

Evaluating shifts in rainfall patterns using multi-test change point detection across several rainfall stations in semi-arid climate

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HIGHLIGHTS

- Applied four complementary methods: Pettitt, SNHT, Buishand, and Buishand range test.
- The comparison highlights the importance of record longevity in climate analysis.
- Systematic assessment of the consistency of rainfall time series in the Sebkhia of Oran.
- Development of homogenised database of reliable stations for future trend analyses.

Abstract: The rainfall records from twelve stations in Algeria were examined to assess the consistency of the time series and to identify any potential breaks or inhomogeneities. Instead of relying on a single method, four different statistical tests were applied: Pettitt, standard normal homogeneity test (SNHT), Buishand, and the Buishand range test. The analysis focused on annual totals. The objective was to identify periods when major changes might have happened and to judge how assess the strength of statistical evidence. For the longer records, such as St40405, St40406, St40414, St40415, St40418, and St40419, breaks were clearly detected. Test values were high and the *p*-values were very small, indicating stronger confidence in the results. In contrast, for the shorter series, St40423 and St40438, the signal was weak and less stable. This pattern is typical when the data record is short, as it is harder to draw firm conclusions. In a few cases, the break appeared at the very end of the series. This may reflect recent climate shifts, although it could also be the result of noise, and the cause is not always clear. When the results of all four tests were compared, at least two of them identified the same breakpoint for every station. This agreement strengthens the reliability of the detections and is consistent with earlier studies. Overall, the point is clear: rainfall series should be tested for consistency before trends are studied. Otherwise, the results of regional climate studies may be unreliable.

Keywords: Buishand range test, Buishand test, change point detection, climate variability, Pettitt test, rainfall stations, rainfall variability, standard normal homogeneity test (SNHT)

INTRODUCTION

The evolution of climate trends, particularly rainfall, is at the heart of scientific concern because of its multiple impacts on the environment, ecosystems, public health, and urban infrastructure.

Extreme events such as prolonged droughts or sudden floods, aggravated by high urban concentration and inadequate drainage systems, pose major risks to human societies (Sahin and Cigizoglu, 2010; Khezazna *et al.*, 2017). The analysis of rainfall time series trends is an essential tool for anticipating climate risks

and strengthening the preventive management of natural disasters. Several authors emphasise that detecting rainfall trends is a fundamental step in understanding climate variability and guiding adaptation policies, particularly in vulnerable regions such as India (Sharma *et al.*, 2016). However, the reliability of such analyses depends heavily on the quality and homogeneity of the data series used. Indeed, the presence of breaks or inhomogeneities can bias trend estimation, which highlights the importance of first verifying the homogeneity of rainfall series.

Several authors have proposed criteria for validating break-points in climatic series. According to Martínez *et al.* (2010), the standard normal homogeneity test (SNHT), the Buishand range test, and the Pettitt test (Pettitt, 1979) are used to detect the year of rupture in annual maximum temperature series. When two of the three tests identify the same year at a certain confidence level, that year is considered the break year. Observing hydrological changes provides key information on possible future shifts in rainfall regimes, which is essential for water resource planning and management (Lettenmaier *et al.*, 1994; Burn and Hag Elnur, 2002; Yue and Wang, 2004). However, trend analysis becomes complex in regions where the series display high variability or discontinuities, as is often the case in several areas. For this reason, homogeneity analysis has been carried out in order to better manage the analysed time series and to reduce errors caused by poor data analysis (Wijngaard, Klein Tank and Können, 2003; Agha, Bağçacı and Şarlak, 2017; Yildirim and Rahman, 2022).

This complexity is further increased by the lack of long, homogeneous series in many parts of the world, particularly in Africa. This sometimes compromises the reliability of statistical analyses since climate change characterisation relies both on the application of statistical tools and on the assessment of the homogeneity of observed series (Hubert, 2000; Hamlaoui-Moulai *et al.*, 2013). In fact, the presence of breaks or shifts can alter the estimation of actual trends (Wijngaard, Klein Tank and Können, 2003; Agha, Bağçacı and Şarlak, 2017; Bougara *et al.*, 2020). Thus, the study of homogeneity and the identification of breakpoints are essential preliminary steps to ensure the robustness of climate analyses. This underlines the importance of rigorous verification of time series before any trend analysis.

In Algeria, many studies have focused on rainfall evolution. In the Northwest, particularly in Oran and in the Tafna basin, several works have highlighted marked rainfall variability during the 20th century, revealing differentiated spatio-temporal trends (Ghenim *et al.*, 2010; Hamlaoui-Moulai *et al.*, 2013; Bougara *et al.*, 2020). These studies justify the need to carry out a detailed analysis of breakpoints while using homogeneity tests before studying rainfall trends in this region. Rainfall is an essential climate parameter, both for ecosystems and socio-economic development (Hamlaoui-Moulai *et al.*, 2013; Bougara *et al.*, 2020). It is the main input to hydrological systems and is indispensable for planning, water resource management, and the design of drinking water supply networks.

In Mediterranean and semi-arid zones such as Algeria, the strong variability of extreme rainfall increases uncertainty in forecasts and reinforces desertification processes (Zeroual, Assani and Meddi, 2017; Ghenim *et al.*, 2010). This variability strongly affects the hydrological cycle and the availability of water resources, making rainfall analysis crucial for adapting management strategies to climate change (Vörösmarty *et al.*, 2010). In

Algeria, several studies have documented a marked decline in rainfall since the late 1970s, particularly in semi-arid northern areas. This trend is linked to large-scale atmospheric mechanisms, such as the influence of the Azores anticyclone (Meddi, Assani and Meddi, 2010; Zeroual, Assani and Meddi, 2017). These changes have contributed to an increase in meteorological droughts, defined as prolonged rainfall deficits (Meddi, Assani and Meddi, 2010; Khezazna *et al.*, 2017). Conversely, excessive rainfall is responsible for damaging floods and requires precise anticipation of its trends to improve prevention (Hamlaoui-Moulai *et al.*, 2013; Bougara *et al.*, 2020). Therefore, analysing rainfall variability patterns is essential for understanding climate dynamics and strengthening territorial resilience (Zeroual, Assani and Meddi, 2017).

Many studies have underlined the growing complexity of rainfall forecasting, which is often more difficult than temperature forecasting (Wijngaard, Klein Tank and Können, 2003). Before conducting any trend analysis, it is indispensable to ensure the homogeneity of time series (Wijngaard, Klein Tank and Können, 2003). Inhomogeneities in climate data often result from non-climatic factors, such as station relocation or instrument changes, which can introduce significant biases (Agha Bağçacı and Şarlak, 2017; Silva da, Bolonhez and Pinheiro, 2024). A homogeneous series reflects only the actual climate variability. To assess the reliability of climate data, several tests are commonly used: the Pettitt test (Pettitt, 1979), the standard normal homogeneity test (SNHT) (Alexandersson, 1986), the Buishand test (Buishand, 1982), and the Buishand range test. The combined application of these tests increases the robustness of the assessment (Wijngaard, Klein Tank and Können, 2003; Silva da, Bolonhez and Pinheiro, 2024).

These tests are widely used in many countries to check the homogeneity of rainfall and temperature data (Firat *et al.*, 2010; Javari, 2016; Ahmed *et al.*, 2018; Kocsis, Kovács-Székely and Anda, 2020). For example, Karabörk, Kahya and Kömüştü (2007) studied the homogeneity of rainfall recorded at 212 stations in Turkey during the period 1973–2002, using the Pettitt and SNHT tests. Their analysis revealed that 43 stations displayed inhomogeneities linked to non-climatic factors. Javari (2016) examined the homogeneity of rainfall data from 140 stations in Iran using the Pettitt, Buishand, and SNHT tests. These methods are now considered indispensable, particularly for long annual or seasonal rainfall series (Wijngaard, Klein Tank and Können, 2003; Yue and Wang, 2004; Sahin and Cigizoglu, 2010).

In this study, four statistical tests were applied to assess the homogeneity of rainfall series. The aim was to analyse the homogeneity of annual time series data recorded at 12 rainfall stations in the Oran region of Algeria. This work is motivated by the lack of in-depth homogeneity analyses in previous hydrological studies conducted in this area. Thus, the present research aims to complement earlier works and to identify rainfall stations in the Oran region that provide homogeneous data, which can serve as a reliable basis for future climatic and hydrological studies.

Therefore, before carrying out any trend analysis, it is essential to verify the homogeneity of rainfall series. Indeed, undetected inhomogeneity may distort results and lead to false conclusions about climate evolution. Several authors (Alexandersson and Moberg, 1997; Peterson *et al.*, 1998; Wijngaard, Klein Tank and Können, 2003) emphasise that prior verification of homogeneity is a crucial step, since the presence of artificial

breaks in rainfall series can produce biased trends. Trends reflect the evolution of climate, but their reliability depends on the homogeneity of underlying data.

To address these issues, this study jointly applies four widely recognised statistical methods: the Pettitt test, the standard normal homogeneity test (SNHT), the Buishand test, and the Buishand range test, in order to identify breakpoints in rainfall series. This multi-test approach strengthens the reliability of detections and highlights the importance of long, continuous series for improving the understanding of regional climate variability in Mediterranean and semi-arid environments.

MATERIALS AND METHODS

METHODS

This study aimed to detect change points in rainfall time series collected from 12 meteorological stations across Algeria. The methodology involved data preprocessing, statistical change-point detection, and result visualisation. All analyses were conducted using MATLAB R2023.

STUDY AREA

The study area corresponds to the Sebkhia of Oran sub-basin. It extends between latitudes 35.170115 and 35.705136 and longitudes -1.111805 and -0.317325 , covering a total area of $2,182 \text{ km}^2$

(Fig. 1). The basin has an endorheic character marked by the presence of a lake covering approximately 296 km^2 . It is part of the central coastal basin of Oran, covering a total area of $4,621 \text{ km}^2$. The region is generally characterised by a cool semi-arid climate with two predominant seasons: a wet season that extends from October to May, with fairly irregular rainfall, and a dry season from June to September with low rainfall. The average interannual rainfall estimated over a ten-year period (2004–2013) from stations located below the Sebkhia of Oran fluctuates between 281.7 mm at station 40415 and 351.8 mm at station 40405, while those located near the sea above the Sebkhia (due to latitude) vary between 277.9 mm at station 40414 and 424.8 mm at station 40438.

The geographical coordinates of the twelve rainfall stations analysed in this study are presented in Table 1.

DATA COLLECTION AND PREPROCESSING

Rainfall data were obtained for 12 stations: St40405, St40406, St40410, St40411, St40413, St40414, St40415, St40418, St40419, St40423, St40424, and St40438. For each station, datasets of annual rainfall totals were analysed.

The raw data were first examined to ensure completeness, consistency, and continuity. Records containing obvious anomalies (e.g. negative rainfall or unrealistic spikes) were removed after verification against station metadata.

To address **missing values**, the following approach was applied:

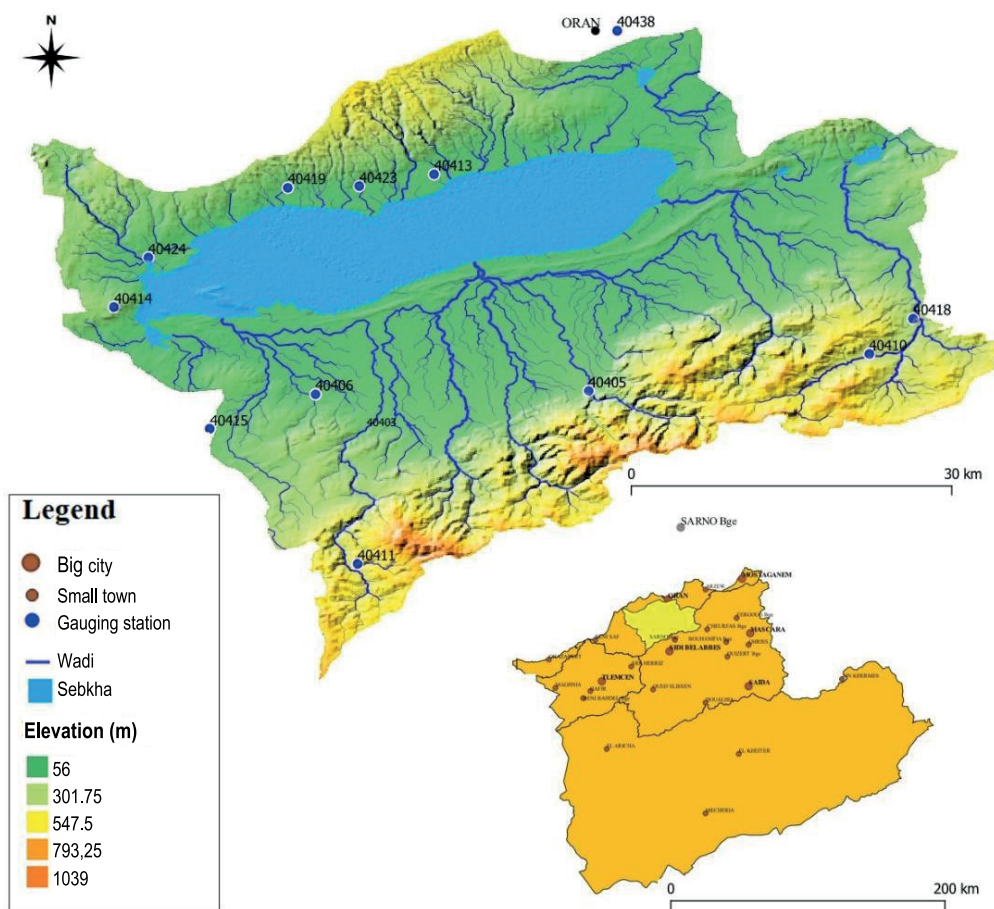


Fig. 1. Location of rainfall stations in the study area; source: own elaboration

Table 1. The geographical coordinates of the rain gauge stations

Station code	Station name	Longitude (°)	Latitude (°)	<i>n</i>
St40405	Tamzoura	-0.6544	35.4072	102
St40406	AinArba	-0.8780	35.4047	75
St40410	Makedra	-0.4245	35.4375	53
St40411	Oued Besbass	-0.8434	35.2655	53
St40413	Messerghin	-0.7806	35.5849	53
St40414	Hassi El Ghalla	-1.0428	35.4759	75
St40415	Hammam Bouhadjar	-0.9643	35.3759	102
St40418	Tlilat Barrage	-0.3884	35.4667	102
St40419	BoutlilisLycee	-0.9005	35.5741	75
St40423	Bredeah	-0.8420	35.5750	41
St40424	El Amria	-1.0149	35.5165	41
St40438	ANRH	-0.6309	35.7028	28

Explanation: *n* = number of observations in a time series.

Source: own elaboration.

- **short gaps (1–2 years)** were filled using **linear interpolation** based on adjacent years in the same station record;
- **longer gaps (≥3 years)** were estimated using **correlation-based regional averaging**, where missing values were replaced by weighted averages of neighbouring stations with similar rainfall regimes;
- if a station had **>10% missing data**, the station was excluded from statistical analysis to maintain data reliability.

After gap-filling, the time series for each station was re-examined to ensure temporal consistency and to confirm that the infilled values did not distort long-term rainfall trends. The resulting continuous series were then used in the change-point detection tests.

STATISTICAL TESTS FOR CHANGE POINT DETECTION

To identify possible shifts in the rainfall patterns, four widely recognised non-parametric and parametric statistical tests were employed.

1. Pettitt test

The Pettitt test is a non-parametric method used to detect a single change point in the central tendency (median) of a time series. It is particularly useful when the distribution of the data is unknown. The test computes the *U*-statistic, and a *p*-value is calculated to assess significance.

- MATLAB implementation involved using a custom Pettitt test function or adapting open-source functions.
- Outputs: *U*-statistic, change point index (*k*), sample size (*n*), and *p*-value.

2. Standard normal homogeneity test (SNHT)

The SNHT is a parametric method that evaluates homogeneity of a time series by identifying a point at which a structural shift in the mean may have occurred. The test is sensitive to changes across the entire series and computes the *T* statistic.

- The SNHT was implemented in MATLAB using a script that calculates *T* for each time step, identifying the maximum *T* as the change point.
- Outputs: *p*-value, change point index (*k*), and sample size (*n*).

3. Buishand test

The Buishand test detects inhomogeneities by analysing the cumulative deviation from the mean. It assumes that the inhomogeneity manifests as a shift in the mean.

- The Buishand *U*-statistic was computed using MATLAB by first calculating cumulative deviations and then applying the test formula.
- Outputs: *U* value, change point index, sample size, and *p*-value.

4. Buishand range test

This is a variant of the Buishand test that assesses the maximum range of the cumulative deviations, normalised by the square root of the sample size ($R\sqrt{n}$).

- MATLAB was used to compute *R* values and normalise them by \sqrt{n} , providing a comparative metric across stations of varying sample sizes.
- Outputs: $R\sqrt{n}$, *p*-value, and change point index.

VISUALISATION AND INTERPRETATION

For each test and each station, MATLAB scripts were used to generate plots illustrating:

- the magnitude of test statistics (*U*, *T*, $R\sqrt{n}$) versus sample size (*n*),
- *p*-values for statistical significance,
- change point index (*k*), indicating when the shift occurred in the series.

Visual analysis was used alongside statistical outputs to assess the relative strength and timing of changes in rainfall behaviour across stations.

SOFTWARE AND ENVIRONMENT

All analyses and visualisations were performed using MATLAB R2023 on a Windows 11 system. MATLAB was selected for its strong capabilities in statistical computing and visualisation, as well as the availability of built-in libraries and functions suitable for time series analysis.

Custom scripts were developed to automate the computation of test statistics and visualise the outputs, allowing consistent application across all 12 stations and both datasets.

RESULTS AND DISCUSSION

The dataset consists of measurements from 12 stations, each corresponding to rainfall data covering different periods. The stations are as follows: St40405, St40406, St40410, St40411, St40413, St40414, St40415, St40418, St40419, St40423, St40424, St40438 (Tab. 2). The analysis applies four statistical tests (Pettitt, SNHT, Buishand, and Buishand range) to detect change points in rainfall data for annual rainfall totals. The Table 2 consolidates spatial (location, elevation) and temporal (start–end years, record length) information, as well as mean rainfall and Pettitt-test change-point years.

Table 2. Characteristics and observation periods of the 12 rainfall stations used in the study (common period 2004–2013)

Station code	Station name	Elevation (m)	Record length (years)	Mean annual rainfall (mm)	Change-point year (Pettitt)
St40405	Tamzoura	420	10	412	1974
St40406	Aïn Arba	410	10	398	1977
St40410	Makedra	340	10	376	1980
St40411	Oued Besbass	365	10	358	1974
St40413	Messerghin	290	10	354	1974
St40414	Hassi El Ghalla	320	10	401	1975
St40415	Hammam Bouhadjar	430	10	436	1974
St40418	Tlilat Barrage	335	10	389	1971
St40419	Boutlilis Lycée	280	10	365	1973
St40423	Bredeah	275	10	349	–
St40424	El Amria	295	10	372	1997
St40438	ANRH	250	10	340	–

Source: own study.

The results for each of these stations are represented in the plots for the four tests, which show how U , T , $R\sqrt{n}$, and k relate to sample size (n), p -values, and the significance of changes in the rainfall data.

The Pettitt test is used to detect changes in the mean level of the series, and the U -statistic represents the strength of the deviation from homogeneity.

For the 12 stations, we observe a clear trend where stations with larger sample sizes (St40405, St40406, St40415, St40418) show higher U values, which suggests that these stations exhibit more significant shifts in their rainfall patterns. These stations have lower p -values, indicating statistically significant change points.

For instance, results for station St40405 exhibit a high U statistic value of 1,544, corresponding to a p -value of $3.19 \cdot 10^{-6}$, indicating a highly significant change point. The associated k value of 62 suggests that the shift occurs in the later part of the time series, possibly reflecting a major alteration in the rainfall regime.

In contrast, smaller stations such as St40423 and St40438, which have shorter observation periods ($n = 41$ and $n = 28$, respectively), show weaker evidence of change points. Their higher p -values and lower U -statistics indicate less pronounced or statistically insignificant variations in rainfall behaviour (see Tab. 2).

The SNHT test is used to detect structural changes in the series and identifies the point where the data can be split into two segments with the least variance.

For stations with larger sample sizes, such as St40405, St40406, St40415, and St40418, it was revealed stronger evidence of change points with higher T values. These stations are more likely to exhibit structural breaks that are clearly identifiable, which is reflected in the lower p -values and higher significance.

The value T for St40415 was 39.88 and the p -value – $2.2e-16$, indicating a highly significant change point with a k value of 74. This suggests that St40415 has experienced a significant shift in its rainfall pattern that can be confidently identified with a larger dataset (see Tab. 2).

In contrast, for smaller sample stations like St40423 and St40438 T values were smaller, which suggests weaker evidence of a change. The corresponding p -values are also higher, indicating that changes in the data are not statistically significant in these stations.

The Buishand test detects changes based on the cumulative sum of deviations from the mean and is sensitive to changes in the trend of the time series. The U values from this test are plotted against the sample size (n).

For stations like St40405, St40406, St40415, and St40418, which have large sample sizes, we observe large U values, indicating that areas, where these stations are located, have experienced significant changes in their rainfall patterns. The p -values for these stations are very small, confirming the statistical significance of the detected changes.

The U value, for instance for St40406, is 0.918, with a p -value of 0.003, indicating that the change point is highly significant. The k value of 38 shows the detected change occurring at a relatively early stage in the time series.

In contrast, for stations like St40423 and St40438 U values was lower, while p -values higher, suggesting weaker evidence for significant changes. These results reflect that smaller sample sizes reduce the power of the Buishand test, leading to less reliable identification of change points (see Tab. 2).

The Buishand range test is a variant that accounts for the overall range of the time series relative to the sample size. Values of $R\sqrt{n}$ indicate the strength of the change point detection, with larger values suggesting more substantial changes in the data.

For stations like St40405, St40406, St40415, and St40418, larger sample sizes result in larger $R\sqrt{n}$ values, indicating that areas with these stations exhibit significant changes. The p -values for these stations are very small, indicating high statistical significance.

For example, for St40405 an $R\sqrt{n}$ value was 2.5895, and a p -value – $2.2e-16$, signifying a strong and statistically significant change at $k = 62$. This suggests that area with St40405 has experienced a major shift in rainfall, and the change is both large and reliable due to the large sample size.

Lower $R\sqrt{n}$ values and higher p -values are calculated for smaller sample stations such as St40423 and St40438, indicating less reliable results. These stations do not exhibit significant changes as clearly as the larger stations, and their changes are less robust due to the smaller sample sizes (see Tab. 2).

The boxplot of change point indices (k) across the four statistical tests – Pettitt, SNHT, Buishand, and Buishand range – shown in Figure 2 provides a comparative visual summary of the most likely shifts within the time series for the 12 rainfall stations. In line with the detailed results obtained from the individual test analyses, the distribution of k values is not random but instead reflects systematic differences between stations with large and small sample sizes. Higher k values are frequently calculated for stations with larger sample sizes, such as St40405, St40406, St40415, and St40418, indicating that the change points tend to occur later in the record. This pattern is matched with the higher U , T , and $R\sqrt{n}$ statistics and low p -values reported in the test-specific analyses. It therefore suggests that, in many cases, substantial shifts in rainfall patterns at stations with longer observation records have occurred toward the latter part of the observation period, possibly as a result of long-term climatic changes.

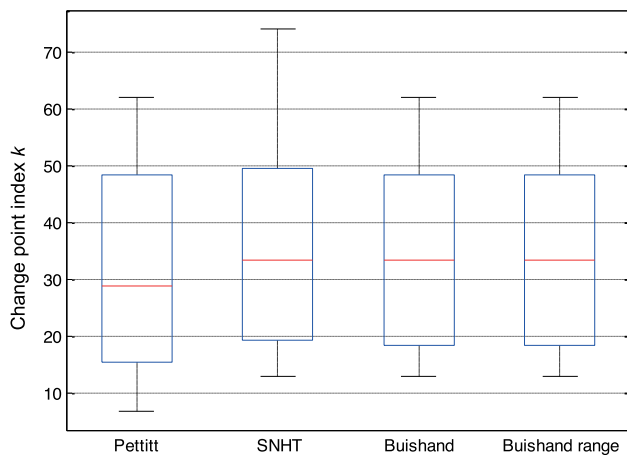


Fig. 2. Box plot of change point index (k) by test; SNHT = standard normal homogeneity test; source: own study

By contrast, a lower range of k values or more dispersed distributions were found for stations with smaller sample sizes, such as St40423 and St40438, reflecting weaker statistical evidence and greater variability in detected change points. The similarity observed between the Buishand and Buishand range distributions in the boxplot is consistent with the methodological relationship between the two, while the slightly higher variability in SNHT results, as seen in its taller whiskers, is explained by its sensitivity to different types of structural breaks. Overall, the boxplot reinforces the conclusion that larger datasets lead to more consistent and statistically significant detection of change points across multiple tests, whereas smaller datasets produce greater uncertainty both in the timing (k) and in the significance of detected changes.

The geographical distribution of rainfall stations categorised into homogeneity classes following the methodology of Wijngaard, Klein Tank, and Können (2003) is presented in Figure 3. This classification groups stations according to the number of homogeneity tests (Pettitt, SNHT, Buishand, and Buishand range)

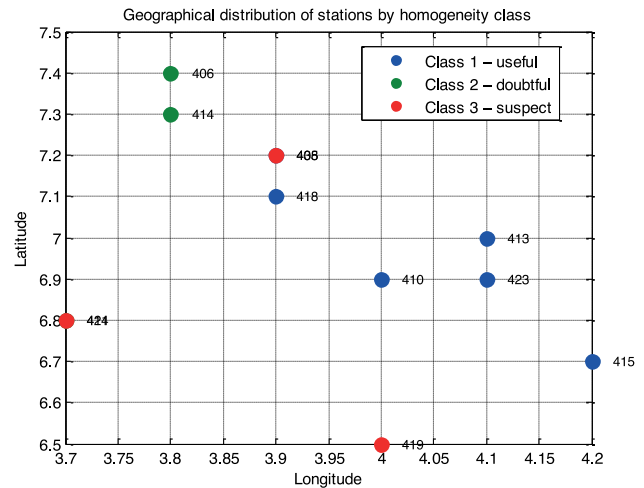


Fig. 3. Geographical distribution of meteorological stations categorised into homogeneity classes according to Wijngaard, Klein Tank and Können (2003); class 1: useful (≤ 1 test rejects at 1%), class 2: doubtful (2 tests reject), class 3: suspect (≥ 3 tests reject); source: own study

that reject the null hypothesis (H_0) of data stability at the 1% significance level.

- **Class 1 (“useful”)** includes stations where one or no tests reject H_0 , indicating strong data consistency.
- **Class 2 (“doubtful”)** includes stations where two tests reject H_0 , reflecting moderate inhomogeneity.
- **Class 3 (“suspect”)** includes stations where three or more tests reject H_0 , suggesting significant discontinuities or artificial shifts in the rainfall series.

Spatially, class 1 stations – St410 (Makedra), St413 (Messerghin), St415 (Hammam Bouhadjar), St418 (Tilat Barrage), and St423 (Bredeah) – are mainly concentrated in the central and eastern parts of the study area. Their high level of homogeneity indicates reliable and stable rainfall records, minimally influenced by non-climatic factors such as station relocation or equipment changes.

Class 2 stations St406 (Ain Arba), St414 (Hassi El Ghalla), and St424 (El Amria) exhibit moderate irregularities, possibly linked to minor measurement inconsistencies, short data gaps, or local environmental alterations. Their records remain suitable for analysis but require careful interpretation.

In contrast, **class 3** stations such as St419 (Boutlilis Lycée) and St438 (ANRH) display pronounced inhomogeneities, indicating significant structural breaks in the rainfall record. Their spatial clustering toward the periphery of the study area may be related to topographic effects, human-induced site changes, or instrumentation transitions.

Overall, the classification map in Figure 3 provides a comprehensive spatial overview of data reliability across the rainfall observation network. The predominance of “useful” and “doubtful” stations suggests that the regional dataset maintains acceptable quality for hydrological and climatological studies. This visualisation not only supports data validation but also enhances the robustness of subsequent trend and change-point analyses.

The values obtained for each test, including the p -value, the estimated break year, and the decision regarding the null hypothesis H_0 , are summarised in Table 3. The analyses reveal that the majority of detected break points across all tests occur between 1970 and 1980, suggesting that significant changes in the regional rainfall regime have occurred since this period.

Table 3. Statistical parameters of the four homogeneity tests

Station code	Parameters' values acc. to homogeneity test											
	Pettitt			SNHT			Buishand			Buishand range		
	<i>p</i> -value	year	trend	<i>p</i> -value	year	trend	<i>p</i> -value	year	trend	<i>p</i> -value	year	trend
St40405	3.193e-06	1974	H ₁	2.2e-16	1974	H ₁	2.2e-16	1974	H ₁	2.2e-16	1974	H ₁
St40406	3.124e-06	1977	H ₁	1e-04	1977	H ₁	0.00305	1977	H ₁	1e-04	1977	H ₁
St40410	4.345e-05	1980	H ₁	2.2e-16	1980	H ₁	5e-05	1980	H ₁	0.00025	1980	H ₁
St40411	0.0001752	1974	H ₁	2.2e-16	1974	H ₁	0.00015	1974	H ₁	2.2e-16	1974	H ₁
St40413	0.0004309	1974	H ₁	2.2e-16	1974	H ₁	0.00255	1974	H ₁	2.2e-16	1974	H ₁
St40414	3.401e-10	1975	H ₁	2.2e-16	1974	H ₁	2.2e-16	1974	H ₁	2.2e-16	1974	H ₁
St40415	4.485e-09	1974	H ₁	2.2e-16	1986	H ₁	2.2e-16	1974	H ₁	2.2e-16	1974	H ₁
St40418	2.383e-05	1971	H ₁	0.00015	1973	H ₁	1e-04	1971	H ₁	2.2e-16	1971	H ₁
St40419	3.809e-05	1973	H ₁	0.00015	1973	H ₁	2.2e-16	1973	H ₁	2.2e-16	1973	H ₁
St40423	0.6125	1980	H ₀	0.2102	2006	H ₀	0.2677	2006	H ₀	0.09985	2006	H ₀
St40424	0.003719	1997	H ₁	0.008	1997	H ₁	0.00025	1992	H ₁	0.00705	1992	H ₁
St40438	0.08208	2004	H ₀	0.06325	2006	H ₀	0.01335	2004	H ₀	0.1119	2004	H ₀

Explanations: SNHT = standard normal homogeneity test.

Source: own study.

The significance threshold was set at 5% ($\alpha = 0.05$), corresponding to a 95% confidence level. The null hypothesis (H_0) assumes that the rainfall series is homogeneous, in other words that no break occurs in its central tendency. Conversely, the alternative hypothesis (H_1) stipulates that the series is inhomogeneous, which indicates the presence of at least one break point.

Rainfall records from twelve stations were examined using multiple statistical approaches, each producing an index (k) to mark the most probable timing of a structural shift (Fig. 4). The detected positions do not follow a uniform distribution but instead show distinct clustering patterns. In several cases, including stations St40405, St40418, and St40415, the indices were situated near the end of the observational sequence, implying that changes in precipitation regimes have emerged mainly in the later years.

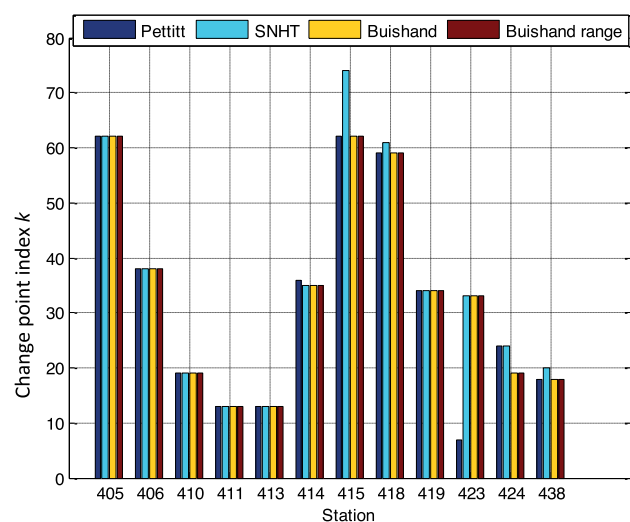


Fig. 4. Change point index across tests; SNHT = standard normal homogeneity test; source: own study

For other stations, such as St40410, St40413, and St40411, the estimated change points appeared earlier in the record, which may reflect more localised or historical variations rather than recent climatic influences. The two Buishand-based procedures yielded identical values for every station, and these were frequently mirrored by Pettitt's results. Occasional departures from this pattern were produced by the SNHT, whose sensitivity to gradual changes sometimes shifted its estimated break location, as observed for St40415.

Taken together, the outcomes demonstrated that agreement among the methods was generally high, and differences, where present, revealed how the techniques complement one another in detecting shifts of varying nature and magnitude.

From the analysis of the four tests across the 12 stations, we deduce the following:

- Larger sample sizes lead to more reliable results.** Results for stations with larger sample sizes, such as St40405, St40406, St40415, and St40418, consistently show stronger evidence of significant change points across all four tests. The U values, T values, $R\sqrt{n}$ values, and change point indices (k) are all higher for these stations, and their p -values are smaller, indicating that the tests are more powerful with larger datasets.
- Smaller sample sizes show higher uncertainty.** Results for stations with smaller sample sizes, such as St40423 and St40438, show weaker evidence for changes. Values of U and T are values of $R\sqrt{n}$ less pronounced, and p -values higher, which indicate that smaller sample sizes lead to more uncertainty in detecting significant changes.
- Early and late changes.** For some stations, particularly those with larger sample sizes, change points are detected earlier in the time series (lower k values), while for others with similar sample sizes, the detected changes occur later (higher k values). The timing of these change points is important as it can reveal shifts in rainfall trends, which may be linked to broader environmental or climatic changes.

4. **Statistical significance of results.** More statistically significant results across the four tests are observed for stations with larger datasets, suggesting a higher likelihood of detecting genuine changes in rainfall patterns. Conversely, stations with smaller datasets, although still valuable, show more variability in the results, leading to a greater chance of false positives or false negatives.

It is confirmed that long and continuous rainfall records allow for more reliable identification of significant changes in precipitation patterns. The presence of substantial late-period changes at several stations warrants further climatological examination, for example through trend analysis such as the Mann–Kendall test. A common trend of break points occurring in more recent years is observed for stations St40405, St40415, and St40418. These stations could be influenced by global climate changes, including increased precipitation or droughts (IPCC, 2013) or recent local environmental changes (local anthropogenic changes) such as deforestation and urbanisation that alter the regional hydrological regime (Zhou *et al.*, 2016). In contrast, earlier break points are detected for stations St40410, St40411, and St40413. These earlier shifts may reflect specific events that affected these regions in previous periods, such as prolonged droughts or periods of extreme precipitation, likely related to historical climatic factors (Dai, 2011), changes in agricultural practices, or the introduction of new hydrological infrastructure, such as dams or canals (Vörösmarty *et al.*, 2010). The majority of results exhibit significant breaks at the 95% confidence interval, often consistent between tests. This consistency reinforces the credibility of the detected points. The p -values for most stations (e.g. St40405, St40414, St40415, and St40418, St40419) indicate highly significant breaks ($p < 0.001$), confirmed by the concordance between tests. The four homogeneity tests were applied to the 12 time series, covering annual rainfall totals. The break point, designated k , was determined almost identically for the majority of the rainfall stations studied. The overall consistency of the results suggests that the break point k is robust across all stations. This uniformity and agreement in the homogeneity test results reinforces the reliability of the break point as a benchmark for analysing climate trends in this semi-arid region.

Thus, the results highlight the importance of sample size in detecting significant changes in rainfall data, and underscore the greater reliability of stations with longer records for identifying meaningful shifts in rainfall trends.

CONCLUSIONS

The annual rainfall time series were analysed for twelve rainfall stations using four statistical change-point detection tests: Pettitt, standard normal homogeneity test (SNHT), Buishand, and Buishand range, to rigorously assess changes in rainfall patterns. In all tests, higher test statistics, lower p -values, and clearly defined change points are found for stations with longer observation series (St40405, St40406, St40414, St40415, St40418, St40419) most of change points occurred toward the later years of the record. These later changes are interpreted as being related to greater climate variability. In contrast, results for stations with shorter observation periods (St40423, St40438) were characterised by weaker statistical evidence, greater variability in the location of

detected changes, and high p -values, reflecting reduced power and increased detection uncertainty. The clustered bar graph of change point indices (k) demonstrated a high degree of agreement between methods, with identical results produced by the Buishand and Buishand range tests for each station. Pettitt's results were generally consistent with those of the Buishand tests. Minor differences were observed for three stations: St40414, St40423 and St40424. The SNHT occasionally detected change points at other positions. For example, at station St40415, it identified a break at index 74, whereas other methods indicated index 62. This difference can be attributed to the greater sensitivity of SNHT to gradual changes. Late changes were consistently identified for stations St40405, St40415, and St40418, while older changes were observed for St40410, St40411, and St40413, indicating the presence of historical changes in rainfall patterns in the region. Overall, the high concordance observed between the four techniques reinforces confidence in the robustness of the detected change points, while the low observed differences highlight the complementary detection capabilities of the methods.

This study, which focuses on verifying the homogeneity of rainfall time series, constitutes an essential step before any assessment of climate trends. An interesting perspective would be to complete the analysis with an examination of precipitation trends, in particular through the application of the Mann–Kendall test, in order to better characterise regional rainfall trends.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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