among the primary methods used for identifying trends in hydrological and climatological data [18]. The use of this test is also recommended by the World Meteorological Organization (WMO). It has been observed that this method performs better than other methods, particularly in determining trend analyses [19]. In this method, the null hypothesis Ho is based on the assumption that there is no trend. The test statistic can be given as in Equation 3:

$$S = \sum_{k=1j}^{n-1} k \sum_{k+1}^{n} \mathrm{sgn}(xj - xk) \quad \text{and} \quad \mathrm{Sgn}(x) = \begin{cases} +1, x > 0 \\ 0, x = 0 \\ -1, x < 0 \end{cases} \quad (3)$$

It is calculated using the following equation. In the equation, x_j, x_k, and n represent the observed values in year, year, and the total number of years, respectively. However, if the total number of years exceeds 10 (n>10), the following Equation 4,5 will be applied.

$$\mu_s = 0 \text{ ve } = \sigma_s = \sqrt{n(n-1)(2n+5)/18} \quad (4)$$

$$z = \begin{cases} \frac{(s-1)}{\sqrt{var(s)}} & s > 1 \\ 0 & s = 0 \\ \frac{(s+1)}{\sqrt{var(s)}} & s < 1 \end{cases} \quad (5)$$

The distribution of the Z statistic shown in the figure follows a standard normal distribution. If the Z value is smaller than the critical value Z/2 , the null hypothesis is accepted, indicating that there is no trend in the time series under investigation. If the Z value is greater than Z/2 , it is concluded that there is a trend. If the s value is negative, the trend is decreasing; if positive, the trend is increasing [20].

2.3. The Innovative Sen Test

The recorded meteorological data series is divided into two equal parts centered around the median year. Each sub-series is then ordered separately in ascending order. The first sub-series (X_i) is plotted on the X-axis and the second sub-series (X_j) on the Y-axis, forming a Cartesian coordinate system. If the data points align along the 1:1 line, it indicates no trend. However, if the points lie in the lower triangle below the 1:1 line, it suggests a decreasing trend; if they are in the upper triangle, it indicates an increasing trend [21, 22].

The innovative nature of the Şen method (Figure 1) lies in its adaptability to nearly all data sets. This method was applied by Şen (2012) to the Menzelet Dam, Aslantas Dam, and Cizre station. The same method was later applied by Şen (2013) to Uludağ/Bursa, Merkez/Bursa, and the Euphrates River. Most recently, it was used on long-term temperature data sets recorded at the Göztepe, Florya, Edirne, Bursa, and Bolu stations [23].

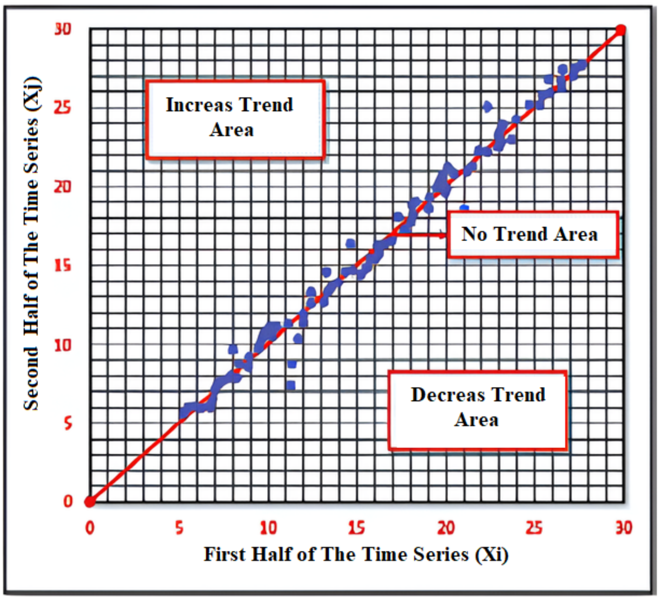


Figure 1. Sen Method [23].

3. Results and Discussion

To determine the trends in seasonal and total precipitation data at the stations within the Konya Closed Basin, data from 1980-2022 were tested using the Mann-Kendall and Spearman's Rho methods, and the resulting values are presented in Table 1. According to these results, when examining annual precipitation amounts, a negative trend was observed in Aksaray and Nevşehir, while a positive trend was noted in Isparta, Mersin, and, to a very low extent, Ankara. However, these trends are not statistically significant.

Table 1. Results of Mann-Kendall and Spearman Tests for Precipitation Data in the Konya Closed Basin.

Method	Mann-Kendall and Spearman'ın Rho's				
Period	Spring	Summer	Autumn	Winter	Annual
Aksaray	-0.217/-0.309	0.050/0.088	-0.052/-0.075	0.127/0.183	-0.032/-0.048
Ankara	-0.059/-0.079	0.094/0.151	-0.102/-0.131	0.061/0.088	0.00/0.033
Isparta	0.00/-0.011	0.217/0.277	0.018/0.041	0.092/0.154	0.103/0.180
Mersin	0.010/ 0.011	0.085/ 0.125	-0.039/-0.063	0.050/0.090	0.039/0.061
Nevşehir	-0.104/-1.141	0.162/0.242	-0.229/-0.321	0.070/0.095	-0.081/-0.102
* %95 (a=0.05) indicates the significance level within the confidence interval					

As seen in Table 1, a statistically significant negative trend is observed in Aksaray during the spring season. In contrast, Isparta shows a statistically significant positive trend during the summer season. Lastly, Nevşehir exhibits a statistically significant negative trend in the autumn season. No significant trends were detected in the seasonal data for the remaining provinces. Furthermore, on an annual basis, no statistically significant trends were observed in any of the provinces.

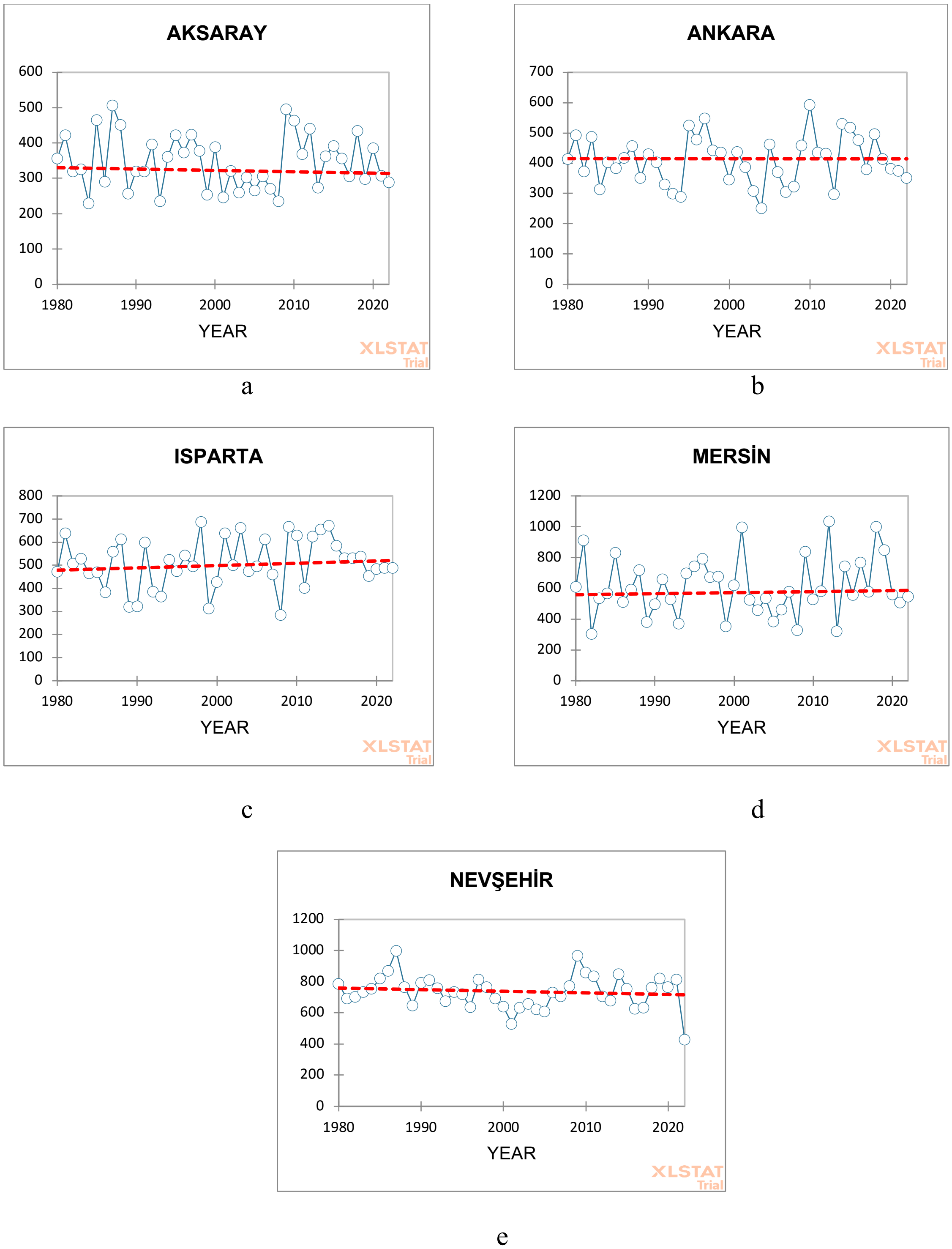


Figure 2 (a-e). Trend Directions of Precipitation in the Provinces within the Konya Closed Basin

The results presented in Figure 2(a-e) show that there is a high level of agreement between the Mann-Kendall and Spearman Rho tests. In Figure 2a, a negative precipitation trend was detected for Aksaray province in the spring season, and both tests confirm this trend. When Figure 2b is examined, a positive precipitation trend is clearly observed in Ankara in the summer season, and this finding is supported by both test methods. When seasonal precipitation changes are considered for Isparta province in Figure 2c, it is understood that the general trends do not show a statistically significant difference. In Figure 2d, no significant change was detected in precipitation trends for Mersin province, and the test results also support this situation. Finally, in Figure 2e, the negative trend observed in Nevşehir in the autumn season was found to be statistically significant and was consistent with both the Mann-Kendall and Spearman Rho tests. These results reveal that precipitation trends in the examined regions show seasonal differences and that the statistical tests used generally produce consistent results.

The Şen trend analysis results presented in Figure 3(a-e) reveal a general trend regarding annual precipitation trends in the provinces examined. According to the analysis results, a decrease in annual precipitation is observed in Aksaray, Ankara, and Nevşehir provinces, while an increasing trend is determined in other provinces. While a negative precipitation trend is detected in Aksaray in Figure 3a, a similar decreasing trend is observed for Ankara in Figure 3b. When Figure 3e is examined, the decrease in annual precipitation in Nevşehir is remarkable. On the other hand, an increasing trend in precipitation is observed in Isparta in Figure 3c and Mersin in Figure 3d.

These findings are generally consistent with the statistical values obtained from the Mann-Kendall and Spearman Rho tests. However, when a holistic evaluation is made regarding the trend analysis, it is seen that the determined trends are not statistically significant. This situation reveals that long-term climate dynamics in regions with high precipitation variability should be analyzed in more detail.

The findings for the five stations within the Konya Closed Basin are presented in Table 2. Accordingly, in Ankara, both positive and negative trends are observed, indicating that the trend direction has varied over time. Similarly, in Mersin, both positive and negative trends are noted; however, a general observation reveals a consistent positive trend. Over the years, Nevşehir has also shown both positive and negative trends, with the trend direction fluctuating. In Aksaray, both positive and negative trends are evident, and the trend direction has also shifted. In contrast, Isparta exhibits an overall positive trend.

Table 2. Seasonal and Annual Rainfall Trends of Basin Stations (1980-2022).

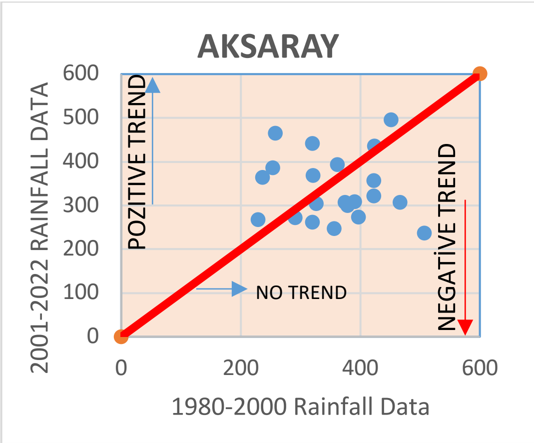
Method	Mann-Kendall and Spearman'ın Rho's				
Period	Spring	Summer	Autumn	Winter	Annual
AKSARAY	⬇ (red)	⇧ (yellow)	⬇ (green)	⇧ (yellow)	⬇ (green)
ANKARA	⬇ (green)	⇧ (yellow)	⬇ (green)	⇧ (yellow)	● (purple)
ISPARTA	● (purple)	⬆ (blue)	⇧ (yellow)	⇧ (yellow)	⇧ (yellow)
MERSİN	⇧ (yellow)	⇧ (yellow)	⬇ (green)	⇧ (yellow)	⇧ (yellow)
NEVŞEHİR	⬇ (green)	⇧ (yellow)	⬇ (red)	⇧ (yellow)	⬇ (green)

⬇ (red) : Statistically Negative Decrease/Positive Increase

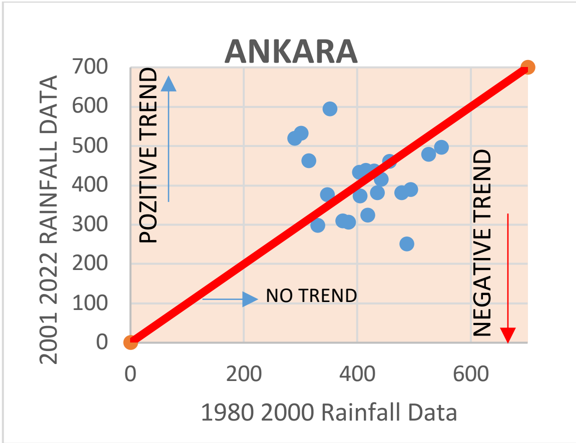
⇧⬇ (yellow/green) : A statistically insignificant negative decrease and positive increase

● (purple) : No trend

Between 1980 and 2022, based on the average precipitation findings in the provinces of Aksaray, Ankara, Isparta, Mersin, and Nevşehir, it was determined that the trends in Ankara and Mersin were not statistically significant. On the other hand, statistically significant trends were identified in Aksaray during spring, in Isparta during summer, and in Nevşehir during autumn. Lastly, there is no annual trend in Ankara.



a



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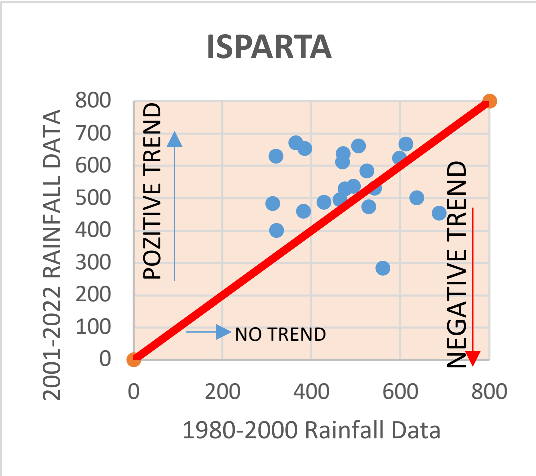

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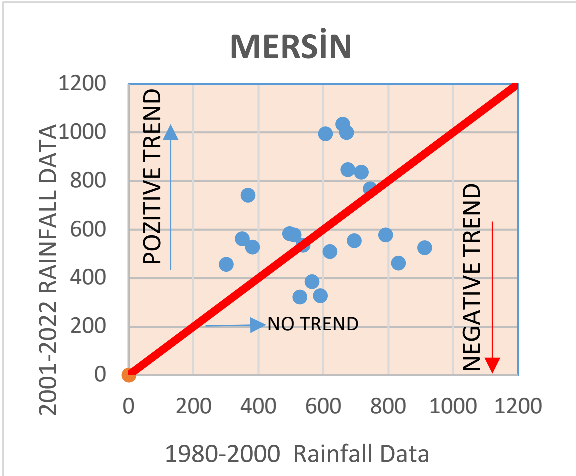

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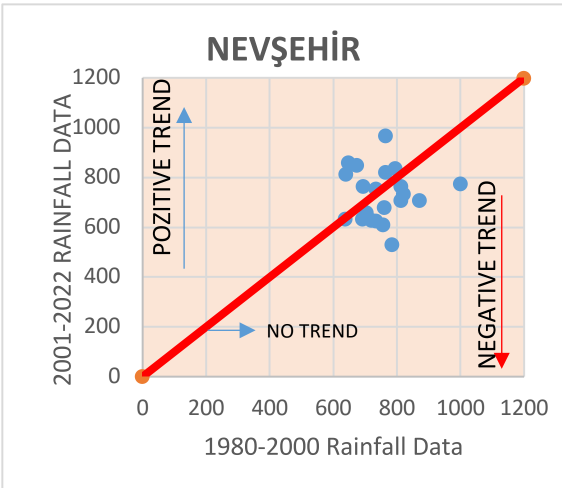

e

Figure 3 (a-e). Trend Directions of Rainfall Data According to the Şen Trend Test.

4. Conclusions

The ongoing changes in precipitation patterns driven by global warming continue to have significant effects on countries around the world. From a meteorological standpoint, precipitation and temperature are among the most affected variables by global warming. The accurate prediction of precipitation patterns is essential for the design and sizing of hydraulic structures, as well as for the effective management and development of water resources. Türkiye, with its 25 hydraulic basins, faces diverse climatic conditions, and the Konya Closed Basin, in particular, is recognized as one of the driest regions in the country. This study aimed to analyze the trends in seasonal and annual total precipitation data for the provinces of Aksaray, Ankara, Isparta, Mersin, and Nevşehir within the Konya Closed Basin over the period from 1980 to 2022.

The trend analyses were conducted using the Mann-Kendall and Spearman's Rho methods, revealing that annual precipitation amounts in Aksaray and Nevşehir exhibited a negative trend, whereas Isparta, Mersin, and to a lesser extent, Ankara showed a positive trend. However, none of these trends were statistically significant. Further analysis using the Innovative Şen method indicated that while precipitation decreased in Aksaray, Ankara, and Nevşehir, an increasing trend was observed in the remaining provinces. Notably, the statistical values derived from the Mann-Kendall and Spearman's Rho tests were found to be in close alignment, reinforcing the consistency of the results across the methods used.

Despite these observed trends, none of the patterns reached statistical significance, suggesting that the overall trend in precipitation within the Konya Closed Basin from 1980 to 2022 is not statistically meaningful. This implies that global warming has not yet exerted a significant impact on precipitation variability in this region. In other words, the changes in precipitation, whether increases or decreases, do not appear to be substantial enough to warrant significant concern at this time.

Given that the Konya Closed Basin is already characterized by arid conditions, it is imperative to focus on strategies that minimize water losses and leakage. To this end, the promotion of water-efficient agricultural practices, including conscious irrigation management, the expansion of dry farming techniques, and the efficient use of existing water resources becomes essential. These measures are critical for sustaining water availability and ensuring the long-term resilience of the basin, particularly in the face of potential future changes in climate conditions.

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