



Homogeneity revisited: analysis of updated precipitation series in Turkey

Bugrayhan Bickici Arıkan^{1,2} · Ercan Kahya¹

Received: 20 August 2017 / Accepted: 3 January 2018 / Published online: 16 January 2018
© Springer-Verlag GmbH Austria, part of Springer Nature 2018

Abstract

Homogeneous time series of meteorological variables are necessary for hydrologic and climate studies. Dependability of historical precipitation data is subjected to keen evaluation prior to every study in water resources, hydrology, and climate change fields. This study aims to characterize the homogeneity of long-term Turkish precipitation data in order to ensure that they can be reliably used. The homogeneity of monthly precipitation data set was tested using the standard normal homogeneity test, Buishand test, Von Neumann ratio test, and Pettitt test at the 5% significance level across Turkey. Our precipitation records including the most updated observations, extracted from 160 meteorological stations, for the periods 1974–2014 were analyzed by all the four homogeneity tests. According to the results of all tests, five out of 160 stations have an inhomogeneity. With regard to our strict confirmation rule, 44 out of 160 stations are said to be inhomogeneous since they failed from at least one of the four tests. The breaks captured by the Buishand and Pettitt tests usually tend to appear in the middle of the precipitation series, whereas the ability of standard normal homogeneity test is in favor of identifying inhomogeneities mostly at the beginning or at the end of the records. Our results showed that 42 out of 44 inhomogeneous stations passed all the four tests after applying a correction procedure based on the double mass curve analysis. Available metadata was used to interpret the detected inhomogeneity.

1 Introduction

In general, hydrological events with extreme occurrences mostly induced by climate fluctuations have social and economic effects on community and, thus has long been the continuing topic of research, considered in a wide spectrum of scientific communities ranging from climatology to public health (e.g., among others, Kalaycı and Kahya 1998; Şarlak et al. 2009; Kaya et al. 2012; Meral et al. 2014 and 2015). There is a need for accurate and consistent data to make climate assessments and make accurate predictions and modeling. It is noteworthy that inhomogeneous data sets do not give reliable results in statistical

analyses; therefore, it is necessary to ensure the homogeneity of time series through some statistical methods, combined with metadata, which is pertinent to inhomogeneous data sets. Metadata is a historical information in a station including the state of observation, providing important asset in data quality to be used in homogeneity studies. The best way to maintain homogeneity is keeping gauging stations in a required environment and the measuring system under proper management (Demircan et al. 2015). Availability of long-term, homogeneous, and continuous precipitation series is always essential for climate and hydrologic studies. Nevertheless, precipitation data may suffer from inhomogeneity, owing to various non-climatic factors. The observational data network across Turkey is under continuous development; however, at the same time, it is prone to the effects of urbanization and changes in land-use conditions (Kömüşcü 2010). Homogeneity tests of time series can be examined under two headings as absolute method and relative method. In the former, the test is separately applied for each station as the reference stations are involved in testing in the latter (Wijngaard et al. 2003).

Hanssen-Bauer and Førland (1994) conducted a homogeneity analysis of rainfall data from 165 rainfall stations in Norway using the standard normal homogeneity test (SNHT). They found that 50 of the 165 stations were homogeneous in their

✉ Bugrayhan Bickici Arıkan
bugrayhanbickici@gmail.com;
bugrayhan.bickici@medeniyet.edu.tr

Ercan Kahya
kahyae@itu.edu.tr; ercan.kahya@hotmail.com

¹ Civil Engineering Department, Hydraulics Division, Istanbul Technical University, Istanbul, Turkey

² Civil Engineering Department, Hydraulics Division, Istanbul Medeniyet University, Istanbul, Turkey

study. Tarhule and Woo (1998) studied the alterations in precipitation characteristics in northern Nigeria using the Pettitt test. Mihajlovic (2006) analyzed the homogeneity of the monthly total rainfall series using the SNHT. Kang and Yusof (2012) analyzed the homogeneity of the precipitation data on the peninsula of Malaysia using SNHT, Buishand, Pettitt, and Von Neumann tests. Al-Lami et al. (2014) examined the homogeneity of 36 meteorological stations' data in Iraq for the periods 1981–2010. They applied the Pettitt test, SNHT, Buishand range test, and Von Neumann ratio test to detect the inhomogeneity of precipitation series.

A number of techniques have been used for analyzing the homogeneity of hydrologic and meteorological variables. Türkes (1996) analyzed homogeneity of annual precipitation data of 91 stations in Turkey during the periods 1930–1993 using the Kruskal-Wallis test prior to analyzing their spatial and temporal characteristics. Kahya and Kalaycı (2004) tested homogeneity of trends in monthly streamflow in Turkey using a method developed by Van Belle and Hughes (1984). Karabörk et al. (2007) checked through the homogeneity of rainfall data in Turkey by the SNHT and Pettitt test, and considered a station to be inhomogeneous if at least one of the two tests indicated so. As a result, their outcomes showed that 43 out of 212 stations were found to be inhomogeneous. Göktürk et al. (2007) conducted homogeneity assessment of Turkish rainfall series using the SNHT. They suggested that homogeneity tests should be applied correctly, and metadata should be checked to explain the homogeneity of the stations. Firat et al. (2010) applied the Pettitt test, SNHT, and the Runs test (Swed-Eisenhart) for testing the homogeneity of precipitation data spanning from 1968 to 1998 for 267 meteorological stations throughout Turkey.

The aim of this study is to explore the homogeneity characteristics of monthly precipitation series at carefully selected 160 meteorological stations in Turkey using four common absolute homogeneity tests of the SNHT, Pettitt test, Buishand test, and Von Neumann ratio test. Motivation of this research was inspired from the fact that there recently have been increasing body of hydrology and climate investigations with various aims in Turkey, which mostly require reliable updated precipitation data. At the same time, this study carries a role in complementing previous studies in the same matter by employing a number of different homogeneity tests and having recourse to metadata if possible.

2 Data and study area

We used monthly precipitation data spanning from 1974 to 2014 compiled by Turkish State Meteorological Service (MGM). Our data network consists of specially selected 160 meteorological stations with no missing values distributed all over Turkey. The geographical location of these

meteorological stations, which are almost uniformly distributed across Turkey, is illustrated in Fig. 1.

The geographic location of Turkey lies over the coordinates with latitudes 36° and 42° N and longitudes 26° and 45° E. The country is a peninsula in the Eastern Mediterranean, with three sides surrounded by the sea. The climate of Turkey is changeable due to its geographic location. Three main climate types observed can be listed as Mediterranean climate, continental climate, and temperate oceanic climate. Mediterranean climate is defined by hot and moderately dry summers as well as cool and rainy winters. This climate type is observed for the Mediterranean and Aegean coastal areas of the country. Continental climate is characterized by hot summers and cold winters, which could be observed in the interior regions of Turkey. Precipitation occurrence is less and especially in the form of snow during wintertime. The Black Sea coastal region has a temperate oceanic climate. This climate type is characterized by warm and wet summers with cool and rainy winters. This region receives considerable amount of precipitation and its eastern part has frequent precipitation throughout the year. Sensoy et al. (2008) indicates that the central Anatolia is the most vulnerable to drought in the country due to the mountainous location. Taurus Mountains in the south and Caucasian Mountain in the north and Black Sea Mountains hold the rain clouds, resulting in continental climate. While the eastern part of the Black Sea coasts receives 2200 mm average rainfall, whereas the interior regions such as Konya and Iğdır receive 250–300 mm average rainfall annually. In addition, the Aegean and Mediterranean coasts have different precipitation patterns depending on location; thus, annual precipitation in this region varies from 580 to 1300 mm (Dundar 2015).

3 Methodology

3.1 Homogeneity tests

Hydrological and climatological studies require that the data be homogeneous. However, changes in routine observation methods, relocation of stations, or changes in measurement techniques can cause homogeneity to deteriorate in the data. In addition, changes in population due to population growth in the area being measured, urbanization, or changes in nature due to natural influences can also lead to a deterioration of the homogeneous structure of data records. As a result, studies on this data may lead us to the wrong conclusion. Therefore, homogeneity analysis is necessary.

In this study, we applied four broadly used homogeneity tests to the precipitation data, namely, the Buishand test, the Von Neumann ratio test, the SNHT, and the Pettitt test. Wijngaard et al. (2003) suggested that these tests were sufficient to determine the homogeneity of the data. The most

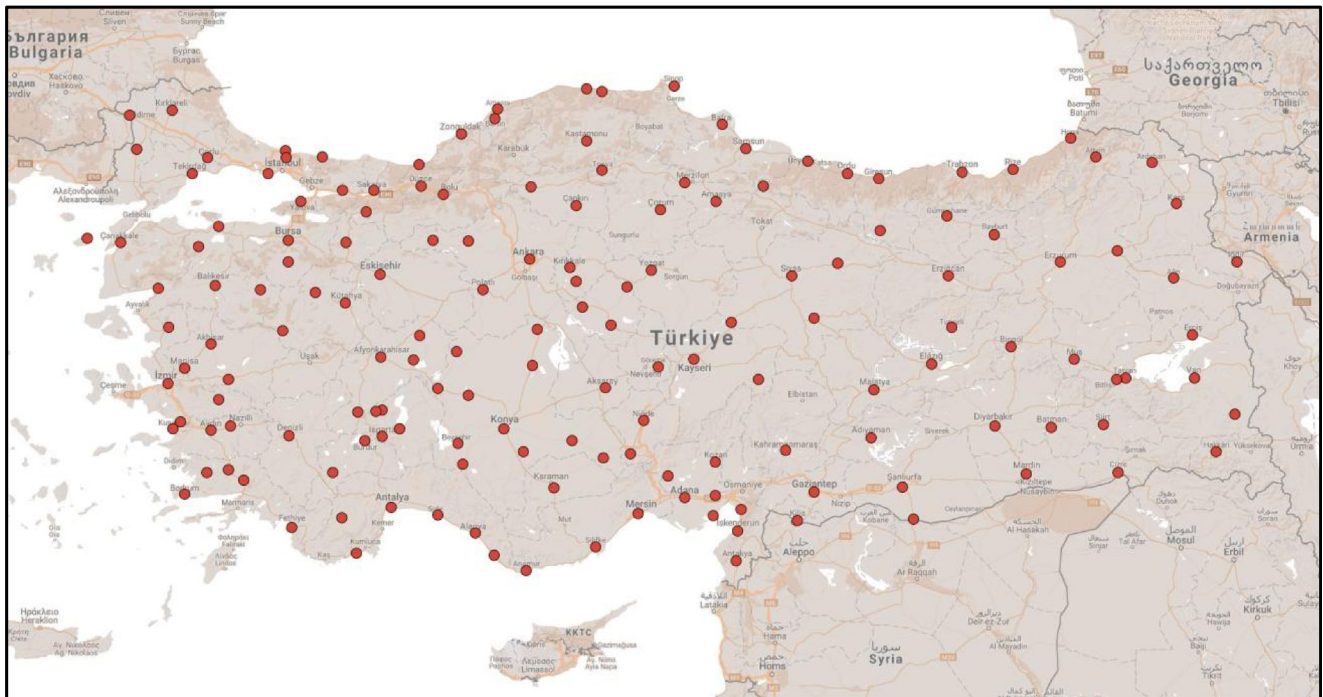


Fig. 1 The geographical distribution of 160 precipitation stations over Turkey used in this study

important property of these tests is that they should complement each other. From these tests, the Buishand, SNHT, and Pettitt tests investigate whether there is a jump in the time series and determine the breaking point. The Von Neumann ratio test assumes that the series do not randomly disperse and do not give information about when homogeneity is impaired. While the SNHT is sensitive to breaks at the beginning and end of the time series, the Pettitt test and the Buishand test are more susceptible to detecting breaks in the middle of the time series.

3.1.1 Von Neumann ratio test

In this homogeneity test, according to the hypothesis H_0 , the data were not randomly distributed. According to the alternative hypothesis, the time series considered is randomly distributed. Von Neumann ratio test does not determine a specific location where homogeneity is impaired and does not provide information about when homogeneity is impaired (Wijngaard et al. 2003).

In this test, N describes the mean squared proportion of the variation of the variance in succession (Von Neumann 1941):

$$N = \frac{\sum_{i=1}^{n-1} (Y_i - Y_{i+1})^2}{\sum_{i=1}^n (Y_i - \bar{Y})^2} \tag{1}$$

Critical values of this test are given in Wijngaard et al. (2003). If the calculated N value exceeds the critical N value, H_0 hypothesis is considered homogeneous.

3.1.2 Buishand test

In Buishand test, which assumes that the data is normally distributed, the data is distributed independently and randomly according to the H_0 hypothesis. This test is sensitive to breaks in the middle of the time series (Wijngaard et al. 2003).

$$S_0^* = 0; S_k^* = \sum_{i=1}^k (X_i - \bar{X}), \quad k = 1, 2, \dots, N \tag{2}$$

where:

- \bar{X} : the mean of time series observations (X_1, X_2, \dots, X_N)
- k : the number of the observation at which a break point has occurred

Rescaled adjusted partial sums are obtained by dividing the S_k^* by the sample standard deviation (Buishand 1982):

$$S_k^{**} = S_k^* / D_X, \quad k = 1, 2, \dots, N \tag{3}$$

$$D_X = \sqrt{\frac{\sum_{i=1}^N (x_i - \bar{x})^2}{N}} \tag{4}$$

The statistic that can be used to analyze homogeneity is expressed as follows:

$$Q = \max_{0 \leq k \leq N} |S_k^{**}| \tag{5}$$

Q/\sqrt{N} value is compared with the critical value given by Buishand (1982). If a calculated value is less than the critical

value, the null hypothesis is accepted; otherwise, the null hypothesis should be rejected (Alghazali and Alawadi 2014).

3.1.3 Standard normal homogeneity test

SNHT is a homogeneity test frequently used in climate studies. This method, developed by Alexandersson, has successfully been used in testing many climatic and hydrological scales (Alexandersson 1986). This method is flexible and simple to use. Alexandersson divides the reference point of the examined series by a “*k*” point and calculates $T(k)$.

$$T(k) = k\bar{z}_1^2 + (n-k)\bar{z}_2^2 \quad k = 1, \dots, n \tag{6}$$

where

$$\bar{z}_1 = \frac{1}{k} \frac{\sum_{i=1}^k (Y_i - \bar{Y})}{s} \quad \text{and} \quad \bar{z}_2 = \frac{1}{n-k} \frac{\sum_{i=k+1}^n (Y_i - \bar{Y})}{s} \tag{7, 8}$$

If the break is located at the point K , $T(k)$ reaches its maximum value at $k=K$. The test statistic T_0 is defined as:

$$T_0 = \max(T(k)) \quad \text{for} \quad 1 \leq k < n \tag{9}$$

Jaruskova (1994) has developed the following equation based on this test statistic.

$$T_0 = \frac{n(T(n))^2}{n-2 + (T(n))^2} \tag{10}$$

If T_0 exceeds the test statistic value, the null hypothesis is rejected. Critical values of this test are given in Wijngaard et al. (2003).

3.1.4 Pettitt test

This nonparametric method, suggested by Pettitt (1979) to detect the point of change in a time series, finds the point of change on a monthly or annual scale. While the null hypothesis indicates independent and random distribution of the series, the alternative hypothesis indicates a sudden change. Pettitt test is a nonparametric rank test. To calculate the statistics, the ranks $r_1 \dots r_n$ of the $Y_1 \dots Y_n$ are used (Pettitt 1979):

$$X_k = 2 \sum_{i=1}^k r_i - k(n+1), \quad k = 1 \dots n \tag{11}$$

If there is a break in year K , the statistic is maximal or minimal near the year $k=K$:

$$X_K = \max_{1 \leq k \leq n} |X_k| \tag{12}$$

The statistical significance for a probable level α is given as:

$$X_{K\alpha} = [-\ln\alpha(n^3 + n^2)/6]^{1/2} \tag{13}$$

The critical values of this test are given in Pettitt (Pettitt 1979). If the X_K values do not exceed the critical values, the H_0 hypothesis is accepted; that is to say, it is homogeneous.

3.2 Double mass curve analysis

Double mass curve analysis (DMCA) is frequently used in the literature for homogenization by correcting errors in hydro-meteorological data. Rainfall data may have lost their homogeneity properties due to faults coming from various sources. These errors are classified into two types, randomly and systematically. Errors that are described as random and sampling error occur from misreading in observations. Systematic faults may occur due to changes in station location, misplacement of the measuring instrument, urbanization, and so on. These types of errors are incompatible and the observed values are always less or always greater than the actual values. Therefore, homogeneity of rainfall data can be obtained by correcting such mistakes. For this correction, DMCA is used. This technique is widely used for detecting and correcting inconsistent precipitation data. (Linsley et al. 1982).

The control of the values of a station by DMCA is made by comparing the annual or monthly total values of that station and the average annual or monthly values of a group of stations neighboring that station.

The correction is performed by adjusting the records prior to the break to reflect the new state (after the break). To accomplish this, the rainfall records prior to the break are multiplied by the ratio of slopes after and before the break (Ponce 2014).

$$M_c = \frac{c}{a} M_a \tag{14}$$

where,

- M_c : Adjusted precipitation
- M_a : Observed precipitation
- c : Slope of graph to which records are adjusted
- a : Slope of graph at time M_a was observed

4 Results and discussion

Our precipitation data set having the most updated observations across Turkey was compiled from 160 meteorological stations for the periods 1974–2014. We analyzed the homogeneity of time series at each station using the SNHT, the Pettitt test, the Buishand test, and the Von Neumann ratio test at significance level of 5%. In this study, all of the 160 precipitation stations were particularly selected as having no missing value, among a total of nearly 250 stations. In this study, R statistical software was used for the homogeneity

analysis. Our decision criterion for a station to be homogeneous was rigidly set as a full confirmation through all of the four tests used in this study. Previous similar studies in Turkey did not adopt such a rigid criteria for the confirmation of homogeneity of precipitation series as applied in this study.

Keeping this criterion in mind, all stations were subjected to the four homogeneity tests. As a result of overall evaluation, we determined 44 out of 160 stations to be inhomogeneous since either one or more tests did not confirm. Test-wisely speaking, the results of the SNHT and the Pettitt test showed that a set of 25 out of 160 stations were impacted from inhomogeneity. According to the Buishand test, 13 out of 160 stations were found to be inhomogeneous while the Von Neumann test revealed 22 inhomogeneous stations. Moreover five out of 160 stations possess inhomogeneity characteristic with the respect to the results of all four tests. Table 1 summarizes all these tests' results. Since we set the level of significance at 5%; the critical values are 167, 8.10, 8.07, and 1.49 for the Pettitt, SNHT, Buishand, and Von Neumann ratio tests, respectively.

It is important to visually inspect the distribution of inhomogeneous stations in order to catch an underlying unexpected specific reason or to justify the required homogeneity correction. For this purpose, we mapped the distribution of inhomogeneous stations depending on applied test method in Fig. 2. The Pettitt test (Fig. 2a) revealed 25 inhomogeneous stations as twice as that of the Buishand test (Fig. 2b) (implying that the former exhibits more conservative outcomes than the latter) as both tests are capable of detecting a break point in the middle of a series. It is important to note that all 13 inhomogeneous stations detected by the Buishand test were also comprised in the set of inhomogeneous stations of the Pettitt test.

The SNHT, known as a good tool for detecting a break point at the head or end part of a time series, brought out a fact that the reason behind inhomogeneity of 25 stations (Fig. 2c) was a break point appearing mostly in the second half of time series (in particular 1996 or later). It is also noticeable that the year of 2008 was the most frequent break point as happened at six stations. The Von Neumann ratio test, which focusing on all parts of the time series, pointed out to seven inhomogeneous stations that were not caught by the other three tests; namely, Cankiri, Tatvan, Hakkari, Keskin, Ilgin, Baskale, and Milas stations (Fig. 2d).

Among the 44 inhomogeneous stations, five stations (Nallihan, Sinop, Ardahan, Kars, and Mardin), which could not pass the four tests, are shown in Fig. 2e. Two stations (Nallihan and Odemis) still remain inhomogeneous after applying DMCA to the set of 44 non-homogeneous meteorological stations. It is noted that one of these two stations (Nallihan) takes place in Fig. 2e.

Subsequently, we adopted the DMCA to each of 44 inhomogeneous stations included in Table 1 to see if any station

could possibly turn out to be homogeneous. We drew a double mass curve by setting the annual precipitation total of an inhomogeneous station under consideration at ordinate axis and corresponding an average of precipitation total values of neighboring homogeneous stations at horizontal axis. We used minimum four neighboring stations in this analysis. Our results showed that 42 out of inhomogeneous 44 stations passed all the four analysis tests after being applied to correction based on the DMCA. However, it was not possible for only two stations, namely Odemis and Nallihan, to make them homogeneous. At this point, we thought that it would be useful to exemplify what was done in each station subjected to DMCA. For this purpose, we randomly selected Akcakoca station, which is located in the northwestern Turkey, and presented its homogeneity test results prior to the correction in Table 2 with a plot in Fig. 3a. It is obvious that there is a jump in the mean around the break year of 1989. It is concluded that the new data set found after such analysis are homogeneous (please see Table 2 and Fig. 3).

Applying the DMCA to precipitation data at Akcakoca station, the detected anthropogenic influence in this station data was successfully corrected (Fig. 3b). Moreover, the corrected data of Akcakoca station has successfully passed from all our four homogeneity tests at the 5% significance level. In this particular example, we used a group of four neighboring stations (namely Sakarya, Bolu, Duzce, and Zonguldak) of Akcakoca station for the DMCA.

In Fig. 4, we showed the linear regression fit to precipitation series in Akcakoca station before and after the homogenization. A visual inspection and noticeable difference in the numerical value of slope coefficient strongly indicate that homogenization made important change in the variability of the station. Specifically speaking, an obvious upward trend-like behavior almost diminished after the homogenization procedure applied.

4.1 Inhomogeneity interpretations based on metadata

We had limited amount of metadata for our data network (only for 12 stations) (Table 3); therefore, we had to interpret inhomogeneity reasons for those with available information. Utilization of metadata in understanding the reason(s) behind the detected inhomogeneity at a station finds the best example in our data network at the two stations, namely Artvin and Uzunkopru, whose break point and moving years are very close, providing a direct cause explanation. Specifically speaking, the gauging station in Artvin was first moved to a location 300 m away and 31 m higher elevation in 1983, and then was subjected to other moving in 1989 and 2009. Our statistical tests showed two breaking points as 1984 and 1987 are both in the vicinity of moving years. The case in the gauging station in Uzunkopru indicated a smooth example having

Table 1 Inhomogeneous precipitation stations and the homogeneity tests results

Station number	Station	Test statistic (break year)			Test statistic
		Pettitt test (K)	SNHT (To)	Buishand's test (Q)	Von Neumann ratio test
17015	Akcakoca	266 (1989)	11.9 (1989)	10.918 (1989)	–
17020	Bartın	178 (1994)	–	8.627 (1994)	–
17026	Sinop	240 (1986)	13 (1986)	10.864 (1986)	1.15
17030	Samsun	202 (1986)	8.45 (1986)	8.772 (1986)	–
17034	Giresun	184 (1999)	–	–	–
17038	Trabzon	202 (1987)	–	–	1.48
17040	Rize	171 (1984)	–	–	–
17045	Artvin	208 (1987)	8.31 (1984)	8.654 (1987)	–
17046	Ardahan	295 (2001)	18.5 (2001)	12.991 (2001)	1.17
17052	Kirklareli	–	8.52 (2013)	–	–
17054	Corlu	–	8.34 (2008)	–	–
17074	Kastamonu	–	11.1 (2008)	–	1.26
17080	Cankiri	–	–	–	1.37
17089	Bayburt	218 (1994)	–	8.652 (1994)	–
17097	Kars	336 (2000)	21.7 (2000)	14.328 (2000)	1
17099	Agri	198 (1995)	–	8.403 (1995)	1.43
17100	Igdir	176 (2000)	–	–	–
17110	Gokceada	184 (1993)	–	–	–
17116	Bursa	192 (1996)	9.7 (2009)	–	–
17145	Edremit	–	10 (2008)	–	–
17150	Balikesir	–	10.3 (2008)	–	1.46
17190	Afyon	172 (1995)	–	–	–
17205	Tatvan	–	–	–	1.31
17208	Bitlis	182 (1996)	–	–	1.29
17246	Karaman	170 (1981)	8.93 (1981)	–	–
17250	Nigde	–	8.75 (2008)	–	1.42
17275	Mardin	232 (1988)	10.9 (1988)	10.323 (1988)	1.43
17285	Hakkari	–	–	–	1.47
17608	Uzunkopru	–	11.4 (2013)	–	1.28
17622	Bafra	–	9.98 (2012)	–	–
17674	Gonen	–	9.93 (2008)	–	–
17679	Nallihan	304 (1998)	15.3 (1998)	12.355 (1998)	0.665
17716	Zara	–	10.2 (2011)	–	1.33
17730	Keskin	–	–	–	1.42
17748	Simav	196 (1981)	11 (1981)	8.524 (1981)	–
17754	Kulu	181 (1999)	–	–	–
17822	Odemis	–	8.67 (1981)	–	1.48
17832	Ilgin	–	–	–	1.42
17840	Sariz	182 (1998)	9.03 (2010)	–	1.48
17862	Dinar	168 (1993)	–	–	–
17880	Baskale	–	–	–	1.41
17884	Milas	–	–	–	1.3
17900	Cumra	–	8.11 (1977)	–	–
17950	Cizre	206 (1996)	8.48 (1996)	9.367 (1996)	–

one break year (2013) and its metadata providing one moving year just a year later (2014) to a location at 2.4 km in northeast.

In the inhomogeneous 12-station set (Table 3), we counted six stations in which the break year took place before moving

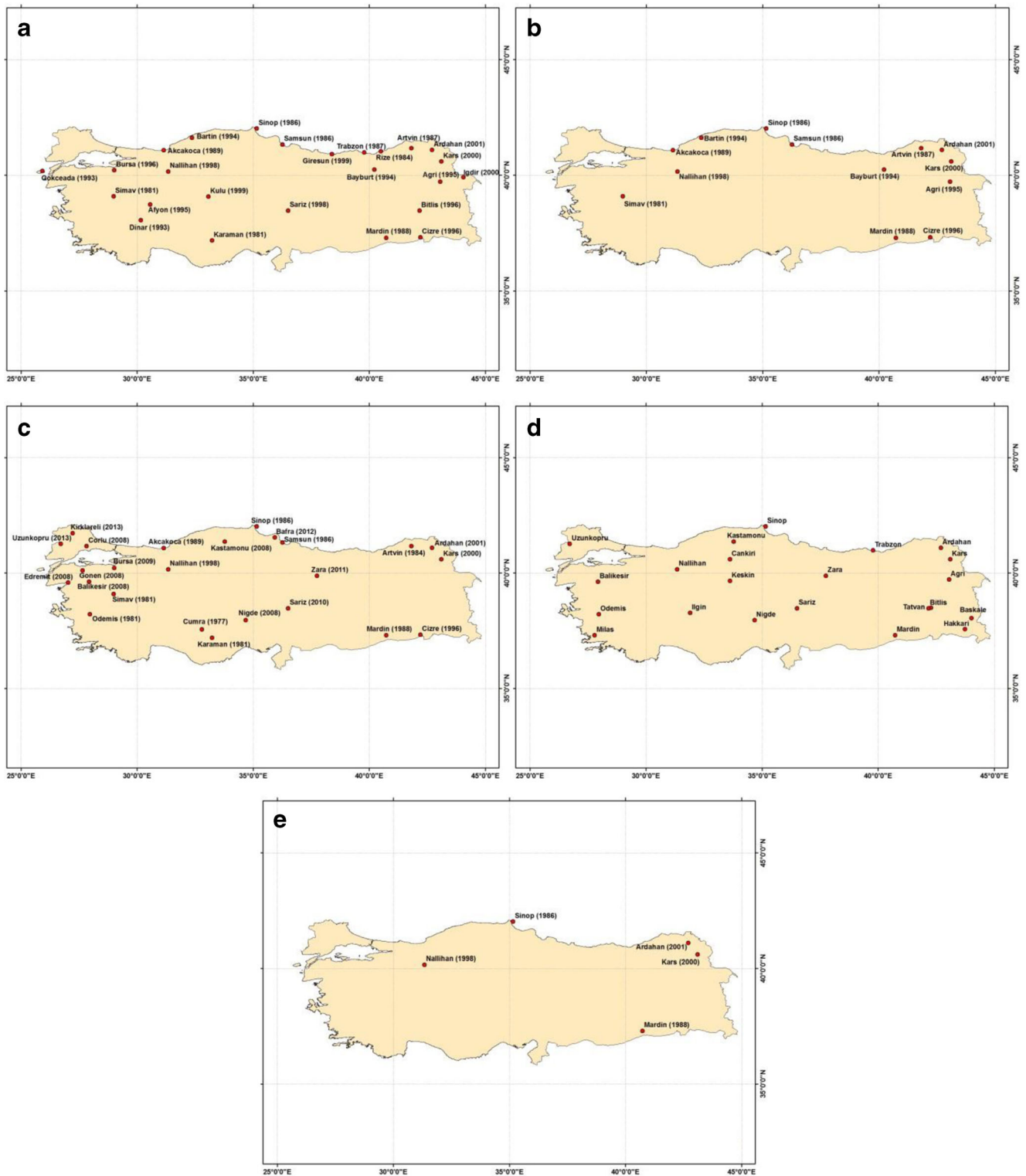


Fig. 2 a Stations whose homogeneity was not approved by the Pettitt test; b The same as (a), except for the Buishand test; c The same as (a), except for the SNHT; d The same as (a), except for the Von Neumann ratio test; e Stations whose homogeneity was not approved by all four tests

year, namely Bartın, Trabzon, Corlu, Simav, Cumra, and Uzunkopru stations. The length of time period between the break point and moving year has a span from 1 to 31 years. Among these, Uzunkopru and Corlu stations having such

respective span as 1 and 6 years are the ones that were possibly affected by moving and allowing dispersion in the sensitivity of statistical test although the break year happened prior to the moving year. However, majority came out to be in favor

Table 2 Homogeneity test results for Akcakoca station prior to the correction

Homogeneity test	Test statistic	Break year	Critical values at 0.05 sig. level
SNHT	11.92	1989	8.1
Pettitt test	266	1989	167
Buishand test	10.92	1989	8.07
Von Neumann test	1786	–	1.49

of more than 19 years, implying that environmental factors certainly played a significant role in the inhomogeneity process as the case in the following stations: Bartin, Trabzon, Simav, and Cumra. Bartin station has a break point in 1994, experienced a negligible move within 5 m in 2013 at nearly the end of the record, indicating that there is relation between moving and break point. The second to fourth stations had similar pairs for the periods 1987–2006, 1981–2012, and 1977–1997, implying a possible reasoning for inhomogeneity, which might be logical to search in other causing physical parameters other than moving.

The remaining stations in the inhomogeneous 12-station set (Table 3), in which break year take places after moving year, are Samsun, Giresun, Ardahan, Balikesir, and Bafra stations. The length of time period between moving year and break point has a span from 5 to 30 years; therefore, we interpreted that moving was always not perceived as single direct effect to cause the detected break point in such stations. The Samsun station with a break point in 1986 was subjected to move twice, first in 1973 (to a location 16 km away) and second in 2015 (to a location in northeast 100 m away). A recorded move in Giresun station happened at the end of first quarter of the series (1984) but its break point appeared in 1999. As opposed to the other stations in the same category, Ardahan and Balikesir stations have relatively less span between the moving year and break point having such pairs as of 1994–2001 and 2003–2008, implying that the effect of moving station on the homogeneity condition was gradually sensed. Finally, Bafra station experienced a move in 1982

but its break point happened in 2012, implying that moving has no effect on inhomogeneity condition whatsoever.

5 Conclusions

In this research, the homogeneity of the most recent monthly precipitation data set comprised of 160 meteorological stations across Turkey for the periods 1974–2014 was analyzed for the confident future use. The data set was selected in such a way that there is no missing observation in each series. We applied the SNHT, Pettitt test, Buishand test, and Von Neumann ratio test to each precipitation series and individually evaluated the outputs of these tests at the 5% significance level to determine inhomogeneity with break years.

The results of the SNHT showed that 16% of the entire data set was impacted from inhomogeneity. According to the Buishand test, 8% of the entire data set was found to be inhomogeneous. The Von Neumann ratio test revealed 14% inhomogeneity portion of the data network. Finally, the Pettitt test showed that 16% of the entire data set was found to be inhomogeneous. In addition, five out of 160 stations have an inhomogeneity according to the results of all tests (please see Fig. 2). Therefore, 44 out of 160 stations are said to be inhomogeneous as they failed according to at least one of the four tests. The breaks captured by the Pettitt test and Buishand test usually tend to appear in the middle of the study period, whereas the results of SNHT frequently showed inhomogeneity at the beginning or end of the records. Our results showed

Fig. 3 Testing of homogeneity by SNHT, Pettitt, and Buishand tests. **a** Homogeneity test results prior to the correction. **b** Homogeneity test results after the DMCA correction

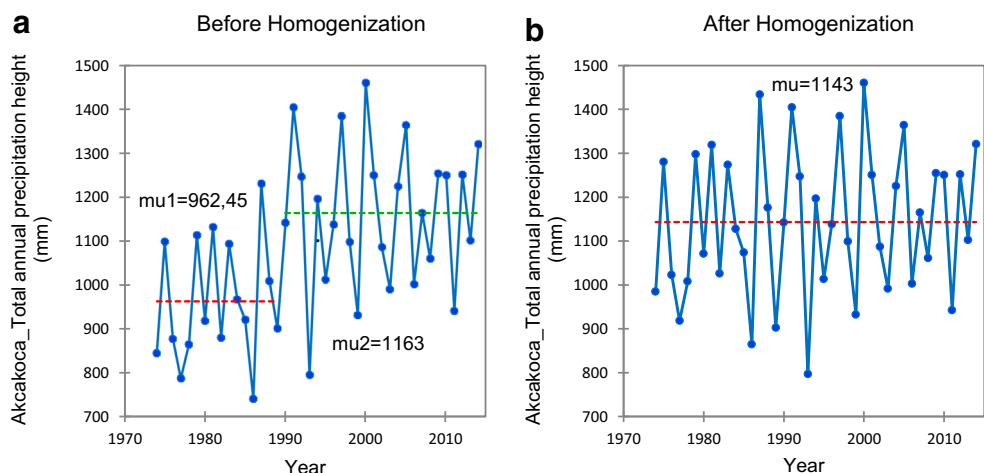
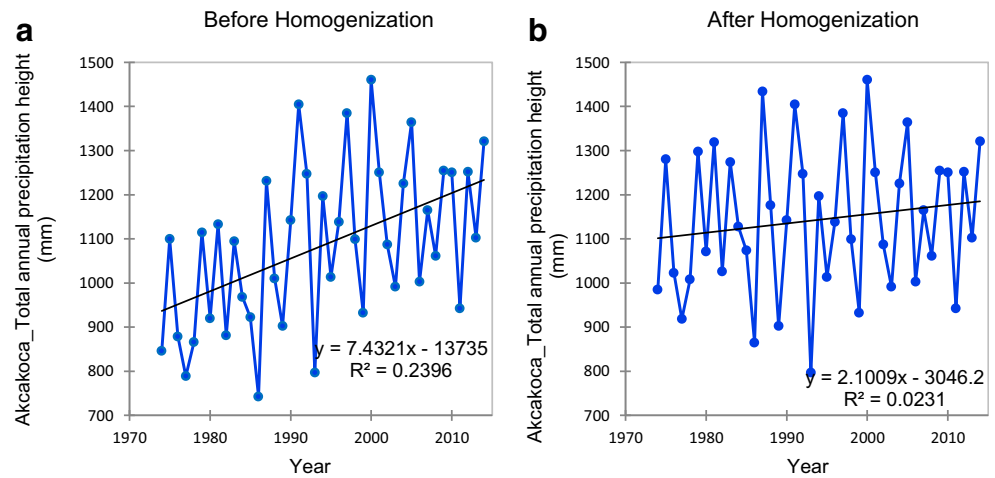


Fig. 4 Plots of the trend for precipitation series in Akcakoca station. **a** Results prior to the correction. **b** Results after the correction



that 42 out of 44 inhomogeneous stations responded affirmatively to all the four tests after correction based on the DMCA. In conclusion, the size of our precipitation data set was decreased to 158.

In this study, we used four different homogeneity tests to determine the inhomogeneous precipitation stations. If there is any heterogeneity in the data, the statistical parameters do not reflect the physics of the phenomenon, the practices and interpretations made are erroneous; in short, the healthy result cannot be obtained for the analysis to be performed. Available metadata was used to interpret the detected inhomogeneity. In this study, in order to determine the reasons underlying the homogeneity of station data, we made comments using the metadata obtained from the Turkish Meteorology General Directorate. Accordingly, it is estimated that the cause of homogeneity in the Artvin station is the change of station location. The simultaneous appearance

of fracture years in data sets in multiple locations suggests that these breaks are natural breaks of the climate. This situation was observed at Artvin-Trabzon and Corlu-Balikesir stations. Outside of these stations, there are environmental factors and an anthropogenic effect. This information is important because it is used in data quality, continuity, and homogeneity studies.

Our results showed that these homogeneity methods could be used in an accomplished way to test the homogeneity of rainfall series in Turkey. The results of this study, in general, came out to be consistent with earlier indications of studies, which were mentioned in the introduction section. This study carries a role in complementing previous studies in the same matter by employing a number of different homogeneity tests and having recourse to metadata. We hope that the updated outputs of this study would have recourse at the very first phase of future studies in hydrology and meteorology fields in Turkey.

Table 3 Metadata of inhomogeneous precipitation stations

Station number	Station	Break year	Metadata
17020	Bartın	1994	In 2013, the location of the observation station was changed (to a location 5 m away).
17030	Samsun	1986	The location of the observation station was changed twice. First in 1973 (to a location 16 km away) and second in 2015 (to a location in northeast 100 m away)
17034	Giresun	1999	In 1984, the location of the observation station was changed.
17038	Trabzon	1987	In 2006, the location of the observation station was changed.
17045	Artvin	1984, 1987	The location of the observation station was changed three times. First in 1983 (to a location 300 m away and 31 m higher elevation), second in 1989, and third in 2009.
17046	Ardahan	2001	In 1994, the location of the observation station was changed.
17054	Corlu	2008	In 2014, the observation station was moved to a location 2.5 km away in north.
17,150	Balikesir	2008	In 2003, the location of the observation station was changed.
17608	Uzunkopru	2013	In 2014, the observation station was moved to a location 2.5 km away in northeast.
17622	Bafra	2012	In 1982, the location of the observation station was changed.
17748	Simav	1981	In 2012, the location of the observation station was changed.
17900	Cumra	1977	In 1997, the location of the observation station was changed.

Acknowledgements This research paper was supported by TUBITAK-2211C (Turkish National Science Foundation). We would like to thank TUBITAK and Istanbul Technical University BAP department for their kind supports. The authors are thankful to MGM (Turkish State Meteorological Service) authorities for providing precipitation data. And finally, we are greatly indebted to Assoc. Prof. Dr. Esra AKDENİZ and Dr. Olgay SEN for their valuable contributions. We also wish to thank to Mr. Turhan Uludag, who is acting as an English instructor at ITU North Cyprus, for editing the manuscript entirely.

References

- Alexandersson H (1986) A homogeneity test applied to precipitation data. *J Clim* 6(6):661–675. <https://doi.org/10.1002/joc.3370060607>
- Alghazali NOS, Alawadi DAH (2014) Testing the homogeneity of rainfall records for some stations in Iraq. *Int J Civil Eng Technol (IJCIET)* 5(5):76–87
- AL-Lami AM, AL-Timimi YK, AL-Salihi AM (2014) The homogeneity analysis of rainfall time series for selected meteorological stations in Iraq. *Diyala J Pure Sci* 10(2):60–77
- Buishand T.A (1982) Some methods for testing the homogeneity of rainfall records. *Journal of Hydrology*, Elsevier Scientific Publishing Company, 58, 11–27, Amsterdam, Netherlands, 1-2, DOI: [https://doi.org/10.1016/0022-1694\(82\)90066-X](https://doi.org/10.1016/0022-1694(82)90066-X).
- Demircan M, Çiçek İ, Türkoğlu N, Ekici M, Arabacı H (2015) Ortalama sıcaklıklardaki türdeşlik kırılmalarının iklim göstergeleriyle ilişkisi. VII. Uluslararası Katılımlı Atmosfer Bilimleri Sempozyumu, pp 13–21
- Dündar B (2015) Trend analysis of climate extreme indices for Turkey. Istanbul Technical University, Eurasia Institute of Earth Sciences. M.Sc. Thesis, pp:4–5, Istanbul
- Firat M, Dikbas F, Koc AC, Gungor M (2010) Missing data analysis and homogeneity test for Turkish precipitation series. *Sadhana* 35(6): 707–720. <https://doi.org/10.1007/s12046-010-0051-8>
- Göktürk OM, Bozkurt D, Şen ÖL, Karaca M (2007) Quality control and homogeneity of Turkish precipitation data. *Hydrol Process* 22: 3210–3218
- Hanssen-Bauer I, Førland E (1994) Homogenizing long Norwegian precipitation series. *J Clim* 7(6):1001–1013. [https://doi.org/10.1175/1520-0442\(1994\)007<1001:HLNPS>2.0.CO;2](https://doi.org/10.1175/1520-0442(1994)007<1001:HLNPS>2.0.CO;2)
- Jaruskova D (1994) Change-point detection in meteorological measurement. *Mon Weather Rev* 124:1535–1543
- Kahya E, Kalaycı S (2004) Trend analysis of streamflow in Turkey. *J Hydrol* 289(1-4):128–144. <https://doi.org/10.1016/j.jhydrol.2003.11.006>
- Kalaycı S, Kahya E (1998) Susurluk havzası nehirlerinde su kalitesi trendlerinin belirlenmesi. *Turk J Eng Environ Sci* 22:503–514
- Kang HM, Yusof F (2012) Homogeneity tests on daily rainfall series in Peninsular Malaysia. *Int J Contemp Math Sci* 7(1):9–22
- Karabörk M. Ç, Kahya E and Kömüşçü A. U (2007) Analysis of Turkish precipitation data: homogeneity and the Southern Oscillation forcings on frequency distributions. *Hydrological Processes*, John Wiley & Sons, Ltd., 21, pp 3203–3210
- Kaya S, Basar UG, Karaca M, Seker DZ (2012) Assessment of urban heat islands using remotely sensed data. *Ekoloji* 21(84):107–113. <https://doi.org/10.5053/ekoloji.2012.8412>
- Kömüşçü AÜ (2010) Homogeneity analysis of long-term monthly precipitation data of Turkey. *Fresenius Environ Bull* Volume 19(7): 1220–1230
- Linsley R.K, Kohler M.A, and Paulhus J.L.H (1982) *Hydrology for engineers*, 3rd edn. McGraw-Hill Book Company, London
- Meral G, Uslu A, Akçay F, Unsur E, Kayaoglu S, Erzurumlu E (2014) The comparison of menarcheal age with familial pattern and body mass index. *Sci J Public Health* 2(6):584–588. <https://doi.org/10.11648/j.sjph.20140206.23>
- Meral G, Uslu A, Yozgatli AU, Akçay F (2015) Association of body mass index and lipid profiles in children. *Open J Pediatr* 5(02):141–146. <https://doi.org/10.4236/ojped.2015.52021>
- Mihajlovic D (2006) Monitoring the 2003–2004 meteorological drought over Pannonian part of Croatia. *Int J Climatol* 26(15):2213–2225. <https://doi.org/10.1002/joc.1366>
- Pettitt A. N (1979) A non-parametric approach to the change-point problem. *Applied Statistics*, Leics, England, 28, No 2, 126–135
- Ponce V.M (2014) *Engineering hydrology, principles and practices*. Chapter 2, pp 32
- Şarlak N, Kahya E, Bég AO (2009) Critical drought analysis: a case study of Göksu River (Turkey) and North Atlantic oscillation influences. *J Hydrol Eng* 14(8):795–802. [https://doi.org/10.1061/\(ASCE\)HE.1943-5584.0000052](https://doi.org/10.1061/(ASCE)HE.1943-5584.0000052)
- Şensoy S, Demircan M, Ulupınar Y and Balta I (2008) *Climate of Turkey*. Department of research. Turkish State Meteorological Service, Ankara, Turkey
- Tarhule A, Woo MK (1998) Changes in rainfall characteristics in Northern Nigeria. *Int J Climatol Royal Meteorol Soc* 18(11):1261–1271. [https://doi.org/10.1002/\(SICI\)1097-0088\(199809\)18:11<1261::AID-JOC302>3.0.CO;2-Z](https://doi.org/10.1002/(SICI)1097-0088(199809)18:11<1261::AID-JOC302>3.0.CO;2-Z)
- Türkeş M (1996) Spatial and temporal analysis of annual rainfall variations in Turkey. *Int J Climatol* 16(9):1057–1076. [https://doi.org/10.1002/\(SICI\)1097-0088\(199609\)16:9<1057::AID-JOC75>3.0.CO;2-D](https://doi.org/10.1002/(SICI)1097-0088(199609)16:9<1057::AID-JOC75>3.0.CO;2-D)
- Van Belle G, Hughes JP (1984) Nonparametric tests for trend in water quality. *Water Resour Res* 20(1):127–136. <https://doi.org/10.1029/WR020i001p00127>
- Von Neumann J (1941) Distribution of the ratio of the mean square successive difference to the variance. *Ann Math Stat* 13:367–395
- Wijngaard JB, Klein Tank AMG, Konnen GP (2003) Homogeneity of 20th century European daily temperature and precipitation series. *Int J Climatol* 23(6):679–692. <https://doi.org/10.1002/joc.906>