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Analyzing Trend and Variability of Rainfall in The Tafna Basin (Northwestern Algeria)

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Abstract: Northwest Algeria has experienced fluctuations in rainfall between the two decades 1940s and 1990s from positive to negative anomalies, which reflected a significant decline in rainfall during the mid-1970s. Therefore, further analyzing rainfall in this region is required for improving the strategies on water resource management. In this study, we complement previous studies by dealing with sub basins that were not previously addressed in Tafna basin (our study area located in Northwest Algeria), and by including additional statistical methods (Kruskal–Wallis test, Jonckheere-Terpstra test, and the Friedman test) that were not earlier reported on the large scale (Northwest Algeria). In order to analyse the homogeneity, trends, and stationarity in rainfall time series for nine rainfall stations over the period 1979–2011, we have used several statistical tests. The results showed an increasing trend for annual rainfall after the break detected in 2007 for Djbel Chouachi, Ouled Mimoun, Sidi Benkhala stations using Hubert, Pettitt, and Buishand tests. The Lee and Heghinian test has detected a break at the same year in 2007 for all stations except Sebdou, Beni Bahdel, and Hennaya stations, which have a break date in 1980. We have confirmed this increasing trend for rainfall with other trend detection methods such as Mann Kendall and Sen's method that highlighted an upward trend for all the stations in the autumn season, which is mainly due to an increase in rainfall in September and October. On a monthly scale, the date of rupture is different from one station to another because the time series are not homogeneous. In addition, we have applied three tests enabling further results: (i) the Jonckheere-Terpstra test has detected an upward trend for two stations (Khemis and Hennaya), (ii) Friedman test has indicated the difference between the mean rank again with Khemis and Hennaya stations and the Merbeh station, (iii) according to the Kruskal-Wallis test, there have been no variance detected between all the rainfall stations. The increasing trend in rainfall may lead to a rise in stream flow and enhance potential floods risks in low-lying regions of the study area.

Keywords: rainfall variability; trend analysis; statistical test; water resource; Tafna basin

1. Introduction

The Mediterranean basins particularly in semi-arid regions are characterized by high temporal and spatial variability of extreme rainfall [1,2] which may enhance the process of desertification [3]. The rainfall variability has been increasing and, in turn, rises the uncertainty of predictions on rainfall in terms of its trend as well as the spatial distribution [4,5]. The variability in rainfall has an important impact on the hydrological cycle and availability of water resources [6]. Around 13% of Algeria has a Mediterranean climate, and the watersheds of this region contribute to approximately 75% of the annual surface water flow [7] with a situation of water scarcity in dry periods [8]. A reducing trend of rainfall with an order of 20% in the northern center of Algeria was observed in the late 1970s [9], which led to a drastic decrease of stream flow by almost 55% in this region, and fluctuations from 61% to 71% brought a decline in stream flow in the extreme northwest [10] due to a reduction of more than 36% of rainfall [9]. The major cause of this phenomenon is due to the negative correlation between temperature and the North Atlantic oscillation and the tropical South Pacific Ocean oscillation represented by the climate index Nino4 (El Niño Southern Oscillation). When the temperatures of tropical South Pacific and North Atlantic surface are increased, there is a decrease in precipitation in North Africa. This is a likely consequence of the predominance of warm tropical air associated with the Azores anticyclone that hinders cloud development and rainfall in the western Mediterranean region. This also coincides with a proven negative correlation indicated between the temperature and the climate index WeMO (Western Mediterranean Oscillation) in the Western Mediterranean region. This decrease in rainfall has been identified since the mid-1970s [11–14].

Rainfall is the most adapted climate variable in order to accurately analyse and characterise the climate of an area [15,16] in addition to being the major input data into any hydrological system. Therefore, analysing rainfall data deserves the highest priority for improving water management by adapting strategies to climate change. The comprehensive analysis of rainfall can help more deeply understand the variation of climate and the problems associated with floods, droughts, and its impact on water resources [17–20].

Rainfall being one of the most important climate variables indicates climate change [21]. Therefore, the study on the variability and trend analysis of rainfall for a long time series and its spatial distribution has a considerable potential to help understand climate change and its impacts [22]. However, long-term time series data is not available in several regions of the world especially in the African continent, and may affect the accuracy and impact of the results of trend analysis. The importance of analyzing the complexity and variability of the space–time precipitation patterns has clearly revealed the need for expanding the actual rainfall-monitoring networks and improving the quality control and maintenance of databases. These improvements in monitoring networks and data pre-processing will increase the options to detect possible changes in climate and improve the understanding of the climate and the water cycle [23]. The analysis of climate variables needs to be based on homogeneous data [24,25], which are not affected by non-climate factors such as changes in instrumentation and the location of meteorological stations as well as their surrounding and the other disturbing factors [26]. The study on climate change requires several tools for statistical analyses [27] aimed at the detection of breakpoints and trends (magnitude and their directions) [17]. There are several parametric and non-parametric tests available for detecting the trend in climate variables. However, the widely used statistical tests for trend analysis is the Mann-Kendall test with Theil-Sen's slope.

Several studies have been given high attention in detecting the trend in climate variables (mainly rainfall and temperature) world-wide [16,28–38]. Some of them in the Mediterranean region include the study in the Campania region located in Southern Italy. In this case, the trend analysis of rainfall time series from 211 stations during the period 1918–1999 was performed using the parametric t-test and the non-parametric Mann Kendall test. The results of this study revealed that the trend appears to be predominantly negative, both at the annual and seasonal scale, except for the summer period [25]. In the study at Cobres River basin, Southern Portugal, Da Silva et al. [30] used Mann-Kendall and Sen's methods for analyzing the trend in precipitation over 40 years and found a decrease in the annual rainfall amount. Further studies going beyond the Mediterranean region covering study sites all over the world includes the study of Batisani and Yarnal [5] where they applied the Mann-Kendall (MK) test for detecting rainfall variability in annual and monthly time steps in the semi-arid area in Botswana and found a decreasing trend in both annual and monthly rainfall with only an exception in the month of July, which showed an increasing trend. Gocic and Trajkovic [39] used the non-parametric Mann-Kendall and Sen's methods for detecting annual and seasonal trends for seven meteorological variables in Serbia from1980 to 2010, and found no significant trend in rainfall. Duhan and Pandey [40] applied the Mann-Kendall (MK) test and Sen's slope estimator test in Madhya Pradesh in India for a rainfall time series of 102 years (1901–2002) and found a decreasing change on an annual basis whereas seasonal analysis showed a significant increasing trend in the summer and a decreasing trend in the monsoon. In Africa, the study of Gedefaw et al. [41] used the annual and seasonal rainfall variability with the innovative trend analysis method (ITAM) and evaluated the results by comparing with the Mann-Kendall (MK) test and Sen's slope estimator test at five selected stations of the Amhara regional state, Ethiopia. The results showed an increasing rainfall trend at some stations and decreasing at others. Referring to a monthly scale and a seasonal scale, the months from May until September indicated an increasing trend, whereas, for the other months, followed a decreasing trend. Compared to two statistical tests (i.e., homogeneity and trend analysis), the tests of stationarity are less used in rainfall time series [42–44].

Several studies have dealt with the trend analysis and variability of rainfall over different parts of Algeria. Focus is on the studies carried out in Northwestern Algeria such as the study of Hamlaoui-Moulai et al. [45], where they analyse the trend in annual rainfall for a period of 91 years (1914–2004) considering 21 rainfall stations using the tests of Spearman, Mann-Kendall, and Pettitt. The study revealed a decreasing trend in most of the investigated stations. On the other hand, in Northeast Algeria, Mrad et al. [46] applied the trend tests on rainfall time series from 35 rainfall stations of the Constantinois Seybouse Mellegue watershed (CSM) over a period of 43 years (1969–2012). The results showed an increasing trend with a confidence interval of 95% at an annual time scale. As a consequence, it can be concluded that the rainfall trend varies at different locations in Algeria in terms of both magnitude and direction of trend (increasing as well as decreasing).

The Tafna basin (located in Northwestern Algeria) is characterized by temporal variability of rainfall from the 1950s until the 1990s and reflected a significant decline of more than 20% of annual rainfall amount starting from the mid-1970s. This variability revealed two synchronous periods from positive to negative anomalies, which explains the decrease in rainfall [11]. The decline in rainfall resulted in a significant drop of surface water resources by more than 69% and further led to a decline in the storage level of Meffrouche dam [47,48]. Hamlaoui-Moulai et al. and Ghenim and Megnounif [45,49] have carried out trend analysis of rainfall on a large scale (Northwest Algeria) and included a number of basins. However, they considered a lower proportion of rainfall stations in each basin where they have applied several statistical tests including the Mann-Kendall test. The results show a decreasing trend in annual rainfall. However, Belarbi et al. and Bakreti et al. [7,50] applied the Mann–Kendall test on rainfall and stream flow time series in Tafna basin. The majority of the results showed a decreasing trend. Ghenim et al. [47] also performed trend analysis of rainfall in the Tafna basin. However, they did not apply the Mann-Kendall test in their study. Their result showed a decreasing trend in annual rainfall. In our study, we included three sub basins (Oued Boumssoued and upstream Sebdou) that have not been considered in the previous studies. In addition, we have applied statistical tests such as Sen's method, Kruskal-Wallis, Friedman, and Jonckheere-Terpstra tests, which have been unemployed in the past studies to detect a trend in the study area. We consider the inclusion of sub basins and application of additional trend methods for the study area as the innovative features of our research and expect an advantage in analyzing the rainfall trend over the previous research studies.

The overall aim of the present study is to analyze the variability and trend in rainfall at a monthly, seasonal, and annual time scale of 32 years (1979–2011) considering nine rainfall stations in the Tafna basin, Northwest Algeria using the application of several statistical tests mentioned in Table 1.

2. Study Area

The Tafna basin (Figure 1) is a transboundary basin covering an area of 7245 km^2. The biggest part of its area is located in the Northwest of the Algerian territory (Wilaya of Tlemcen) and the upper part on the territory of Morocco. According to the new structure of Hydro geological units in Algeria, the Tafna basin belongs to the entire Oranie-Chott-Chergui [51].

It extends between 1° to 2° west longitude and 34°5′ to 35°3′ north latitude [51] and consists of eight sub basins in which two are located upstream in the Moroccan territory (2007 km^2 which is around 27.7% of the total area) [52]. The Tafna basin features a very rugged terrain with an average altitude of 780 m above the mean sea level (a.m.s.l.) and a maximum altitude exceeding 1800 m (a.m.s.l.). It has a 170 km long stream with its source in the Tlemcen Mountains, i.e., region of Sebdou and Isser Wadi and Maghnia region (Mouillah Wadi effluent from the Moroccan part). The Tafna basin can be subdivided into three parts: the high Tafna, the middle Tafna, and the lower Tafna [51].

Our study area consists of six sub basins belonging to part of the Tafna basin located in the Algerian territory only (Figure 1).

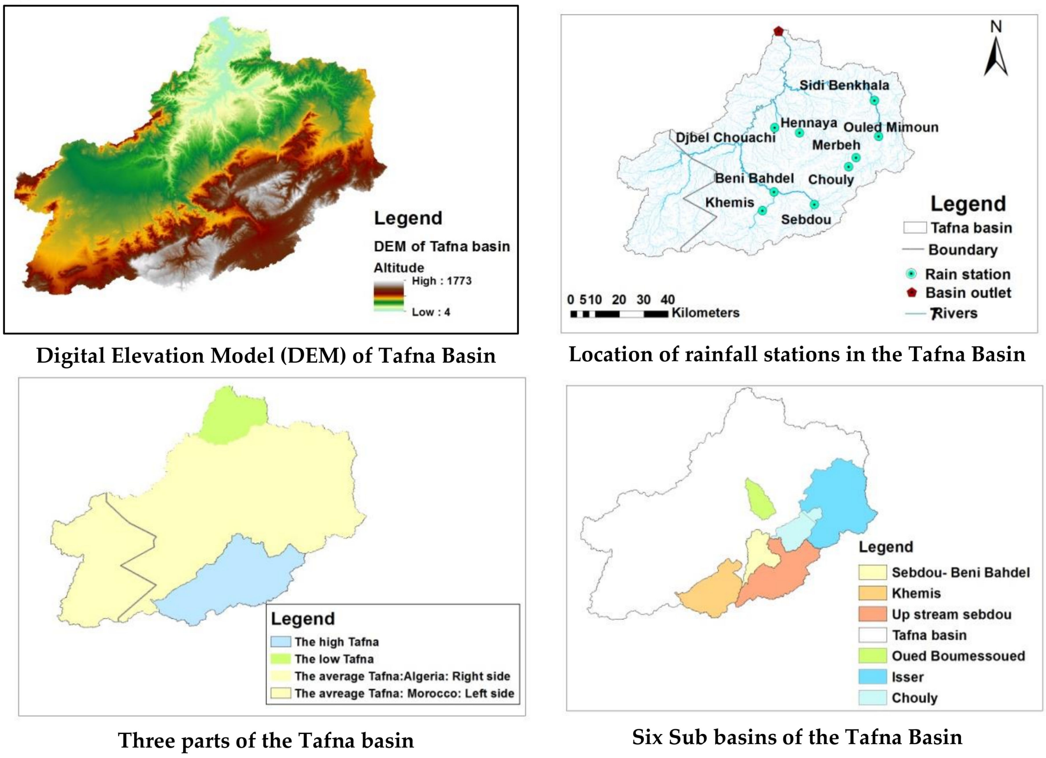

Figure 1. Digital Elevation Model (DEM), location of the rainfall stations and parts as well as sub basins of the Tafna Basin (study area).

3. Materials and Methods

3.1. Methodology

Non-parametric tests (also known as distribution-free inferential statistical methods) do not require the data to be normally distributed. Since most of the hydro-meteorological time series data are not normally distributed. Hence, non-parametric methods have been widely used [33,53]. In this study, we have applied several non-parametric tests (as mentioned in Table 1) for trend detection, stationary tests, and homogeneity analysis of rainfall (monthly and annual time scale) for nine rainfall stations located in six sub basins of the Tafna basin (Figure 1) over a time period between 1979 and 2011.

Four tests (Pettit's test, Buishand test, Hubert test, Lee and Heghinian test) were applied to study homogeneity on an annual and monthly time scale. These tests analyse the time series and detect the break point, which is defined as a change of distribution of the variable in time series (i.e., change in the mean). The Khronostat software was used to perform these tests.

Three tests (Kruskal-Wallis test, Jonckheere-Terpstra test, and Friedman test) aim to analyse the stationarity of rainfall time series on a monthly time scale using SPSS software.

The Mann-Kendall test with Theil-Sen's slope method was employed for detecting a rainfall trend on monthly, seasonal (Autumn (September, October, November), Winter (December, January, February), Spring (March, April, May), Summer (June, July, August)), and annual time scale.

First, serial correlation in the rainfall dataset was analyzed. The trend detection tests require the series of data to be serially independent because the presence of serial correlation may affect the results of the analyzed statistical tests. The initial analysis of rainfall data showed non-significant serial correlation at a 5% level of statistical significance and, therefore, we have applied the trend analysis directly to the original data without applying any correction for serial correlation. All the tests were considered as two-sided hypothesis at a 1%, 5%, and 10% level of statistical significance. The applied tests mentioned above have been widely used for evaluating the trend in climatic and hydrological data.

Table 1. Summary of statistical tests.

Statistical Method	Statistical Test Types	Description
Change point detection test	Pettitt Test	Detect a single change-point in hydrological or climate data with continuous long-term time series
	Buishand Test	Detect a change in variables according to any distribution.
	Hubert Test	Detect multiple breaks in time series.
	Lee and Heghinian Test	Detect change of means in the data with a continuous time series.
Stationarity test	Kruskal-Wallis test	Comparison of the means of several samples and makes it possible to check whether several samples come from the same population and that they have the same characteristics.
	Jonckheere-Terpstra test	Indicating a trend of independent samples.
	Friedman Test	Two-way analysis of variance for indicating and comparing results.
Trend analysis	Mann-Kendall (MK) Trend Test	Non-parametric test, which is commonly employed to detect monotonic trends in series of data for mainly climate or hydrological data.
	Sen's Slope Estimator	Computing the linear rate of change (slopes) by choosing the median of the slopes of all lines through pairs of points also computes the upper and lower confidence limits for Sen's slope.

3.1.1. Tests for Change Point Detection (Homogeneity Test)

The change point detection test is the analysis of variance for data distribution, i.e., the shift in the mean of the variable in the time series. These methods assume a null hypothesis that there is no change in the variance of the series studied [54].

(1) Pettitt Test

The Pettitt test is a non-parametric test developed by Pettitt [55] for detecting the change point [56]. The statistic, $U_{t,N}$, is defined using the two sums obtained in order to assess whether the two samples belong to the same population by the equation [17,57]:

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

N is the size of time series, t is the time, and the sgn is the coefficient given by the equation as follows.

$$\text{Sgn} = \begin{cases} +1 & \text{if } (x_j - x_i) > 0 \\ 0 & \text{if } (x_j - x_i) = 0 \\ -1 & \text{if } (x_j - x_i) < 0 \end{cases} \tag{2}$$

Under the null hypothesis, the statistic of the variable to be the test is *K* given as:

$$K = Max|U_t| \tag{3}$$

The exceedance probability of the k as:

$$\text{Prob}(k_N > k) \approx 2\exp\left(\frac{-6\,k^2}{N^2 + N^3}\right) \tag{4}$$

When the exceedance probability is smaller than the significant level α, the null hypothesis is rejected for a significance level α [17,58].

(2) Buishand Test

The Buishand test has the same hypotheses as the Lee and Heghinian test. The statistic U of the test is given as follows.

$$U = \frac{\sum_{K=1}^{N-1}\left(S_k/\sigma_x\right)^2}{N(N+1)} \tag{5}$$

$$S_k = \sum_{i=1}^{k}\left(X_i - \overline{X}\right) \tag{6}$$

where S_k is the partial sum and σ_x is the standard deviation (calculated using Equation (7)).

$$\sigma_x^2 = \frac{1}{N}\sum_{i=1}^{N}\left(X_i - \overline{X}\right)^2 \tag{7}$$

The null hypothesis stands for no break point in time series. The rejection of the null hypothesis means a break point in the time series. In addition to these different procedures, the building of a control ellipse makes it possible to analyze the homogeneity of the (xi) series [59,60].

(3) Hubert Test

Hubert's segmentation procedure detects multiple breaks in the time series [54,55,61]. The principle is to cut the time series into m segments (m > 1) such that the calculated means of the neighboring sub-series should differ significantly. To limit the segmentation, the mean of two contiguous and the point of satisfying Scheffe's test should be different. The procedure gives the timing of the shifts. Giving a m^{th} order segmentation of the time series, i_k. k = 1, ... m, the rank in the initial series of the extreme end of the k^{th} segment (with $i_0 = 0$), we defined the following by two equations.

$$\overline{X_k} = \frac{\sum_{i=i_{k-1}+1}^{i=i_k} x_i}{n_k} \tag{8}$$

$$D_m = \sum_{k=1}^{m}\sum_{i_{k-1}+1}^{i_k}\left(X_i - \overline{X}_k\right)^2 \tag{9}$$

D_m is the quadratic deviation between the series and the segmentation. For a given segmentation order, the algorithm determines the optimal segmentation of a series in such a way that the deviation Dm is minimal. This procedure can also be interpreted as a stationary test where the null hypothesis of the studied series should be non-stationary. If the procedure does not produce acceptable segmentations of an order bigger or equal to two, the null hypothesis is accepted [59,60].

(4) Lee and Heghinian Test

The Lee and Heghinian test is based on the assumption that the series is normally distributed. The tests are Bayesian procedures based on Equation (10), which supposes a change in the series as follows.

$$x_i = \begin{cases} \mu + \varepsilon_i,\ i = 1\ldots,\tau \\ \mu + \sigma + \varepsilon_i\ ,\ i = \tau + 1,\ldots.,N \end{cases} \tag{10}$$

where ε_i are independent and normally distributed with a mean equal to zero and a variance equal to σ^2. τ is the position in time and σ is the scope of the possible change in the mean [59,60].

3.1.2. Stationarity Test

Stationarity means the statistical properties (mean, variance, and covariance) do not depend on time. The test is practically performed to determine whether all groups of datasets have the same median value, or if one median value is different, at least for one group [62–64].

(1) Kruskal-Wallis Test

The Kruskal-Wallis is a non-parametric test alternative to one-way analysis of variance and an extension of the Mann-Whitney test [65] for more than two independent samples. This test compares series mean ranks (i.e., medians). The null hypothesis is that the series medians are equal and the alternative hypothesis is that there is a difference between at least two of them. This statistic test is performed by Equation (11) [66].

$$\mathrm{T} = \frac{12}{\mathrm{N}(\mathrm{N}+1)} \sum_{\mathrm{j}=1}^{\mathrm{k}} \frac{\mathrm{R}_\mathrm{j}^2}{\mathrm{n}_\mathrm{j}} - 3(\mathrm{N}+1) \tag{11}$$

where $\mathrm{R_j}$ is the total of the ranks for the $\mathrm{j_{th}}$ sample, $\mathrm{n_j}$ is the sample size for the $\mathrm{j_{th}}$ sample, k is the number of samples, and N is the total sample size.

(2) Jonckheere-Terpstra test

Jonckheere-Terpstra test assumes that the distribution of the response variable does not differ among classes. It is developed to detect the alternative hypothesis of ordered class differences, which can be shown as $\mathrm{n_1 < n_2 < n_3 \ldots n_T}$ (or $\mathrm{n_1 > n_2 > n_3 \ldots n_T}$) with at least one of the inequalities being strict. The Jonckheere-Terpstra test requires independent samples (grouping variable) to be orderly arranged [66].

The Jonckheere-Terpstra test can be used, with test statistic $\mathrm{T_{JT}}$ and calculated as:

$$\mathrm{T_{JT}} = \frac{\sum \mathrm{U_{xy}} - \frac{\mathrm{N^2} - \sum_{\mathrm{j}=1}^{\mathrm{k}} \mathrm{n_j^2}}{4}}{\sqrt{\frac{\mathrm{N^2}(2\mathrm{N}+3) - \sum_{\mathrm{j}=1}^{\mathrm{k}} \mathrm{n_j^2}\left(2\mathrm{n_j}+3\right)}{72}}} \tag{12}$$

where $\mathrm{U_{xy}}$ is the number of observations in-group y that are greater than each observation in-group x. This is compared with a Standard Normal distribution.

(3) Friedman Test

The Friedman test is an extension of the sign test for matched pairs [65] and is used when the data arise from more than two related samples. The usual form of the Friedman statistic is as follows [66].

$$\mathrm{T} = \frac{12}{\mathrm{bk}(\mathrm{k}+1)} \left(\sum_{\mathrm{j}=1}^{\mathrm{k}} \mathrm{R_j^2} \right) - 3\mathrm{b}(\mathrm{k}+1) \tag{13}$$

where k is the number of the measurements, b is the number of samples, and $\mathrm{R_j}$ is the total of the ranks for the sample.

3.1.3. Trend Analysis

Trend is a direction of a phenomenon through a fixed period. It can be discovered by statistical tests, which is applied to further investigate whether the trend is upward or downward of the data during a time period while considering the level of statistical significance [25,29,30,41,46,67].

(1) Mann-Kendall (MK) Trend Test

The non-parametric MK trend test is the rank-based test [45,68] used to assess the significance of a trend in hydro-meteorological time series [39]. The statistic S of the MK test is calculated as follows.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}\left(x_j - x_i\right) \tag{14}$$

where n is the number of data points, x_i and x_j are the data values in the time series i and j (j > i), respectively, the positive value of S indicates an increasing trend, and the negative indicates a decreasing trend. The data values of each x_i is used as a reference point to compare with the data values of x_j, and $\mathrm{sgn}(x_j - x_i)$ is the sign function given as:

$$\mathrm{sgn}\left(x_j - x_i\right) = \begin{cases} +1 & \text{if } x_j - x_i > 0 \\ 0 & \text{if } x_j - x_i = 0 \\ -1 & \text{if } x_j - x_i < 0 \end{cases} \tag{15}$$

The variance is calculated as:

$$\mathrm{Var}(s) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{P} t_i(t_i-1)(2t_i+5)}{18} \tag{16}$$

where n is the number of data points, P is the number of tied groups, and t_i is the number of data values in the Pth group. The standardized test statistic Z is calculated as:

$$Z_S = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(s)}} \text{ if } S > 0 \\ 0 \text{ if } S = 0 \\ \frac{S+1}{\sqrt{\mathrm{Var}(s)}} \text{ if } S < 0 \end{cases} \tag{17}$$

Positive values of Z_S indicate increasing trends while negative Z_S values show decreasing trends. The null hypothesis (H_0) stands for a significant trend, and the alternative hypothesis (H1) represents no statistically significant trend [45,68].

(2) Sen's Slope Estimator

Sen's method was used for estimating the slope of detected significant trends, and the variance of the residuals should be constant in time. It is calculated as:

$$Q_i = \frac{x_j - x_k}{j - k} \text{ for } i = 1, \ldots\ldots, n \tag{18}$$

where X_j and X_k are the data values in the times series j and k respectively; n is the number of time periods.

N = n(n − 1)/2. There is only one data in each time period.

N < n(n − 1)/2. There are multiple observations in one or more time periods.

The median of Sen's slope estimator is calculated as follows.

$$Q_{med} = \begin{cases} Q[(n+1)/2] & \text{if n is odd} \\ \frac{Q[^n/_2]+Q[(n+2)/2]}{2} & \text{if n is even} \end{cases} \tag{19}$$

The Q_{med} sign reflects a data trend while its value indicates the steepness of the trend. To determine whether the median slope is statistically different than zero, one should obtain the confidence interval of Q_{med} at a specific probability. The confidence interval about the time slope can be computed as follows.

$$c_{\alpha} = Z_{\frac{1-\alpha}{2}} \sqrt{\mathrm{Var(s)}} \tag{20}$$

where Var(S) is variance and $Z_{(1\text{-}\alpha)/2}$ is obtained from the standard normal distribution table [30,39,69].

3.2. Dataset

Daily rainfall data were collected from nine climate stations (Sebdou, Beni Bahdel, Khemis, Hennaya, Djbel Chouachi, Chouly, Merbeh, Oueld Mimoun, and Sidi Benkhala) located in different parts of six sub basins of Tafna basin (Figure 1).

National Agency of Hydraulic Resources (ANRH) of Algeria provided rainfall data for a time period of 32 years (1979–2011). The major characteristics of the stations (name, code, coordinates, database periods) and the sub basins (area and perimeter) are presented in Table 2.

The amount of missing daily precipitation data was about 0.8%, 0.8%, and 2.3% for Sebdou, Khemis, and Beni Bahdel stations, respectively, with a standard error of estimation not exceeding the value of 4%. The share of missing data was about 1.5% and 0.8% for Hennaya and Djbel Chouachi stations, respectively, with a standard error of estimation not exceeding a value of 7%. The amount of missing data reported to be 1.6% and 6.1% for Chouly and Merbeh stations and about 1.6% and 1.2% for Ouled Mimoun and Sidi Benkhala stations with a standard error of estimation not exceeding the value of 6%, respectively. Overall, in general, the average missing daily rainfall data of the nine rainfall stations were 2.27% only.

We filled the missing data in the nine stations by a linear regression method as well as considering the data from the other adjacent stations (Meffrouch, Sebra, Zaouia Ben Amer, and Smala Sidi stations). The equations of the linear regression method is based on checking the correlation coefficient between the complete time series for the number of adjacent stations with the study area rainfall stations separately.

Table 2. Descriptive information of rainfall stations.

N	Sub Basin	Stations	Code of Station	Longitude (W)	Latitude (N)	Elevation (m)	Area (km^2)	Perimeter (km)	Period of Data
1	Up stream Sebdou	Sebdou	16-04-01	1°33′	34°65′	875	439.30	153.88	1979–2011
2	Sebdou-Beni Behdel	Beni Bahdel	16-04-03	1°51′	34°71′	666	162.37	87.91	1979–2011
3	Khemis	Khemis	16-04-06	1°56′	34°64′	920	342.22	104.35	1979–2011
4	Oued Boumessao-ud	Hennaya	16-05-16	1°39′	34°92′	515			1979–2011
		Djbel Chouachi	16-05-18	1°50′	34°94′	110	108.76	57.16	1979–2011
5	Chouly	Chouly	16-06-01	1°14′	34°83′	700			1979–2011
		Merbah	16-06-02	1°17′	34°79′	1100	176.39	78.80	1979–2011
6	Isser	Ouled Mimoun	16-06-07	1°03′	34°90′	705			1979–2011
7		Sidi Benkhala	16-06-10	1°05′	35°03′	430	696.10	164.26	1979–2011

4. Results and Discussion

4.1. Preliminary Analysis

Basic descriptive statistics were calculated to evaluate rainfall variability and major results are summarized in Table 3. The skewness, which is a measure of asymmetry in a frequency distribution around the mean reached the highest value at the Merbeh station (1.6) indicating more low values of rainfall than high values, whereas the Hennaya station has the lowest skewness (−0.2). The Beni Bahdel station receives the most rainfall, which is indicated by the highest mean (400.4 mm per year) while the Djbel Chouchi station has the lowest mean (278.7 mm). The coefficient of variation (CV) is a statistical measure of the dispersion of data point in a time series around the mean. CV of the stations considered in our study varied between 26.3% at the Hennaya station to 42.9% at the Khemis station. As visualized in Figure 2, it is clear through the Boxplot that the station of the highest length of the box (range) and the presence of the outliers are the station of the highest variability and station of the lowest range. Absence of the outliers are the station of least variability.

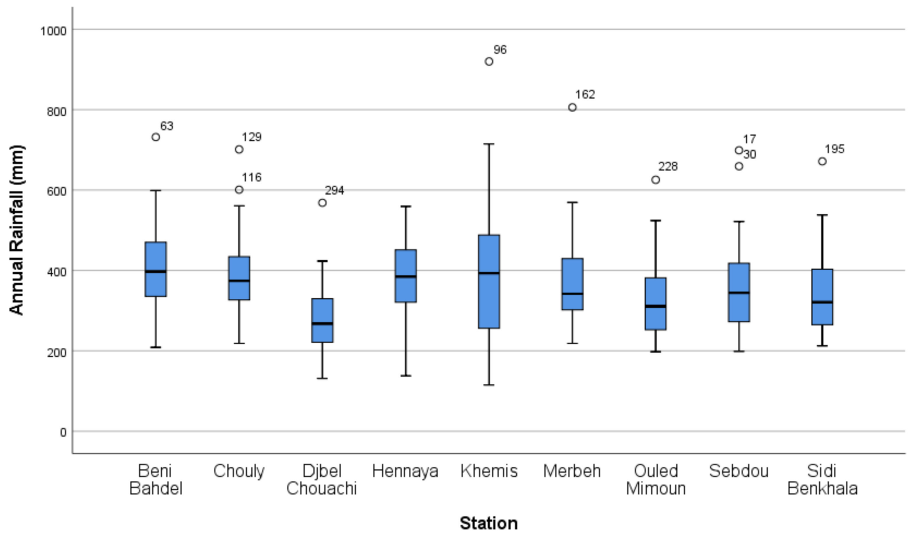

Figure 2. Annual rainfall box plot. The upper and lower limit of the box indicate the 25th and 75th percentiles, respectively. The linear extensions mark the highest and lowest observed values.

Table 3. Statistics of the annual rainfall (mm) in the Tafna basin.

Statistics		Stations								
		Sebdou	Beni Bahdel	Khemis	Chouly	Merbeh	Sidi Benkhala	Ouled Mimoun	Hennaya	Djbel Chouachi
Mean		361.8	400.4	399.3	393.9	375.2	340.5	330.6	378.3	278.7
Standard Error of Mean		20.5	20.6	29.8	18.1	20.6	17.6	17.1	17.3	15.8
Standard Deviation		117.9	118.2	171.2	103.7	118.6	101.1	98.4	99.4	90.6
Coefficient Variance		32.6	29.5	42.9	26.3	31.6	29.7	29.7	26.3	32.5
Variance		13,891.2	13,966.3	29,307.2	10,755.6	14,055.9	10,228.6	9674.9	9878.9	8199.7
Range		500.1	523.1	804.7	482.7	587.3	459.1	427.6	421.3	437.1
Minimum		198.8	208.7	115.2	218.4	218.4	212.3	197.9	137.9	131.2
Maximum		698.9	731.8	919.9	701.1	805.7	671.4	625.5	559.2	568.3
Skewness		1.13	0.5	0.9	1	1.6	1.224	1	-0.2	0.9
	25	269.6	318.1	256.1	321.5	285.9	262.3	250.1	310.7	221.1
Percentiles	50	344.4	397.3	393.3	374	341.8	321	310.8	384.6	267.8
	75	424.2	471.5	493	451.9	434.9	404.2	382.8	457.9	333.7

The Chi Square test is used to determine whether a statistically significant relationship exists between the two categorical variables. We used this test to verify for a relation between the number of rainfall days and the rainfall stations featured by location or elevation. Table 4 shows the results with a significant level at 5% while the value of the test is 908.309. The assumption of the test has not been violated, which emphasizes the percentage of the cells less than the value of 5 should not be more than 20% (less value of the cells in the data series is 15.33). It is clear that the station (location, elevation) and the count of the range number of rainfall days (Table 5, Figure 3) are not independent because the significance level is less than 5% and, therefore, we accepted the null hypothesis that the station (location, elevation) where the higher number of non-rainfall days (10,800 day) corresponds to the station of the low altitude (110 m) and near to the sea(Djbel Chouachi), and the lower number of non-rainfall days (9747 day) corresponds to the higher altitude (1100 m).

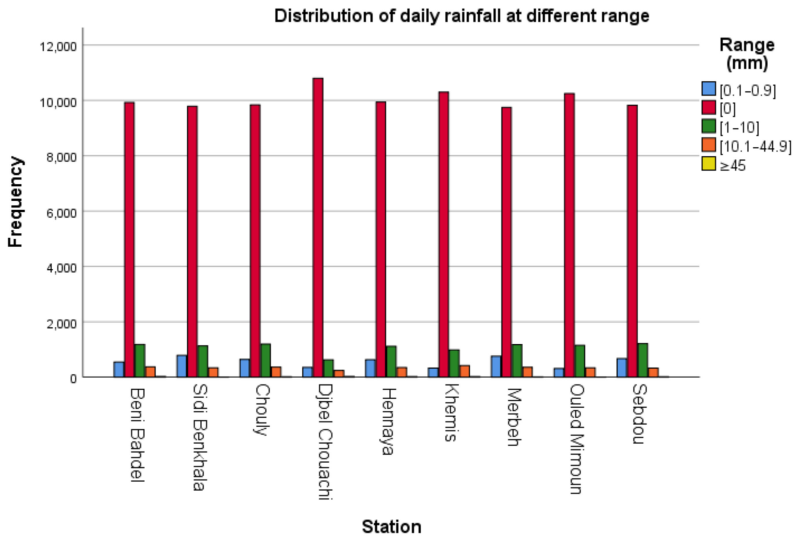

Figure 3. Range distribution of rainfall intensity (in mm) for each station.

Table 4. Results of the chi-square test.

	Value	df	Asymptotic Significance (2-Sided)
Pearson Chi-Square	908.309 [a]	33	0.000
Likelihood Ratio	973.059	33	0.000
N of Valid Cases	108,477		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 15.33, df (degrees of freedom): The degrees of freedom is basically a number that determines the exact shape of our distribution.

Table 5. Range of daily rainfall.

Classification of Range of the Number of Rain Days							
		[0.1–0.9]	**[0]**	**[1–10]**	**[10.1–44.9]**	**≥45**	
Station	Beni Bahdel	547	9925	1182	376	23	12,053
	Sidi Benkhala	788	9789	1129	340	7	12,053
	Chouly	640	9837	1196	365	15	12,053
	Djbel Chouachi	356	10,800	627	244	26	12,053
	Hennaya	631	9940	1115	349	18	12,053
	Khemis	330	10,297	987	421	18	12,053
	Merbeh	760	9747	1179	357	10	12,053
	Ouled Mimoun	311	10,246	1151	338	7	12,053
	Sebdou	673	9822	1214	330	14	12,053
	Total	5036	90,403	9780	3120	138	108,477

Table 6 contains results of the normality tests for rainfall time series. The normality tests are used to determine whether the data set is fitting a normal distribution or not. We applied two tests for the normality known as the Kolmogorov-Smirnov and Shapiro-Wilk test. According to the Kolmogorov-Smirnov test, the annual rainfall data are following a normal distribution only at the Sidi Benkhala station. Annual rainfall is fitting the normal distribution as per the Shapiro-Wilk test at Sebdou, Merbeh, Sidi Bounkhala, and Ouled Mimoun stations. Monthly rainfall data do not follow a normal distribution for all stations according to both tests.

4.2. Change Point Detection Test

We present in Table 7 the results of the break detection tests (Pettitt, Hubert, Buishand, Leeand Heghinian) for nine rainfall stations on an annual scale at p = 0.01 and 0.05 levels of statistical significance. The results showed that the Lee and Heghinian test rejected the null hypothesis (no break in time series) for all the stations and indicating the break point corresponding to 1980 for Sebdou, Beni Bahdel, and Hennaya and for the remaining stations in 2007. Pettitt's test did not detect any change except for the Djbel Chouachi station in 1999, which is also confirmed by the Buishand test that detected a change in 1999 and 2007 and a change was revealed in 2007 by the Hubert test. The application of the segmentation method of Hubert leads to reject the null hypothesis for three stations: Djbel Chouachi, Ouled Mimoun and Sidi Benkhala in 2007 and accepted the null hypothesis for other stations.

Most changes (break) of the distribution in annual time series is detected for the Djbel Chouachi station. This seems to be caused by the effect of characteristics of the zone where the station is located (such as the altitude). The Djbel Chouachi station has the lowest altitude (110 m) and may impact the measurements representing the actual amount of rainfall in the area. The study of Hamlaoui-Moulai et al. [45] has already demonstrated the relationship between the characterization of the zones in Northwest Algeria such as the altitude with rainfall on an annual basis.

Analyzing at a monthly time scale (Table 8) indicates rejection of the null hypothesis (no break) and also acceptance of the null hypothesis in different months, as detected by all the applied tests (Pettitt, Buishand, Hubert, Lee, and Heghinian) leading to break points in monthly time series. Only the months of June, July, and August with Buishand and Lee and Heghinian tests has not affirmed the acceptance or the rejection of the hypothesis in detecting breaks for all stations at any statistical significance level due to the sensitivity of the two tests by dealing with the level of the data variability for these months (extreme values). The Sebdou station rejected the null hypothesis in August. We conclude that the time series on rainfall are not homogenous because a break point was detected.

Figure 4a–c, respectively, serve graphical results obtained by the khronostat software of some tests such as the Pettitt, Leeand Heghinian and Buishand tests on the annual time scale. As depicted in Figure 4a, the Pettitt test rejected the null hypothesis at the Djbel Chouachi station and indicated the date of the break corresponding to 1999 with the direction of rupture representing an upward for the rainfall trend. The Lee and Heghinian test in Figure 4b showed the date of break in 2007 at the Sidi Benkhala station. While Buishand confirmed with the Djbel Chouachi station, the same date of the break in 1999 as indicated by the Pettitt test and proposed 2007 as a further year of break in Figure 4c. The two break points are followed by an upward trend of rainfall. This result leads to the conclusion that the rainfall time series are not homogeneous and can, therefore, be divided into three sub-series: 1979–1999, 1999–2007, and 2007–2011.

Table 6. Results of normality on annual and monthly rainfall.

Scale	Test		Sebdou	Khemis	Beni Bahdel	Djbel Chouachi	Hen-naya	Chouly	Merbeh	Ould Mimoun	Sidi Benkhala
Annual	Kolmogorov-Smirnov	Statistic	0.15	0.09	0.08	0.11	0.11	0.11	0.14	0.11	0.16
		Significance	0.06	0.20	0.20	0.20	0.20	0.20	0.1	0.20	0.02
	Shapiro-Wilk	Statistic	0.91	0.95	0.97	0.95	0.95	0.95	0.88	0.93	0.90
		Significance	0.01	0.15	0.55	0.13	0.87	0.13	0.002	0.002	0.005
Monthly	Kolmogorov-Smirnov	Statistic	0.18	0.22	0.2	0.20	0.18	0.18	0.18	0.17	0.19
		Significance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Shapiro-Wilk	Statistic	0.82	0.74	0.79	0.81	0.83	0.83	0.82	0.85	0.82
		Significance	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 7. Results of the change point detection on annual rainfall.

Test	Investigative Work	Sebdou	Khemis	Beni Bahdel	Djbel Chouachi	Hennaya	Chouly	Merbeh	Ouled Mimoun	Sidi Benkhala
Pettitt	Conclusion on H0	Accepted	Accepted	Accepted	Rejected	Accepted	Accepted	Accepted	Accepted	Accepted
	Break date	/	/	/	1999 *	/	/	/	/	/
Hubert	Conclusion on H0	Accepted	Accepted	Accepted	Rejected	Accepted	Accepted	Accepted	Rejected	Rejected
	Break date	/	/	/	2007 **	/	/	/	2007 **	2007 **
Buishand	Conclusion on H0	Accepted	Accepted	Accepted	Rejected	Accepted	Accepted	Accepted	Accepted	Accepted
	Break date	/	/	/	1999,2007	/	/	/	/	/
Lee and Heghinian	Break probability	0.1267	0.1380	0.1332	0:2345	0.2473	0.3842	0.2183	0.5171	0.3505
	Conclusion on H0	Rejected	Rejected	Rejected	Rejected	Rejected	Rejected	Rejected	Rejected	Rejected
	Break date	1980	2007	1980	2007	1980	2007	2007	2007	2007

** at $p = 0.01$ significant level, * at $p = 0.05$ significant level.

Table 8. Results of the homogeneity test on monthly rainfall.

	Sebdou			**Khemis**			**Beni Bahdel**			**Djbel Chouachi**			**Hennaya**			**Chouly**			**Merbeh**			**Ouled Mimoun**			**Sidi Benkhala**		
Test	Sep	Oct	Nov	Sep	Oct	Nov	Sep	Oct	Nov	Sep	Oct	Nov	Sep	Oct	Nov	Sep	Oct	Nov	Sep	Oct	Nov	Sep	Oct	Nov	Sep	Oct	Nov
Pettitt	R	A	A	R	R	A	R	R	A	A	A	A	A	R	A	A	A	A	R	R	A	A	A	A	A	R	A
Hubert	A	R	R	R	R	A	R	R	A	A	R	A	A	R	A	R	A	A	R	R	A	R	A	A	A	R	A
Buishand	R	R	A	R	R	A	R	R	A	A	A	A	A	R	A	R	R	A	R	R	A	R	R	A	R	R	A
Lee and Heghinian	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Test	Dec	Jan	Feb	Dec	Jan	Feb	Dec	Jan	Feb	Dec	Jan	Feb	Dec	Jan	Feb	Dec	Jan	Feb	Dec	Jan	Feb	Dec	Jan	Feb	Dec	Jan	Feb
Pettitt	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Hubert	R	A	A	R	A	A	R	A	A	A	A	A	R	A	A	A	A	A	A	A	A	R	A	A	R	A	A
Buishand	A	A	A	NT	A	A	NT	A	A	A	A	A	A	A	A	A	A	A	A	A	A	NT	A	A	A	A	A
Lee and Heghinian	R	R	R	R	R	R	NT	R	R	R	R	R	R	R	R	R	R	R	R	R	R	NT	R	R	R	R	R
Test	Mar	Apr	May	Mar	Apr	May	Mar	Apr	May	Mar	Apr	May	Mar	Apr	May	Mar	Apr	May	Mar	Apr	May	Mar	Apr	May	Mar	Apr	May
Pettitt	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Hubert	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A	A	A	R	A	A
Buishand	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Lee and Heghinian	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Test	Jun	Jul	Aug	Jun	Jul	Aug	Jun	Jul	Aug	Jun	Jul	Aug	Jun	Jul	Aug	Jun	Jul	Aug	Jun	Jul	Aug	Jun	Jul	Aug	Jun	Jul	Aug
Pettitt	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	R	A	A	A
Hubert	A	A	A	A	A	A	A	A	A	R	A	A	A	A	A	R	A	A	A	A	A	A	A	R	A	A	A
Buishand	NT	NT	R	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT
Lee and Heghinian	NT	NT	R	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT	NT

A: accepted null hypothesis. R: rejected null hypothesis. NT: No Test.

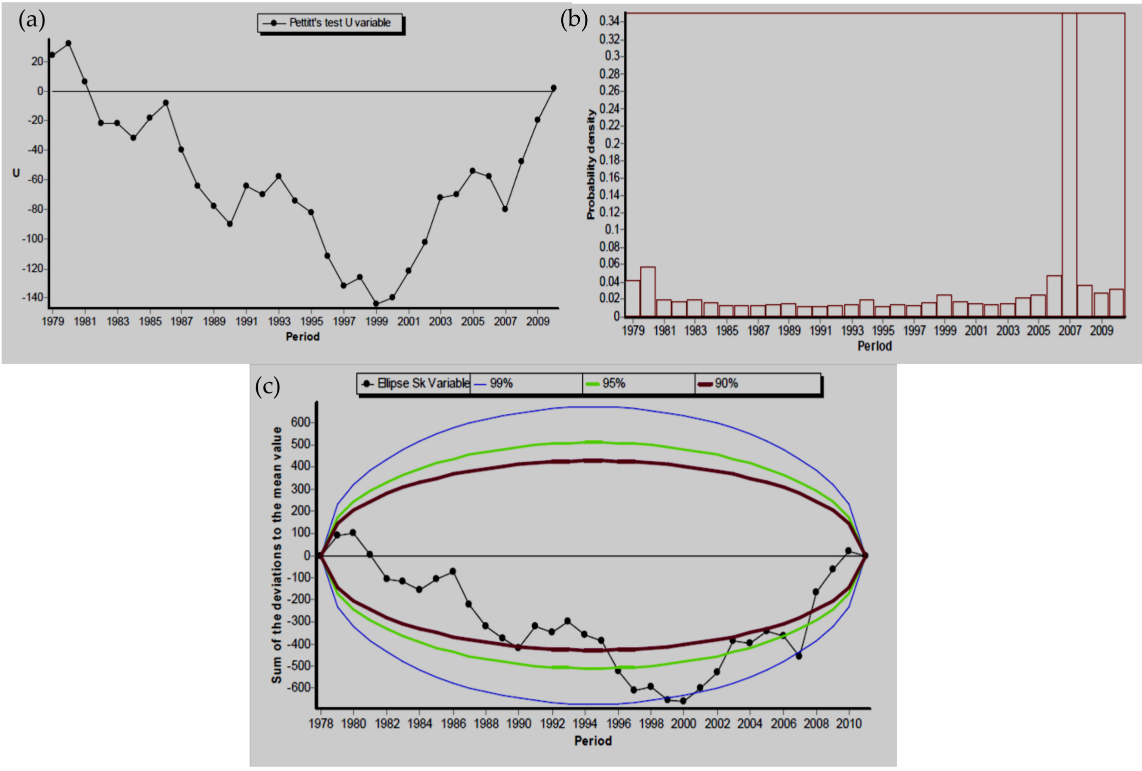

Figure 4. Khronostat results of annual rainfall: (**a**) Pettitt at Djbel Chouachi, (**b**) Lee and Heghinian at Sidi Bounkhala, and (**c**) Buishand at DjbelChouachi.

4.3. Stationarity Test

The Kruskal-Wallis H and Friedman tests revealed no statistically significant differences on monthly rainfall at p = 0.05 significant level for Sebdou, Beni Bahdel, Djbel Chouachi, Chouly, Ouled Mimoun, and Sidi Benkhala stations. Whereas Khemis, Merbeh, and Hennaya stations show no significant difference at p = 0.05 only for the Kruskal-Wallis H test. The statistic values of the Kruskal-Wallis H test variate between χ^2 = 19.036 (Djbel Chouachi) and χ^2 = 41.648 (Khemis). Consequently, the rainfall amount was equivalent for this period of time.

The Jonckheere-Terpstra test showed no statistically significant trend of monthly rainfall for Sebdou, Beni Bahdel, Djbel Chouachi, Hennaya, Chouly, Ouled Mimoun, and Sidi Benkhala stations at p = 0.05, whereas Khemis and Merbeh stations showed a significant trend at p = 0.05 (Table 9).

Table 9. Results of the stationarity test of rainfall.

Test	Statistics	Sebdou	Khemis	Beni Bahdel	Djbel Chouachi	Hennaya	Chouly	Merbeh	Ouled Mimoun	Sidi Bounekhla
Kruskal-Wallis test	Kruskal Wallis H	33.27	41.65	25.26	19.04	26.61	23.11	28.82	24.78	21.14
	Asymp Significance	0.36	0.1	0.76	0.95	0.69	0.85	0.58	0.78	0.91
Jonckheere-Terpstra test	J-T Statistic	39,288	40,970	39,990.50	40,421	39,417.5	39,906	37,944	39,991	39,991
	Asymp Significance	0.31	0.02	0.12	0.06	0.26	0.14	0.02	0.10	0.12
Friedman Test	Chi Square	45.60	58.56	39.72	32.58	46.60	38.82	48.08	42.93	36.93
	Asymp Significance	0.06	0.00	0.16	0.44	0.05	0.19	0.03	0.09	0.25

At p= 0.05 significant level.

4.4. Trend Analysis

The results of the MK test presented by Table 10 on the annual time scale at different levels of statistical significance (p = 0.01, 0.05 and 0.1)shows no statistically significant trend for all the rainfall stations, which is similar to the results of the other study by Zeroual et al. [14]. Monthly rainfall has statistically significant increasing trends for Sebdou, Khemis, Beni Bahdel, Merbeh, Ouled Mimoun, Sidi Benkhala, Chouly, and Hennaya stations. The Sebdou station shows a significant increasing trend for rainfall in August (1.71 mm/month at p = 0.1), September (2.56 mm/month at p = 0.05), and October (2.17 mm/month at p = 0.05). The Khemis station shows an increasing rainfall trend in September (2.93 mm/month at p = 0.01) and October (2.59 mm/month at p = 0.01). Beni Bahdel, Ouled Mimoun, and Sidi Benkhala stations feature a significant increasing trend for September (2.19 mm/month at p = 0.05, 1.83 mm/month at p = 0.1, 1.94 mm/month at p = 0.1, respectively) and October (1.92 mm/month at p = 0.1, 2.47 mm/month at p = 0.05, 2.73 mm/month at p = 0.01, respectively). The Merbeh station shows significant increasing trends for August (2.29 mm/month at p = 0.05), September (2.08 mm/month at p = 0.05), and October (3.04 mm/month at p = 0.01). The Chouly and Hennaya station show a significant increasing trend for the month of October (1.77 mm/month at p = 0.1, 2.53 mm/month at p = 0.05, respectively). We conclude that, among most of the stations with significant increasing trends, this increase is occurring in the months of August, September, and October. Furthermore, the maximum number of significant increasing trends of rainfall in these months (August, September, and October) were found at Sebdou and Merbeh stations. In contrast, no significant trends were detected at the Djbel Chouachi station.

Similar to the monthly time series, increasing trends were also detected on a seasonal scale. The Autumn season (September, October, November) indicated an increasing rainfall trend for Khemis (2.43 mm/month at p = 0.05), Beni Bahdel (1.97 mm/month at p = 0.05), Chouly (2.06 mm/month at p = 0.05), Ouled Mimoun (2.56 mm/month at p = 0.05), Sidi Benkhala (2.25 mm/month at p = 0.05), Hennaya (2.68 mm/month at p = 0.01), and Merbeh (2.76 mm/month at p = 0.01). However, as an exception, Sebdou has no significant trend. For the other seasons, spring (March, April, and May), summer (June, July, and August) and winter (December, January, and February), no statistically significant trend was revealed. Figure 5 presents the spatial distribution of trend results of rainfall for the Mann–Kendall test. We validated the results that show an increasing trend of the Mann–Kendall test with Sen's method, which confirmed near-zero or positive slopes that display an increasing trend almost for all the stations for the months (August, September, and October) and the autumn season. The rainfall trend seems to be rising at the end of the time series, as depicted in Figure 6.

The occurrence toward showing a positive trend of rainfall in autumn can be explained by the positive anomalies in the rainfall amount that was experienced in areas of North Africa [70–73]. This increase is due to the influence of a negative trend of the North Atlantic Oscillation (NAO) index. This negative phase is related to storm tracks represented in the pressure associated with the lower Azores height compared to the normal value and, at the same time, the Icelandic Low is formed. Contributing to the creation of a depression traffic mode, corresponds to drawing further south and, thus, affects the Mediterranean regions of the south shore, which gets wetter [74]. This is described by an increase in the amount of rainfall. This corresponds with temperature extremes, which are found to be strongly connected to the NAO index, where the negative period of this index is associated with higher temperature extremes [72,75], and that, in general, affect West Africa in the Mediterranean region. The NAO index is found to be stronger, which affects the Southwestern Mediterranean region than the El Nino Southern Oscillation ENSO index that was found to be more significant toward the eastern parts of the Mediterranean. This is to be expected considering the relative proximity of the areas in which these two modes of variability act [72].

Table 10. Results of the Mann-Kendall test and Sen's method on monthly, annual, and seasonal rainfall.

Test	Time Series	Sebdou	Khemis	Beni Bahdel	Djbel Chouachi	Hennaya	Chouly	Merbeh	Ouled Mimoun	Sidi Benkhala
Test Z	January	0.39	0.37	0.71	−0.26	1.27	0.99	0.84	0.34	0.81
	February	0.00	0.06	−0.91	0.96	−1.05	0.02	0.26	−0.03	0.50
	March	−0.70	−0.29	−0.29	0.22	−0.56	−0.15	−0.88	−0.22	−0.85
	April	0.88	1.27	0.90	−0.56	0.67	1.10	1.63	1.46	1.08
	May	−0.50	0.96	−0.05	1.32	−0.48	0.23	0.82	−0.19	−0.28
	June	−0.03	0.29	0.74	0.00	0.48	0.03	0.06	−1.00	−0.21
	July	0.14	0.81	1.02	/	0.79	0.31	0.57	0.26	0.43
	August	1.71 +	0.53	0.36	/	−1.20	1.55	2.29 *	1.52	1.58
	September	2.56 *	2.93 **	2.19 *	/	1.36	1.63	2.08 *	1.83 +	1.94 +
	October	2.17 *	2.59 **	1.92 +	/	2.53 *	1.77 +	3.04 **	2.47 *	2.73 **
	November	−0.64	0.11	0.19	/	1.27	0.08	1.24	0.98	0.67
	December	−1.53	−0.48	−0.70	/	−0.67	−0.88	−0.91	−1.19	−0.98
	ANNUAL	−0.20	1.35	0.42	/	0.26	0.39	1.26	1.04	0.54
	Spring	−0.60	0.85	−0.09	/	−0.67	0.26	0.43	0.02	−0.54
	Summer	0.60	0.30	0.53	/	0.03	−0.03	0.48	−0.06	0.25
	Autumn	0.85	2.43*	1.97*	/	2.68 **	2.06 *	2.76 **	2.56 *	2.25 *
	Winter	−0.45	−0.17	−0.26	/	−0.51	−0.26	−0.45	−0.29	0.00
Q	January	0.211	0.182	0.390	−0.060	0.513	0.622	0.420	0.162	0.440
	February	0.009	0.064	−0.527	0.654	−0.602	0.000	0.139	−0.021	0.313
	March	−0.403	−0.165	−0.162	0.108	−0.329	−0.123	−0.489	−0.103	−0.275
	April	0.267	0.646	0.522	−0.135	0.388	0.589	0.800	0.593	0.485
	May	−0.131	0.317	−0.016	0.403	−0.229	0.097	0.260	−0.031	−0.083
	June	0.000	0.000	0.018	0.000	0.009	0.000	0.000	0.000	0.000
	July	0.000	0.000	0.000	/	0.000	0.000	0.000	0.000	0.000
	August	0.200	0.000	0.000	/	−0.019	0.024	0.181	0.020	0.005
	September	0.677	0.633	0.768	/	0.389	0.416	0.653	0.496	0.466
	October	1.119	1.116	1.005	/	1.238	0.811	1.534	1.062	0.961
	November	−0.340	0.077	0.145	/	0.743	0.071	0.702	0.553	0.275
	December	−0.702	−0.194	−0.337	/	−0.363	−0.709	−0.438	−0.331	−0.460
	ANNUAL	−0.038	0.403	0.112	/	0.049	0.061	0.199	0.175	0.090
	Spring	−0.265	0.427	−0.020	/	−0.353	0.071	0.104	0.010	−0.110
	Summer	0.059	0.000	0.023	/	0.000	0.000	0.033	0.000	0.003
	Autumn	0.320	0.858	0.731	/	0.959	0.574	0.895	0.755	0.611
	Winter	−0.265	−0.118	−0.260	/	−0.233	−0.081	−0.187	−0.134	−0.001

Z: Mann–Kendall test.Q: Sen's slope estimator. + if trend at ≤ 0.1 level of significance. * if trend at ≤ 0.05 level of significance. ** if trend at ≤ 0.01 level of significance.

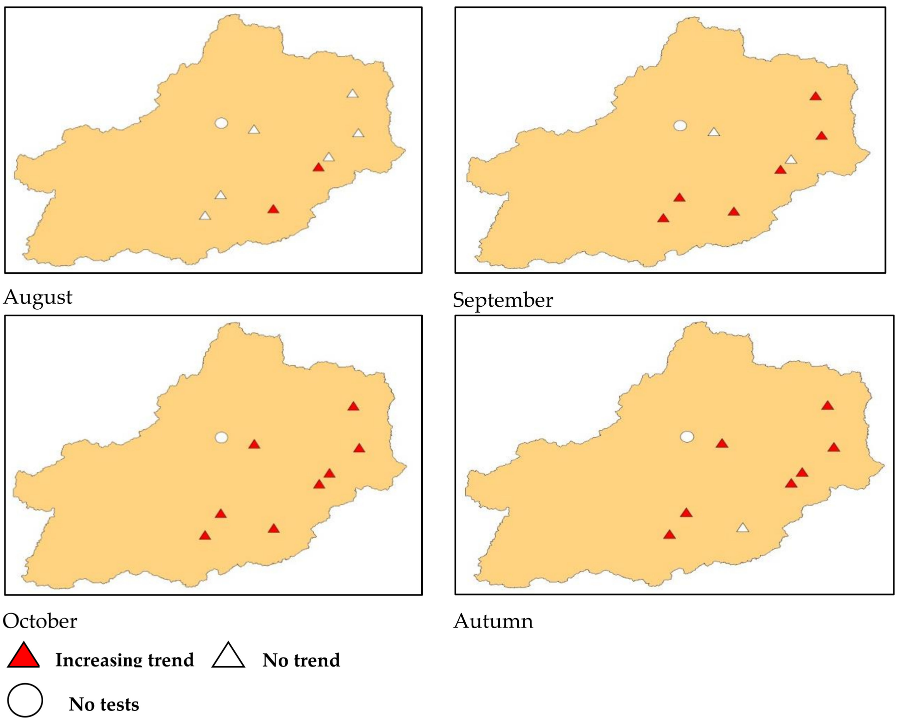

Figure 5. Spatial distribution of the Mann–Kendall test for rainfall.

The heavy floods of the Tafna catchment located in Western Algeria are generally occurring in autumn and spring. This is due to the north-westerly rainy winds loaded with moisture from the Mediterranean. Since the 1980s, the NAO index show an opposite sign indicating that the negative phase of this index is associated with the increase in the number of rainy days (the probability for wet months is around 42-52% for a negative NAO) [76], which can be understood as the result of warming over the Northern Atlantic Ocean, which draws rains, especially in the wet season in the region (October–March) [71]. The significantly negative correlations between NAO index and rain days appear only within the Western Mediterranean. This is in-line with the study of Reference [52] that reported most of the seasonal floods recorded in the upstream Sebdou sub basin occurred during the autumn and spring seasons with the largest recording of these floods in September by 22%.Records from the Isser sub basin reveal that more than 55% of its floods in the autumn and spring are concentrated in the two months, i.e., September and March, respectively. Topographic features consisting in steeply slopes and a discontinuous vegetal cover create an environment conducive to high floods by intense rain in the autumn for flushing the sediment accumulated on the exposed soils after a dry summer season [77].

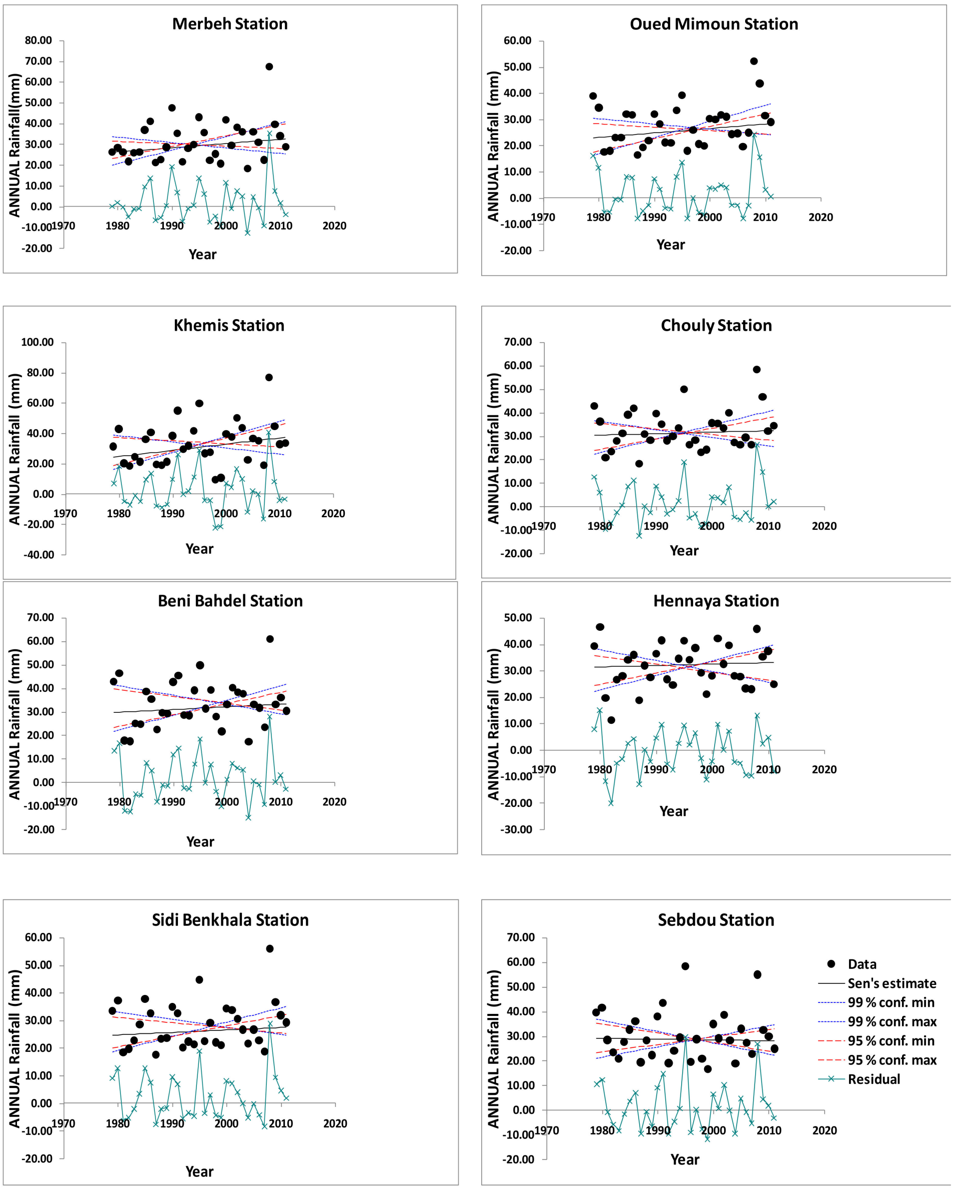

Figure 6. Annual time series and significant trend statistics of rainfall.

The previous studies on rainfall variability in Northwestern Algeria reported the drought in the forties of the last century and revealed a decrease in spring rain as a potential reason [7,78]. 1944 is characterized as a wet year and the two wettest decades follow in the 1950s and 1960s [11]. The drought decade in the 1970s was detected by References [7,11,47] in the Tafna basin. This decreasing trend is also evident in the Mediterranean region of Northern Morocco [11,13] and can be explained by a change in atmospheric circulation [11,79]. The situation is changing with having a wet year in 1975. This is followed by a dry year in1976 [47], and, then, the occurrence of the two driest decades in the 1980s and 1990s [7,11,80]. Especially in the 1980s, a dry level is due to a decrease in the winter rainfall [7,78] and the fluctuation to the wet years after the break date in 2007, which is driven by an increase of a rainfall trend in the autumn. This generates runoff leading to heavy floods, which can be qualified as moderate to high compared with the results found in the major rivers of Europe and Africa [52]. This is confirmed by our study results with the Mann–Kendall test and Sen's method, which indicated a significant increasing trend for rainfall in September and October (representing the autumn season). In contrast, the Merbeh station, located ata high altitude (1100 m), showed a significant increasing trend of monthly rainfall in August, September, and October and featured an upward trend in the total mean of rainfall, which is in-line with the Friedman test indicating a difference of mean in monthly rainfall. Flood events are accompanied by erosion and suspended loads, which leads to sedimentation in riverbeds and siltation in reservoirs and, in turn, cause serious problems by affecting the manageable storage as well as service life of dams. Thus, we should consider re-thinking of flood management structures as well as strengthening options to adapt to drought periods and water conservation practices in the basin. In order to provide sound information for designing and operating these structures, monitoring networks need to be improved.

The Mann-Kendall test did not show any significant trend for the Djbel Chouachi station in the time series of annual, monthly, and seasonal rainfall data and these results do not interpret any specific regional behavior.

In general, the majority of the change point detection tests showed that the Djbel Chouachi station has a significant change while the trend test showed no statistical significant trend. This is likely due to the low location of the station (110 m), where the results of the study of Bakreti et al. [50] showed a relationship between the altitude and the rainfall amount. It was explained that the spatial rainfall was affected by the altitude gradient, where the lower stations have a lower amount of rainfall in the Tafna basin. Thus, it does not show an increase or decrease in the region.

5. Conclusions

The presented study is based on rainfall data collected from six sub basins of the Tafna basin and covers the time period between 1979 and 2011. We have analyzed annual, seasonal, and monthly variability in rainfall.

The Lee and Heghinian test detected two significant break dates for an annual time scale in rainfall, i.e., in 1980 for Sebdou, BeniBahdel, and Hennaya stations and the rest of the stations in 2007. For the single station Djbel Chouachi, a break date was revealed in 1999 with Pettitt and Buishand tests, whereas the trend test showed no significant trend at the same station, which can be explained by the multi breakpoint at the rainfall time series not indicating any increase or decrease of a rainfall trend. The stationarity test Jonckheere-Terpstra confirmed the results of no trend at the DjbelChouachi Station. According to the Hubert test, the break date for Djbel Chouachi, Ouled Mimoun, and Sidi Benkhala station was in 2007. It was likely that the break point in 1999 appeared only in the Djbel Chouachi station due to the unsuitable quality of data, where the station location in an isolated area made the observation of the data and reliability of the measurement difficult. This caused difficulty in providing an explanation for any specific behavior. While the appearance of the break point in 2007 at nearly all stations indicated a difference of the data distribution in rainfall time series (before and after the break point date) where the rainfall trend seems to be rising at the end of 2000s because of the increase of rainfall in the autumn season, which has been confirmed with the trend analysis. These are similar results to the study of Nouaceur and Mursrescu [74], which showed that the regional analysis of rainfall indicate the last years of 2000s, which are distinguished by rainy years [81,82] recorded with a percentage of 55.72% from 2007–2013 in Algeria, while the rainy years recorded with a percentage of 85.71% from 2008 to 2010 in Morocco. This hypothesis was supported by the teleconnections with positive signs between the North Atlantic Oscillation (NAO), as it is the climate model dominant in the North Atlantic region and EL Nino Southern Oscillation (ENSO) with a low impact of the ENSO index in this region [83,84].

The monthly time series featured irregular results regarding the break point in the time series. These appear in terms of incompatibility of the results for each month with various tests (Pettitt, Hubert and Buishand, Lee and Heghinian) or results of one test with different months. There are exceptional cases of some stations indicating the heterogeneity of the dataset. The summer months (June, July, and August) have not affirmed the exception or the rejection results of the hypothesis for both the Buishand and Lee and Heghinian test, which is plausible due to the similar approach of the two tests and due to the minimal amount of rainfall close to zero in this period (extreme values). Hence, it can be concluded that there is no distribution of the rainfall time series for lack of the values, which express the variability and fit the assumption of the tests.

Homogeneity, trend, and stationarity tests are an important basis for the quality and reliability testing of meteorological data and it should be noted that the data should represent a long-term series (at least more than 30 years) for detecting climate change. In addition, other factors such as the method for collection of data and reliability of the measurement should be considered as an important aspect in climate change studies. The analysis of trends based on statistical tests may be limited mainly because of data gaps, insufficient length of time series, inadequate quality of data, and other causes introducing uncertainty into the estimations. Liuzzo et al. presented the Bayesian procedure for estimating trends and uncertainty sources and, thereby, demonstrated the ability to provide a broader analysis of trends at the regional scale and is recommended for consideration in the follow up studies [85].

This study is useful for conceiving complementary studies required to determinate and understand the relationship between climate variability and availability of the water resources of the Tafna basin.

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