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Scrutinizing variability in full and partial rainfall time series by different approaches

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Abstract
The main goal of this study was established on the effect of splitting full data in disclosing time-related internal variability in a given time series, as well as classical trend analysis procedure. For this purpose, Mann–Kendall (MK), Spearman's Rho (SR), linear regression (LR), and innovative trend analysis (ITA) approaches were applied to the full part and the split data of the seasonal and annual rainfall data provided from the Kizilirmak Basin in Turkey. In the study, it was determined that the ITA method was more effective than other methods in terms of finding out the statistically significant trend in a significant portion of the rainfall data (approximately 87%), whereas this rate varied between 7 and 13% in other methods. Similar results have been experienced when the full data were divided into three groups. Among the trend analysis approaches applied to the split data groups formed for the analysis of the internal variability that occurs during the observation periods in the rainfall time series, the ITA method was quite effective in detecting the mentioned change in the time series. The ITA procedure revealed that there was a statistically significant decrease in rainfall amounts in the seasons with the highest rainfall of the region. This result could not be presented sufficiently when the data were divided into two groups. The remaining three methods failed to produce a remarkable result in determining the internal variability experienced in the data. In this sense, the consideration of full data in the analysis produces information about the average trend, it is insufficient to reveal the hidden information in the data.

Keywords Kizilirmak basin · Rainfall · Trend analysis · ITA test

1 Introduction

The water becoming one of the most important factors in determining the migration route and settlements of living things was effective in settling tribes on river and lakeshores and spreading civilizations to those geographies. In addition to the uncontrolled and polluted use of water resources, global warming has increased the pressure on usable water in this

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century. Besides, in order to meet the demand for food in parallel with the increase in the population, the need for freshwater has been on the rise. From this point, for the optimal use of water, which is absolutely necessary for living life, it is imperative to investigate the available water resources in terms of quality and quantity, and making plans considering the future water need. As a matter of fact, natural water sources where our water needs are met are generally fed by rains. In this sense, it is important to ensure that the parameters related to the hydrological data suitable for the purpose are provided from the homogeneous data in the realization of the engineering services (activities such as construction and operation) envisaged to improve the water resources. In order to obtain reliable project values, it is necessary to determine the change in precipitation and stream flows of the region studied.

The potentials of aboveground and underground water sources, where our needs are met, vary depending on the amount and distribution of precipitation. Global warming having a negative effect on the natural functioning of the hydrological cycle also changed the amount and distribution of precipitation. In the last century, many droughts and flood events have occurred due to global warming in many parts of the world (Hougton 2012; Sellers and McGuffie 2012). It was highlighted in IPCC (2013) that heavy rains would increase in numbers during the second half of the twentieth century. Turkey is shown among the countries that would be affected by this environmental disaster, and it is emphasized that it is one of the risky countries where short or long term climate variations may occur (Türkeş et al. 2012). In IPCC (2007), with the rise of temperatures toward the end of the twenty-first century in the Mediterranean Basin including Turkey, it was underlined that there would be significant reductions in precipitation and, therefore, that this region against the global climate change was one of the most sensitive areas. In addition, it is emphasized by Giorgi (2006) that the Mediterranean basin is one of the most sensitive regions in the sense that extreme precipitation would take place in the future. In Gao et al. (2006), Önol and Semazzi (2009), this global threat is expected to be more effective especially in the southern, middle center, and western parts of Turkey. It is an inevitable fact that the Southeastern Anatolian Project (GAP) in this region, which is an important development and irrigation project both in our country and in the world, would be affected by environmental disaster (Yurekli 2015). The effects of climate change in Turkey especially after the 2000s were the focus of attention by many researchers.

The measures to be taken should be determined in order to use our existing water resources potential effectively, to protect against possible water-related natural disasters, and to minimize damage. Considering the negative effects of water-related change on a sectoral basis for our country, the most serious impact would be on the agricultural sector. About 75% of the available water in Turkey is consumed in the agricultural sector. On the other hand, the fact that the agriculture-based industry in the country is also very high, this means that it would be seriously affected by the drought (Cakmak et al. 2004).

The effects of climate change in Turkey especially after the 2000s was the focus of attention by many researchers. Kanber et al. (2008) analyzed the damage of global climate change on agriculture and concluded that there would be a significant downward in precipitation, the amount of snow and melting times would convert, sowing-planting dates and cultivated areas dealing with some plants would change. Dellal et al. (2011) assessed the four main crops cultivated in Turkey in the context of the impact of global warming and, stated that it led to negative variability in crop yield from 3.8% to 10.1%. In the study by Önol and Semazzi (2009), possible climate change in the eastern Mediterranean Basin for the late twenty-first century was investigated. According to the results of the study, it was reported that precipitation would be decreasing along

Turkey's Mediterranean and Aegean coasts, on the contrary, would be a somewhat upward along the Black Sea coast (especially the Eastern Black Sea). Hemming et al. (2010) pointed out precipitation decrease in Turkey's western coasts based on the models considered in their study. Kitoh et al. (2008) highlighted that there would be a significant downward (30–70%) in the river flows in relation to the decrease in precipitation in the Euphrates Basin toward the end of the twenty-first century. Evans (2009) foresaw the most crucial variation in terms of decreasing precipitation on an area involving the Eastern Mediterranean, depending upon the results achieved by the global climate models. Güventürk (2013) revealed that there was a significant early shift in peak flows in many rivers in Eastern Anatolia. The reason for this experience was explained by the fact that the increasing temperature in recent years has started to melt the snow cover early. Bozkurt and Sen (2012) underlined that climate change would affect the water resources in the Euphrates and Tigris Basins negatively in the future. In the study dealing with the effect of global warming on the hydro-meteorologic structure of the Seyhan Basin in Turkey (Fujihara et al. 2008), it was expressed that the amount of snow and runoff would decrease considerably compared to today's values. On the other hand, the simulation study by Bozkurt and Sen (2011), in which was examined the impact of temperature change in the surface water of the seas surrounding Turkey on rainfall occurring in Anatolian peninsula, revealed that a two-degree increase in summer and autumn seawater temperatures would allow heavy precipitation in different regions of the Anatolian peninsula. According to Bozkurt et al. (2010), the decrease in snow cover due to the increase in temperature in the Eastern Anatolia Region located in the basin of the Euphrates and Tigris Rivers would cause significant seasonal changes in the surface runoff. In the winter season, less snow would accumulate and more water would flow to the surface. Due to less accumulated snow during the snow melting period, less surface runoff would take place. As a result of this event, the flow regime in the rivers would change in the winter and spring periods.

In the literature, statistical methods have been applied for different parts of the world to reveal the changes in the atmospheric elements from global warming. Similar studies are also for Turkey. Yurekli (2015) statistically analyzed seasonal and annual rainfalls for the upper the Euphrates–Tigris basin. For this purpose, Mann-Kendal and the sequential version of Mann–Kendal rank tests were used. The increasing and decreasing monotonic trend was revealed in 63% of the precipitation stations. Hadi and Tombul (2018) tested annual and seasonal precipitation and temperature in Turkey by using the Mann-Kendal test and the Pettitt–Mann–Whitney. In terms of annual precipitation, it was detected the presence of a downward trend in southeastern Anatolia and Mediterranean regions, while being an upward trend in Marmara and Black Sea areas, the other regions have statistically no change. Partal and Kahya (2006) explored the change in the data sequences dealing with monthly rainfalls and mean annual of monthly rainfalls from the 96 precipitation stations across Turkey for the period from 1929 to 1993. The results pointed out the remarkable downward trend in the annual mean precipitation, especially in parts of western and southern Turkey and along the Black Sea coasts. Unal et al. (2012) analyzed the variability in precipitation series of annual, wet, and dry seasons during the period from 1961 to 2008 by using the Mann–Kendall test, continuous wavelet transform approach, and rotated empirical orthogonal function. The trend analysis results highlighted the existence of a downward monotonic trend throughout Anatolia. Toros (2012) made an effort to detect the global warming impact on precipitation amounts in Turkey for the period involving from1961 to 2008, by divided the period to five decades. The conclusion based on the study is that there was a downward trend in precipitation of Turkey depending upon the temperature rise.

The study area (Kızılırmak Basin) which is located within the borders of two geographical regions, called the Middle Black Sea and Middle Anatolian Region, has different climate characteristics due to its position with respect to Turkey. The previous studies provided partial information about this region. Considering 30 precipitation stations for the study area would also contribute significantly to determining the change in precipitation. In spite of the basis that some attempts have been realized to reveal variability in precipitation on Turkey after the 2000s, there has been no comprehensive research to detect the change in precipitation on the Kızılırmak basin yet. On the other hand, the rainfall data sequences including the longer observation period could exhibit a monotonic trend in precipitation better than previous efforts for this region. The specific objectives dealing with the study are summarized briefly in the sections that follow. Among them are: completion of missing rain data, testing the homogeneity of the data, the existence of serial dependency in the data, removing this dependency, if any, analysis of the change in data series with parametric and nonparametric approaches, and analysis of the split data with the same trend approaches to reveal hidden information in whole data.

2 Methodologies

2.1 Study area, rainfall data sets and quality control

Kızılırmak River, which is Turkey's longest river with a length of 1151 km, has the distinction of being the second largest basin in Turkey with 78 647 km^2 area after the Euphrates-Tigris basin. Its drainage area corresponding to approximately 11% of Turkey's surface is located within the borders of Central Anatolia Region and Central Black Sea Region. The basin covers the surface area of 11 provinces partially or completely (Fig. 1). Among these provinces, Kayseri is the city with the highest density of industry and population. The average annual precipitation of the basin is about 445 mm and the average flow rate is around 164.15 m^3/s. Kızılırmak River rises from the southern slopes of Kızıldag Mountain, which is located in the borders of Sivas province in the east of the Central Anatolia Region, continues its flow primarily in the direction of the west and southwest, then forms in the form of a bow and flows in the direction of the Black Sea. The river finally discharges to the Black Sea. While the continental climate is dominant throughout the basin, the black sea climate prevails in its northern part. The central part of the basin has a topographically flatter structure and this part is also the area where the least rainfall falls, the annual precipitation falling to this area is around 300–400 mm. The regional distribution of rainfall based on the annual average rainfall amounts belonging to the stations is given in Fig. 2. It is proved from the figure that the rainfall is distributed quite differently regionally. Grain cultivation is intense throughout the basin, and sugar beet, potato, onion, garlic, garden, lentil, vetch, alfalfa, tobacco, fruit, and corn are grown (Ayaz et al. 2010; Köse et al. 2011; Bahadır 2011). While the average temperature of the basin is 13.7 °C, annual rainfall varies between 300 and 800 mm. The river, which is fed with rain and snow waters, has an irregular regime. While the water regime reaches its highest level in April, it flows at the lowest water level between July and February. There are 15 dams on the river. The project, which was made to supply drinking and potable water from the Kızılırmak River to Ankara, provides 500 million m^3 of water annually (Cakmak et al. 2007).

Although 100 rainfall gauging stations have been identified in the study area, 70 of these stations have insufficient rainfall observation periods for analysis as well as there are

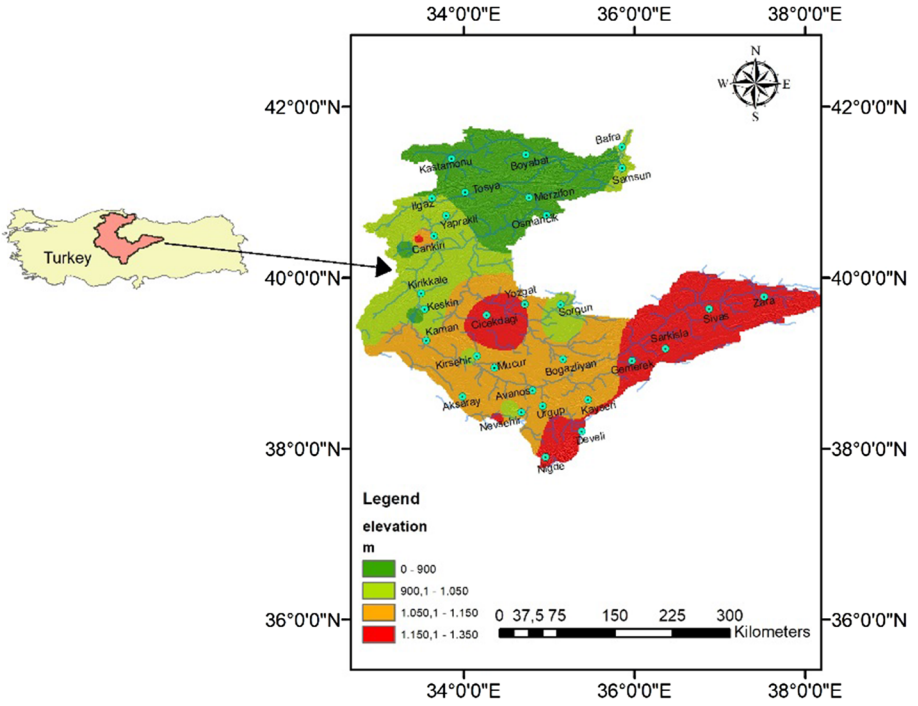


Fig. 1 Rainfall stations in the basin

a lot of missing rainfall amounts in some stations. These rainfall stations, which would not represent the purpose, have been excluded in the research. For the purpose, the stations with a continuous observation period of 30 or more were selected for reaching the expected target in the study. Mckee et al. (1993) suggested a rainfall series of at least 30 years in length for analysis. Some features dealing with these stations are present in Table 1. The rainfall amounts of the stations which have missing observations between the 30 stations were completed with the IDW (inverse distance weighting) method in Chen ve Liu (2012).

Monthly total rainfall amounts obtained from 30 rainfall gauging stations under the control of Turkish State Meteorological Service were used to detect the change in seasonal and annual rainfall series. After the rainfall stations are brought to the point where they can be analyzed, the first statistical test is to check the presence of homogeneity in the rainfall data of each month for the stations. The Mann–Whitney U (MWU) approach, detailed in Yurekli (2015), was used to control the homogeneity in the data. The null hypothesis (H_o) of this approach deals with whether each of the two groups to be tested belongs to the same population. Its U statistic is assumed to be normally distributed, and the Z_U statistic based on the U statistic is compared to the Z-statistic value provided from the standard normal distribution table for the 5% probability level. In the data sets where the H_o hypothesis is not accepted, the double-mass curve procedure was applied to the data sequences having inhomogeneity. The data subjected to the double-mass curve procedure was retested for whether to perform homogeneity condition.

After making rainfall data suitable for analysis, in order to reveal the variation in seasonal and annual rain data, the five cumulative rainfall data sequences formed based

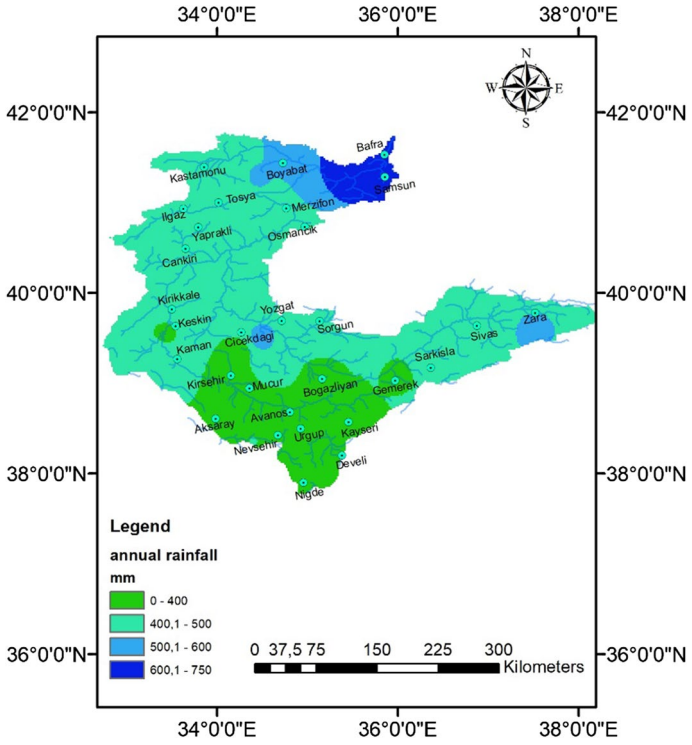


Fig. 2 Regional rainfall distribution based on annual rainfall means

on monthly rainfall amounts were used as a material. The seasonal data series belonging to cumulative rainfall amounts of the months in the first, second, third, and last quarter in the relevant year was referred to as S-1, S-2, S-3, and S-4, whereas annual data sequences were named as AN-5.

2.2 Trend analysis approaches

The parametric and nonparametric approaches commonly used to detect variability in hydro-meteorological variables are briefly summarized below, regardless of their mathematical formulations. The nonparametric Mann-Kendal (MK) and Spearman Rho (SR) tests are considered extensively in many studies, in addition to, linear regression method in cases where normality condition is provided. Innovative trend analysis (ITA) method, which has a different mentality from these trend analysis methods, was taken into consideration in the study, and its analysis phases were given below with its mathematical formulation. These procedures were applied to the seasonal and annual rainfall data of Kızılırmak Basin to be detected variability. On the other hand, the Mann–Whitney–Pettitt and CUSUM methods were used to determine the year in which the change in the rainfall series having a monotonic trend started.

The Mann–Kendall test (MK) is a special application of the test known as Kendall's Tau. This procedure, which is most widely preferred in the analysis of hydro-climatological data and defined as an effective method to reveal monotonic trends, is essential in the

Table 1 Some features of the rain gauge stations in the basin

Meteorological stations	Longitude (E)	Latitude (N)	Elevation (m)	Data period	Annual mean (mm)
Ilgaz	40°54′	33°37′	920	1966–2019	487.5
Tosya	41°00′	34°02′	880	1964–2019	479.3
Osmancik	40°58′	34°48′	420	1965–2019	401.7
Sorgun	39°48′	35°11′	950	1984–2019	440.0
Zara	39°53′	37°45′	1350	1964–2019	519.5
Keskin	39°40′	33°36′	1140	1968–2019	413.8
Cicekdagi	39°36′	34°25′	1300	1956–2019	343.0
Kaman	39°21′	33°43′	1075	1964–2019	464.0
Bogazliyan	39°12′	35°15′	1050	1964–2019	367.0
Avanos	38°42′	34°50′	920	1986–2019	334.9
Urgup	38°37′	34°55′	1050	1972–2019	369.4
Develi	38°23′	35°29′	1330	1965–2019	365.6
Kastamonu	41°22′	33°46′	774	1950–2019	481.1
Cankiri	40°36′	33°36′	730	1950–2019	408.7
Merzifon	40°52′	35°27′	700	1950–2019	414.7
Sivas	39°45′	37°01′	1285	1950–2019	426.7
Kirikkale	39°52′	33°42′	740	1963–2019	379.6
Yozgat	39°49′	34°48′	1300	1950–2019	572.3
Kirsehir	39°08′	34°10′	985	1950–2019	379.0
Gemerek	39°11′	36°03′	1150	1964–2019	390.4
Aksaray	38°22′	33°59′	980	1964–2019	349.1
Nevsehir	38°36′	34°42′	1224	1960–2019	412.5
Kayseri	38°41′	35°29′	1054	1950–2019	384.3
Nigde	37°57′	34°40′	1229	1950–2019	334.1
Boyabat	41°27′	34°46′	330	1964–2019	504.1
Bafra	41°33′	35°55′	15	1963–2019	781.7
Samsun	41°20′	36°15′	4	1950–2019	700.2
Sarkisla	39°20′	36°26′	1240	1963–2019	408.6
Yaprakli	40°45′	33°46′	1210	1971–2019	494.8
Mucur	39°03′	34°22′	1100	1984–2019	389.0

order of the data rather than its size (Burn and Elnur 2002; Yurekli 2015). The most important advantages of this test to other tests are that the procedure has high sensitivity against abrupt breaks and the ability to reveal variability, as well as the probability distribution form followed by the data does not matter (Jaagus 2006). Its statistic "Z_{MK}" is determined by the parameter calculated based on the difference between consecutive observations. The Z_{MK} test value is compared with the critical value being the table value (Z_{Table}) of the standard normal distribution at a 5% significance level. The null hypothesis (H_o) of the MK dealing with rainfall series having independent, identically distributed is accepted in the case where the Z_{MK} value $< (Z_{Table})$. But, before applying the MK test to the data sequences, the fact that the presence of serial dependence in the data is checked should not be overlooked, as its presence would cause misinterpretation of the change in data. Further, any

data set with the existence of positive serial dependence would highlight a considerable monotonic trend (Hamed and Rao 1998; Yue and Wang 2002). In the study, the statistical significance of serial correlation [$Q(r)$ statistic at lag one] was analyzed according to the principles given in Yurekli and Kurunc (2006). The $Q(r)$ statistic follows the Chi-squared distribution. The Chi-squared table value at a 5% significance level should be greater than the $Q(r)$ statistic for the acceptance of the null hypothesis concerning serial independence in the rainfall data set. After proving the statistical significance of serial dependency for any data set, the effect of dependency in this series could be overcome with a trend-free pre-whitening procedure (TFPW) described in detail by Yurekli (2015). The autocorrelation coefficient value at lag one needs for the TFPW analysis.

The Spearman Rho test (SR), which investigates the presence of a statistically significant correlation between the two observation series, is a nonparametric approach commonly used to detect the upward or downward trend in hydro-meteorological variables (Hamed 2016; Chiew and Sriwardena 2005). The approach operating based on the ranks of the data has some advantages. Among them are the following: unaffected by the distribution fitting to the data, relatively robust against extremes, useful even in small sample sizes, and applicability to data obtained at different time intervals (Gauthier 2001). The multiplication, $\left(\rho_S\right)x(N-1)^{0.5}$, of the rank-based test statistic (ρ_S) by the square root of sample size (N) is compared with the value (± 1.96) from the standard normal distribution table at 5% significance level. The null hypothesis (H_o) associated with no monotonic trend is rejected if the absolute product value is greater than the critical value.

The linear regression test (LR) should be applied to only normally distributed data; therefore, the use of any normality test approach is imperative to judge the distribution of available data before analyzing with the LR test on the presence of upward or downward trend in that data set. The existence of the monotonic trend based on the relationship between the dependent variable (y) and independent variable (x), each of which refers respectively rainfall data and the time of interest, is realized with this procedure (Jaiswal et al. 2015). For this purpose, by obtaining the scatter plot of the "x" variable versus the "y" variable, a straight line representing the points of each x and y in the plot is drawn. Whether the slope related to the line is equal to zero or not is tested statistically for the presence of variability in the data of interest. The null hypothesis of this approach is confirmed by the Student t test with regard to $n-2$ degrees of freedom. The critical value (S_{critical}) from the student t table at 5% confidence level is compared to the test statistic (S_{LR}) of the LR procedure, if $S_{\text{LR}} < S_{\text{critical}}$, the H_o hypothesis associated with not increasing or decreasing trend is accepted.

Innovative method (ITA) first introduced by Şen (2012) in detecting trend takes into account the scattered plot against each other of two data sequences with respect to the 1:1 line (or having a slope of 45°). This test has recently come to the fore in trend analysis commonly (Wang et al. 2020; Zhou et al. 2018; Şen et al. 2019; Güçlü 2018; Cui et al. 2017; Kisi 2015; Yagbasan et al. 2020; Ay et al. 2018). The superiority of this technique over other methods has nothing to do with whether the data is normally distributed, the length of the sample size, and the presence of series dependency between observations. Another distinctive feature of this method is that each value of time series has positioned itself in descending or ascending order along the line having slope of 45°. So it is possible to make a judgment over all the values of the data. This feature provides information about the trend of data clustered by different values (low, medium, and high). While applying this method, existing data is divided into two groups, and the scatter plot is formed as mentioned above. The variation in the data of interest is judged based on whether the values are positioned below, above, or on the line 1:1. The cases where the points are above,

below, or on the line having a slope of 45° show an upward, downward trend or no change, respectively. Şen (2017a, b) put forward the statistical significance test associated with the ITA procedure. Its statistical significance test is on the comparison of two sub-series averages from the same data of origin. The null hypothesis of this significance test deals with depending on the smallness of the calculated slope (S_{cal}) than the critical slope value, S_{crit}. To put it another way, the S_{cal} value of the relevant data would be statistically insignificant when it becomes inside confidence interval obtained based on the S_{crit} and the standard deviation (σ_s) of the calculated slope value. The S_{cal} value concerning the trend is calculated regarding Eq. 1.

$$S_{cal} = \frac{2\left(\bar{y}_2 - \bar{y}_1\right)}{n} \tag{1}$$

where $\bar{y}_1$ and $\bar{y}_2$ are the averages belonging to the first and second halves of the unsplit data sequence with "n" observations. The mathematical formulation of the σ_s is given as;

$$\sigma_s = \frac{2\sqrt{2}}{n\sqrt{n}}\sigma\sqrt{1 - \rho_{\bar{y}_1\bar{y}_2}} \tag{2}$$

In Eq. 2, the terms, "$\rho_{\bar{y}_1\bar{y}_2}$" and "$\sigma$," are cross-correlation coefficient and standard deviation of the unsplit data, respectively. The confidence interval depending upon a 5% (α) significance level is calculated as follows;

$$\mathrm{CI}_{(1-\alpha)} = 0 \pm S_{crit}\sigma_S \tag{3}$$

The S_{crit} value is equal to ± 1.960, which is obtained from the standard normal distribution table for 5% significance level.

2.3 Change-point analysis

There are many approaches in the literature to detect an abrupt change in a given sequential time series. These tests search out the period where there has occurred a statistically significant change in a time series. In this study, the nonparametric distribution-free CUSUM and Pettitt tests were used to detect change-point in seasonal and annual sequential rainfall time series of Kızılırmak basin. Brief information on these methods is given below.

The CUSUM procedure (Robson et al. 2000) is based on the difference between each observation and median of the relevant time series (Eq. 4). The sign in the equation takes the numeric values of 1, 0, and − 1, respectively, according to the case where the difference is bigger than zero, equal to zero and smaller than zero. The biggest one,(max |CS|), of CS values fitting to the Kolmogorov–Smirnov (KS) is considered as a test statistic. The presence of a statistically significant change-point in the data set is decided when the $\mathrm{KS}_{1-\alpha}$ critical value $\left(1.36\sqrt{n}\right)$ at a 5% significance level is greater than the(max |CS|).

$$\mathrm{CS} = \sum_{i=1}^{n} \mathrm{sgn}\left(x_i - x_{med}\right) \tag{4}$$

The null hypothesis of the Mann–Whitney–Pettitt (MWP) method (Mallakpour and Villarini 2016) assumes no change in the distribution behavior of the considered random data. To realize this procedure, supposed that there is a point of change most likely at the time

(t) of a series ($x_1, x_2, \ldots x_n$) having the length n, when the relevant data is arbitrarily divided into two groups at the time t, which is represented by $x_1, x_2, \ldots x_t$ and $x_{t+1}, x_{t+2}, \ldots x_n$, in the case where the distributions of two segments are $F_1(x)$ and $F_2(x)$, if $F_1(x) \neq F_2(x)$, one mentions that there is change-point in the data at the time t. The change-point is detected according to the MWP approach as follows;

$$U_{\mathrm{t}} = \sum_{i=1}^{t} \sum_{j=t+1}^{n} \operatorname{sgn}\left(x_i - x_j\right) \tag{5}$$

The sign takes numerical values as specified in the CUSUM method. The largest U_{t} value is accepted as the test value (K_{T}) of the MWP approach. It is decided that there is a change-point at the time t in which the K_{T} has a significantly different value from zero at the level of α. The significant probability dealing with the K_{T} is approximately assessed as below;

$$P = 1 - \exp\left[\frac{-6K_{\mathrm{T}}^2}{n^3 + n^2}\right] \tag{6}$$

3 Results and discussions

In the study, firstly, the frequency distribution behavior of the monthly total rainfall sequences for the 30 stations was evaluated in terms of normality. This is necessary in the context of the selection of the parametric or nonparametric approach to realize homogeneity analysis. Based on Kolmogorov–Smirnov and Shapiro–Wilk approaches, none of the 30-monthly rainfall series satisfied statistically the normality requirement. The nonparametric MWU method was applied to reveal the presence of homogeneity in monthly sequential rainfalls. Monthly rainfall data sets dealing with Merzifon, Boyabat, Sarkisla, Ilgaz, and Yaprakli stations showed inhomogeneity statistically at a 5% significance level. The Z_U statistic values of the MWU associated with these data sets are − 2.790, − 3.437, − 4.000, − 2.296, and − 2.989, respectively. These values are greater than the value of ± 1.960 from the standard normal distribution table for the 5% probability level. These data sets subjected to the double-mass curve procedure to remove inhomogeneity were analyzed in the context of ensuring homogeneity again. The results of the MWU after the double-mass curve application to these data series were − 0.653, − 0.864, − 1.626, − 0.299, and − 0.040, respectively. These Z_U values statistically confirm homogeneity of the relevant data sets.

The seasonal data series (S-1, S-2, S-3, and S-4) constituted for the first, second, third, and last quarters of each year along the observation period and the annual data sets (AN-5) were analyzed with the Ljung-Box $Q(r)$ statistic at lag one. Approximately 15% of 150 data series analyzed (120 seasonal, 30 annual) were found to have serial dependence. The acceptance of the null hypothesis dealing with serial independence in the relevant data sets could not be carried out since the Chi-square table value at a 5% significance level was smaller than the calculated $Q(r)$ statistic. This statistical analysis is imperative to determine the presence of the monotonic trend associated with the Mann–Kendall (MK) test. The serial dependence having an impact on the monotonic trend was removed with the TFPW

method which was applied to the data sequences with statistically significant serial dependence at lag one, before the MK test.

The MK test was fulfilled to detect upward and downward trend in rainfall amounts, after all of the seasonal and annual data series were made suitable to the application of the MK test. The MK test applied to 150 rainfall series exposed that more than approximately 60% of the rainfall sequences associated with the S-1, S-2, S-4, and AN-5 showed a decreasing trend, while about 73% of the data sets in the S-3 had an increasing trend. Although the S-3 season is a very dry period due to its natural climate structure, the reason for the significant increase in the rainfall series in question belonging to this season can be explained by the effect of heavy rains in recent times. Moreover, Kadıoglu (2000) and Toros (2012) reported that the months of July and August have been experienced as the months when rainfall has occurred to a minimum. The downward trend structure in 20 rain gauge stations for S-1 and S-2 seasons and, in18 rain gauge stations for S-4 season and AN-5 were detected, whereas this feature in S-3 season was brought out for 8 rain gauge stations. Nevsehir and Samsun stations had a statistically significant decreasing trend at the 5% significant in the S-1 season while a similar characteristic structure was detected at four stations (Sorgun, Keskin, Urgup, and Boyabat) in S-2 season. No decreasing trend was found statistically significant at any station in the S-3 season when there was a statistically significant upward trend in three stations (Kastomonu, Cankırı, and Kırsehir). In the season of the S-4, the negative trend in Sorgun, Avanos, and Mucur stations and, the positive trend in Kastamonu station were found out statistically significant. The highest number of statistically significant monotonic trends was detected in the AN-5. The five stations (Sorgun, Bogazlıyan, Avanos, Ürgüp, and Gemerek) highlighted a downward trend, while there was an upward trend in only Kastamonu station.

The SR test applied to rainfall data formed for seasonal and annual time periods showed quite a similarity with the findings revealed by the MK test, except for a few situations. Statistically insignificant decreasing trend based on the MK test was found out for Kaman station in the AN-5, and for Kayseri station in the S-3 season, whereas an upward trend for the data sets in question was detected by using the SR test. On the other hand, the opposite result to that of two stations above was brought out for Sarkisla station in the S-2 season. Rainfall data sequences which highlighted to be a statistically significant change as regarding the MK test was found to have the same results in the SR test. Surprisingly, the test values calculated according to both methods for these data series were also very close to each other.

Due to the need for normality assumption in linear regression (LR) analysis, Kolmogorov–Smirnov and Jarque–Bera approaches were used to assess whether rainfall data sets were normally distributed. The rainfall sequences that were found not to be normally distributed were subjected to transformation to ensure the normality. Outlier analysis was performed on the not normally distributed data despite the transformation and, the outliers in Aksaray and Boyabat stations were found statistically significant, these were in the data sets of the S-2 and AN-5 for Aksaray station and, in the data of the S-2 for Boyabat station. Only one outlier value was removed from each data set. After the data sequences have been made suitable for applying the LR test, the analysis has been carried out and the comments on the results are as follows. The LR test produced similar results to those of the trend methods described above. However, this method detected the different results for some data sets apart from the MK and SR tests and, also produced the results being individually compatible with each of these two methods. Based on the LR test, rainfall data sets in the S-1and S-3 seasons of Gemerek and Bogazliyan stations showed an increasing trend, respectively. Besides, a downward trend was found in the data sequences related

to the S-1 of Boyabat station and the S-4 of Samsun station, unlike the other two tests. There were similar trend results in the context of decreasing and increasing for Sarkisla and Kaman stations in the S-2 and AN-5 according to the SR and LR test, respectively, whereas a downward trend in the season S-3 for Kayseri station was determined with the MK and LR tests.

ITA method, in which trend analysis is carried out without any prerequisites, revealed that there was a statistically significant change in approximately 87% of the rainfall series. However, this finding was approximately 12% in the MK test, 11% in the SR test, and 7% in the LR test, respectively. Wang et al. (2020) emphasized that the ITA method is more effective in detecting hidden trends in hydro-climatic time series than methods in common use. In their study, they achieved results that coincided with the findings of this study. Zhou et al. (2018) also underlined that the ITA test was much more successful than both tests (the MK and LR) in defining the change in time series. Kişi (2015) noted in his study on the monthly pan evaporation series that the ITA method determined the change in the data set more successfully according to the MK and the SR tests. Güçlü (2018) further elaborated on the issue and suggested the alternative methodology based on the ITA and the MK test to search out the trend stability and, realized the full and partial data analysis of the MK and ITA procedures. In the study, the analysis based on dividing the time series into three parts was concluded to be the most convenient way for the more successful stability test since trend analysis applied to all data reveals the average trend.

More importantly, with the ITA test in this study, it was determined that there was a statistically significant increasing trend in all of the rest except for three of the rain data in the S-3 season. In the context of the rain gauge stations for the ITA, the presence of increasing and decreasing trends in rainfall series in other seasons and annual period was generally compatible with the findings of three methods, except for statistical significance. The numerical amounts of the trend results belonging to four approaches for the seasonal and annual series are as shown in Fig. 3. As can be seen from the figures, the LR has been less successful than other methods in detecting rainfall series where there are statistically significant changes. Based on the ITA method, most of the stations in the Central Anatolia

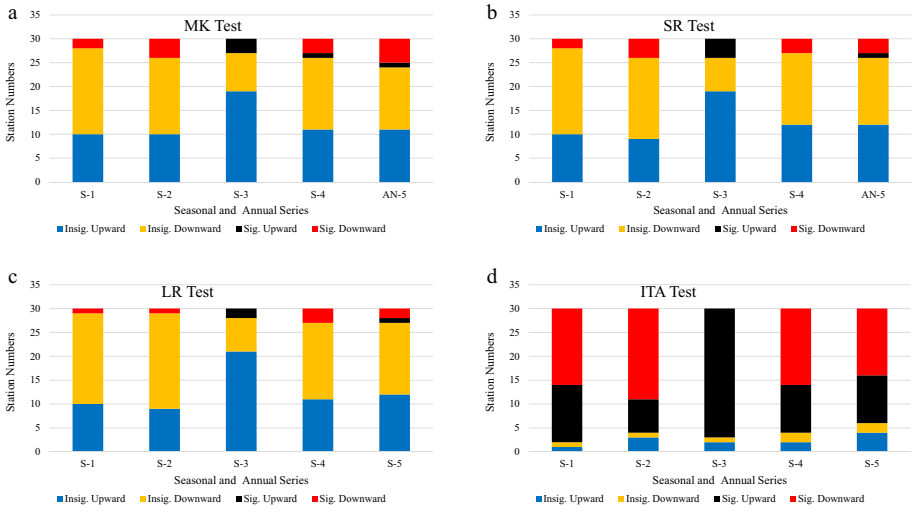


Fig. 3 Numerical amounts of the trends in rainfall series

Region of the Basin produced a decreasing trend in the S-2 and S-4 seasons in which rainfall occurs much more in Turkey. Türkeş (2012) reported being a significant downward trend in rainfalls in all geographic regions outside the region of the Black Sea in Turkey. Giorgi (2006) pointed out the Mediterranean basin also surrounding Turkey, as one of the very risky areas in the context of extreme precipitation. Altınsoy et al. (2012) underlined that the significant decrease in rainfall would be experienced in Turkey.

From Fig. 3d, more than half of the stations had a downward trend in all of the remaining seasons excluding the S-3 season while an increasing trend in more than 50% of the stations in annual data sets had. In the S-3 season, a decreasing trend was detected only in Gemerek station. According to the ITA results, rainfall data in all time periods of Osmancık and Kayseri station had a statistically significant increasing trend. But, a statistically significant decreasing trend was found in three of the 5 rainfall series associated with Gemerek station, and the statistically insignificant downward trend was detected in the rest.

There are the results dealing with detecting change-points in all of the rainfall data sets based on the MWP and CUSUM tests in Table 2. Both methods produced results that were compatible with each other, in approximately 70% of the stations. However, while the MWP determined statistically significant change-points at the 26 of all data sequences, the CUSUM found the change-points statistically significant at the 13 data sets. Adhering to these tests, it was not possible to judge a certain change-point about all stations. Duhan and Pandey (2012) determined the change-point of precipitation data with MWP and cumulative deviation tests. They divided the precipitation series into two groups with reference to the point of change and thus analyzed the change in the precipitation of the subgroups. Similarly, the considered times series in some studies were divided into subgroups having different observation lengths to compare the first group with other groups (Şen 2017a, b; Mohorji et al. 2017; Güçlü 2018). In this study, by partitioning the actual data into three parts as P1, P2, and p3, the sub-rainfall data sets were analyzed with the MK, SR, LR, and ITA methods. Thus, the internal change experienced along its observation period in any rainfall series would be tested. However, due to the mentality of the ITA method, its application was different from the others, so each split data is compared with each other; thus, the change of each group data based on other group data was tried to be determined. These results dealing with four procedures are given in Tables 3 and 4.

Based on Table 3, it was possible to make the following comments. The number of stations with the downward trend in the S-1 season decreased from the first group to the last group according to the MK, SR and LR tests. This result implies that there is an upward trend in the rainfalls of this season toward the last years in the region. These findings associated with the MK, SR, and LR tests do not match that of the complete data. In the S-2 season with most rainfall in Turkey, it has been determined that the rainfall data of the stations in the region have decreased in recent years. This decrease was more pronounced especially in P2 split data. In fact, this result corresponds to about 55% of the stations according to three test approaches. It was demonstrated by these three test methods that there was a significant decrease in the rainfall data belonging to the split p3 in the driest season S-3 in Turkey. This finding has deviated considerably from the result of full data. The results of the SR test were slightly different than those of the MK and LR test, especially in the data of the p3. Compared to those of the full and split P1 and P2 data, the remarkable different results dealing with the split P3 in the S-3 season were found out. A gradual downward trend has been identified from the split P1 to split P3 data associated with the S-4 and AN-5 periods for the MK, SR, and LR, excluding the data of the split P2 of the AN5 for the MK and SR. This finding emphasizes that the downward trend numerically is higher than the decrease obtained from the complete or unsplit data sets.

Table 2 Change-point analysis results based on both approaches

Stations	S-1		S-2		S-3		S-4		AN-5	
	CPT-1	CPT-2	CPT-1	CPT-2	CPT-1	CPT-2	CPT-1	CPT-2	CPT-1	CPT-2
Ilgaz	2009	2002	1972	1971	1995	1995	2000	2001^{+}	1972	1971
Tosya	1972	1971	2001	1991	1995*	1994	1999	1998	2009	2013
Osmancik	2002	1998	2009	2008	1995	1995	1973	1972	2009*	2008
Sorgun	1989	2006	2002*	2001^{+}	1994	2009	2011*	2010	2003*	2002^{+}
Zara	2012	1988	2002	2001^{+}	1995	1997	2013	1986	2001	2000
Keskin	2009	2008	2003*	2002	2007	2008	1999	1998	2002	2001
Cicekdagi	1971	1970^{+}	1980	1970	1995	1994	1976	1978	1975	1965
Kaman	1972	1971	2001	1991	1995	1994	1985	1998	1980	1994
Bogazliyan	1989	1988	1999	1995	2011	2010	1999	1998	1999	1998
Avanos	2016	2015	2016	2011	2002	2009	1999*	1998^{+}	2012*	1998^{+}
Urgup	2001	2000	2003	2002	1976	1997	1999	1979	2003*	2002
Develi	1998	1997	2006	2005	1984	1983	1999	1998	2011	2010
Kastamonu	1971	1970	2008	2007	1995*	1976^{+}	1967*	1974	1978*	1977
Cankiri	1972*	1971	2009	2008	1995*	1994	1975	1974	2009	2008
Merzifon	1971*	1970^{+}	1985	1986	1965	1964	1985	1984	1987	2005
Sivas	1977	1969	2012	2011	1971	1985	1985*	1979^{+}	1976	1975
Kirikkale	2009	2008	1992	1991	1999	1994	1985	1967	1989	1996
Yozgat	1971	1970	1980	1979	1995	1980	1979	1978	1979	2000
Kirsehir	1971*	1970	1990	1970	1995*	1994	1965	1964	2009	2008
Gemerek	1989	1997	2012	2002	2010	2009	2011	1986	2012*	2011
Aksaray	1982	1981	2001	2000	1995	1983	1999	1998	1999	1998
Nevsehir	2001	2011	1994	1995	1968	1997	1999	1984	1999	2000
Kayseri	1996	1970	2001	1985	2010	1997	1979*	1976	1975	1978
Nigde	1970	1969	1989	1988	2002*	2001^{+}	1983*	1984	1955	1954
Boyabat	1994	2006	2001*	2000^{+}	2005	2004	2007	1977	2006*	2005
Bafra	1984	1983	2006	2008	2014	1973	2013	2000	2013	1986
Samsun	1971*	1970^{+}	1967	1966	1992	1991	1965	2010	1987	1972
Sarkisla	1989	1999	1971	1970	1984	1983	2011	2010	1989	1981
Yaprakli	2009	2013	1994	1975	1995	1994	1998	1995	2014	2013
Mucur	2009	1993	2002	2001	1995	1994	1999*	1998	1999	1998

CPT-1 change-point test by the MWP, *CPT-2* change-point test by the CUSUM

$^{*,+}$ statistically significance at 5%

In Table 4, the ITA test results of the three split rainfall data sets were presented. Comparing each other of both parts obtained by dividing the complete rainfall data into two also is present in the same table. The ITA results dealing with P1–P2 and p1–p3 for the S-1 season showed a decreasing trend in 26 and 19 stations, respectively. These findings highlight that the rainfall amounts of the split p2 and p3 is smaller than that of the split P1. As can be seen in the table, the rainfall sequences of the p2 have an upward trend according to the rainfall data sets of the P3, except seven stations. It was not possible to reach this hidden information from the ITA results obtained by dividing the full data into two parts. From the ITA results of the season S-2, it has been determined that the rainfall series associated with

Table 3 The numbers of the stations with upward and downward trend for three approaches

Direction in trend	Mann-Kendal					Spearman Rho					Linear regression				
	Seasons				AN	Seasons				AN	Seasons				AN
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
F-Inc	10	10	22	12	12	10	9	23	12	13	10	9	23	11	13
P1-Inc	11	20	23	16	19	8	20	24	15	19	11	21	23	15	19
P2-Inc	16	14	23	13	20	13	13	22	14	20	11	14	23	13	15
P3-Inc	17	16	10	11	11	17	15	8	8	11	14	14	12	7	11
F-Dec	20	20	8	18	18	20	21	7	18	17	20	21	7	19	17
P1-Dec	19	10	7	14	11	22	10	6	15	11	19	9	7	15	11
P2-Dec	14	16	7	17	10	17	17	8	16	10	19	16	7	17	15
P3-Dec	13	14	20	19	19	13	15	22	22	19	16	16	18	23	19

P1, P2, and P3 are associated with split data

F represents complete data; *Inc.* statistically significant and insignificant increasing trend, *Dec.* statistically significant and insignificant decreasing trend

Table 4 The numbers of stations with upward and downward trend for ITA approach

Direction in trend	Seasons				AN-5
	1	2	3	4	
FH–SH (Inc.)	13	10	29	12	14
P1–P2 (Inc.)	4	18	19	26	18
P2–P3 (Inc.)	23	5	22	2	11
P1–P3 (Inc.)	11	10	25	17	12
FH–SH (Dec.)	17	20	1	18	16
P1–P2 (Dec.)	26	12	11	4	12
P2–P3 (Dec.)	7	25	8	29	19
P1–P3 (Dec.)	19	20	5	13	18

FH first halve of the complete data, *SH* second halve of the complete data

the P2 tended to increase over the rainfall series of the P1. On the other hand, ITA results related to p2–p3 and p1–p3 matches show that 83% and 67% of stations have a decreasing trend, respectively. This conclusion proves a downward trend toward recent years in the rainfall amounts of the many stations in the region.

The ITA dealing with the season S-3 produced quite different results. The ITA belonging to the FH–SH detected a decreasing trend in only one station, whereas the number of stations having a downward trend for the P1–P2, P2–P3, and P1–P3 matches was 11, 8, and 5, respectively. A surprising result was detected for the season S-4. The ITA of the P2-P3 match produced a downward trend in 29 stations while the decreasing trend was detected at 18 stations for the case where the full data was divided into two groups. On the contrary, the increasing trend was achieved in 26 stations in the P1–P2 match. For the AN-5 data sets, the number of decreasing trends for all stations gradually increased from the first match to the last match.

The alternative hypothesis (H1) results of the MK, SR, LR, and ITA, which is associated with rejecting the null hypothesis, belonging to the split data sequences of P1, P2, and P3 for each station for the significance level of the 5% are illustrated in Fig. 4. The test results concerning the complete data in order to compare with those of the split data sets were given together in the figures representing each trend approach. Detecting the internal change that occurred during the observation period in full data was sufficiently not satisfactory with the MK SR, and LR approaches. In this sense, it is difficult to reach a clear judgment about the direction of the change experienced by the rainfall stations in the region during the observation period. Neither in full data nor in all split data was found out an upward trend in the S-1 and S-2 season with the LR test and in the S-1 season with the SR test. Additionally, a decreasing trend in the S-3 season was not detected with the SR test. Based on the MK, SR, and LR trend tests, there was a statistically significant trend

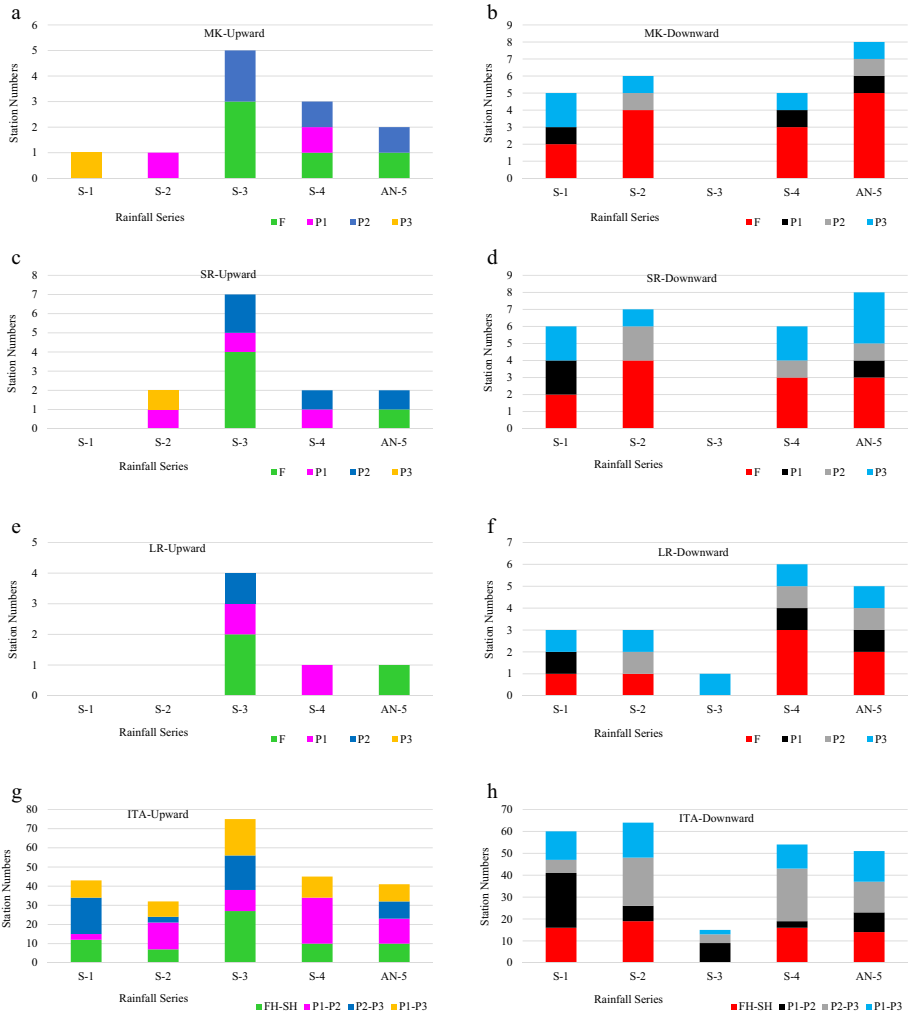


Fig. 4 Statistically significant trend numbers four approaches

in approximately 4%, 5, and 3 of the 150 data sequences for each split group, in the case where the data was divided into three groups (P1, P2, and P3).

Due to the fact that the analysis was carried out by dividing the full data into double and triple groups during the implementation of the ITA method in the study, scrutinizing the time-related internal change of the rainfall time series was realized by comparing each series in the group with each other, unlike the other three methods. The ITA analysis results of the formed matches after partitioning the full data into two halve and three parts were quite different from each other. This is an important proof of a time-related internal change in the time series. The matches of the P2–P3 had a statistically significant downward trend in rainfall data sequences in the 22, 24, and 14 stations for the S-2 and S-4 seasons, and AN-5. The ITA results based on both halves for the S-2 and S-4 seasons indicated that a statistically significant decreasing trend was detected at approximately 14% and 33% fewer stations while being equal to that of the P2–P3 match for the AN-5. These findings proved that there was a serious decrease in the amount of rainfall of the stations in the region in the mentioned periods. The other finding was that some of the matches belonging to the triple groups for the season S-3 produced a statistically significant downward trend although the ITA result based on the matches of double-ITA (FH–SH) was no decreasing trend for the S-3. In the S-1 season, the decreasing trend was detected in the data of 25 stations for P1–P2 matching, while this number decreased to 6 in p2–p3 matching. In other words, it is possible to talk about a statistically increasing trend in the rainfall data of this season toward the last years. It is obvious from Fig. 4g that this result would be reached. Finding out the change in the rainfall data with the ITA methodology, especially the statistically significant change, has been much more effective, whereas the conclusions provided from the ITA method were not reached in the application of the other trend methodologies. It has been determined in the study that many hidden information can be revealed by dividing the data into subgroups.

The visualization of the ITA procedure applied to three split rainfall sets (P1–P2, P2–P3, and P1–P3 matches) to examine the time-related internal change of the rainfall time series is presented in Fig. 5b. Figure 5a represents the ITA visualization of two halves (FH–SH match). Both figures were formed with total rainfall amounts received from Samsun rain gauge station for the S-1 season. It is because of the impossibility to give figures for the entire number of data that only one data is included to form the ITA graph in the study. In this sense, the data of Samsun station were considered as an example, and in general, it was aimed to represent the change of all data sets over time. When the 1: 1 line is taken as reference, the positions of the sub-series with respect to each other (or the scatter of the matches of the sub-series) reveal very clearly how the full data changes during the observation period. Figure 5a emphasizes that in the case where the data are divided into two

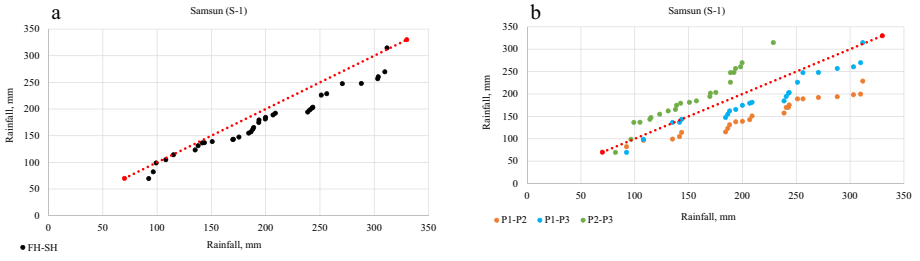


Fig. 5 Variability in the observation period of the rainfall time series for Samsun station

halves, the data of the second part have a decreasing trend compared to the data of the first part. However, when the data are divided into three parts, the P2–P3 match, in other words, the comparison of the second part and the last part groups showed that the data in the last part has an increasing trend. Therefore, it has been determined by visual and calculations that the subject data have a statistically significant increase trend toward recent years. In addition, the remaining matches (P1–P2 and P1–P3) also give us clear information about the change of full data over time. On the other hand, it seems impossible for us to have this hidden information when the data are divided into two parts. Because in the comparison of the two groups, it was determined that the data in the second part tended to decrease continuously.

4 Conclusion

This study was established to reveal the changes in four seasonal and annual total rainfall series for 30 rain gauge stations located in the Kızılırmak basin, and the change information hidden in these series. For this purpose, the study was carried out according to four different trend approaches (MK, SR, LR, and ITA). These tests were applied to the data, especially after the prerequisites required for MK and LR analyzes were satisfied in the data. First of all, by applying these tests to the full (unsplit) data, information about the average trend was obtained. This is actually a traditional approach to trend analysis. With this type of approach, it is not possible to detect information about the variability hidden in the data. With this traditional approach to trend analysis, the most effective methods in determining the statistically significant change in rainfall series based on four analysis methods were ITA, MK, SR, and LR, respectively. In fact, it is obvious that the ITA method was much more effective than other trend methods because the ITA, MK, SR, and LR methods detected statistically significant trends in approximately 87%, 12%, 11%, and 7% of 150 rainfall data sets, respectively.

In revealing the variability experienced during the observation period of the rainfall time series, rather than traditional trend analysis applied to the full data, the consideration of the split data in this study allowed the detection of the hidden information. In this sense, again, the most effective approach has been the ITA. None of the remaining approaches have produced the desired level of results. The fact that the ITA results differed considerably from each other when the full data was divided into two parts and three parts was the evidence of a time-related internal change in the time series. A decreasing trend was detected at approximately 73%, 80%, and 47% of the stations for the S-2 and S-4 seasons and AN-5 (annual series) in the P2–P3 match of the triple-ITA, respectively. These seasons are the periods when rain occurs most. The finding supported that the region evolved into an arid period as the split p3 consisted of rainfall data in the last period. It can be judged from the study that it is difficult to reach many hidden information described above when full data are taken into account in the analysis.

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