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ORIGINAL PAPER

Detecting hydro-climatic change using spatiotemporal analysis of rainfall time series in Western Algeria

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Abstract The knowledge of the climatic behavior especially that one of semi-arid regions is required to optimize the management of water resources. Here climate variability is directly related to water resources that are of a high socio-economic and environmental significance. This work deals mainly with a statistical analysis of the precipitation regime to assess its spatial distribution and temporal variation in north-western Algeria. For this, a time series and a principal component analysis are performed on rainfall series representing annual precipitations of twenty-one meteorological stations for the period 1914 to 2004, the most complete and longest of West Algeria, in order to detect patterns and trends in the region. A spectral analysis of the time series revealed the existence of a period of roughly 30 years for all stations. Furthermore, the trend of a wide part of the obtained spectra suggests the existence of another period longer than the samples size.

Keywords Rainfall series · Statistics · Cartography · Spectra analysis · West Algeria

1 Introduction

To optimize the hydraulic constructions, one needs necessary to know the climatic behavior of the concerned region the role of which is very important in the water resources management in short, medium and long term. Currently, one of the main preoccupations of

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the researchers is to answer the following question: Is there climate change in the region? And on which basis can one confirm this?

Answering this question requires the verification of the temporal homogeneity of the hydro-meteorological time series, particularly stating whether the series of total annual rainfall presents trends. Long series are required to obtain indication on the presence of climate change.

Numerous studies have been carried out to analyze the precipitation variability throughout the world in general and more especially in Mediterranean basin and in African region. Linear trends for the 1901–2005 period show high spatial variability. Generally, positive trends in annual precipitation were observed over North and South America, the Eurasian continent and Australia. On the other hand, significant decreases in annual totals were observed in western Africa, Sahel, western coast of South America and Mediterranean basin (IPCC 2007).

In the Sahelian zone, several studies indicated decreasing trends in rainfall series during the two decades (1970–1990) (Demarrée 1990; Hubert and Carbonnel 1987; Hubert et al. 1989; Laraque et al. 1997). The drought affects also countries around the Gulf of Guinea in the late sixties (Paturel et al. (1997). Lebel and Abdou (2009) attempted to characterize the Sahelian rainfall regime of the two last decades (1990–2007) by comparison to the rainfall regime of the previous decades, namely the 20-year wet period (1950–1969) and the 20-year dry period (1970–1989). While the rainfall deficit remained unabated in the western Sahel, the central Sahel progressively recorded wetter years from the end of the 1990s, but this recovery was limited (1990–2007 average larger by 10 % than the 1970–1989 average, but still lower than the 1950–1989 average). There are also significant differences between the western Sahel and the Central Sahel when looking at the inter-annual variability pattern and at the seasonal cycle.

In Mediterranean areas, some decreases in annual precipitation have been detected by several researchers. Buffoni et al. (1999) investigated series of annual and seasonal precipitation from 32 stations for the period 1833–1996. They observed some decreasing trends in the annual series, which were statistically significant, only in central southern Italy. On the seasonal basis, a decreasing trend was significant only for spring in the central south and for autumn in the North of Italy. Caloiero et al. (2011) performed a statistical analysis of annual and seasonal precipitation over 109 rainfall series with more than 50 years of data observed in southern Italy (Calabria). The employed rainfall data were first processed using a pre-whitening technique in order to reduce the autocorrelation of rainfall series. This study showed a decreasing trend for annual and winter-autumn and an increasing trend for summer precipitation. Moreover, high percentages of rainfall series show breaks during the decade 1960–1970.

However, some analyses, which were carried out for parts of the Mediterranean region, indicate that the prevailing evolution is a nonsignificant decrease of precipitation or a lack of linear trend whether during the whole last century or a shorter period (Lana and Burguenõ 2000a; Dechemi et al. 2000; Douguédroit et Norrant 2003).

A study of changes in data series of climatic variables at annual and monthly scales in the western part of the French Mediterranean area showed that annual precipitation did not evidence any trend Chaouche et al. (2010). However, monthly rainfall has been found to decrease in June and increase in November throughout the area. Changes in precipitation for the Balearic Islands (Spain) have been analyzed by Homar et al. (2010). They used daily time series during the period 1951–2006. The results showed a negative tendency for annual precipitation. An abrupt decrease in mean yearly precipitation of 65 mm has been detected in the time series around 1980.

At the regional scale of the southern Mediterranean, this work is devoted to the spatiotemporal study of precipitations using a variety of statistical methods, in order to detect trends, to locate different break dates, and to identify spatial patterns of rainfall variability. For this purpose, series representing annual total rainfall of about twenty stations of western Algeria, for a period of 91 years (1914–2004), are analyzed. We will first analyze the data using the Spearman test for trend detection, and then the Mann–Kendall and Pettitt tests for the detection and the location of trends. To determine whether these variations are random or present a cyclic character, we will apply a spectral analysis. A regionalization using a principal component analysis will be performed to identify regions of coherent precipitation variability.

2 Area of study and precipitation data

The considered region extends between the meridians 2° West and 4° East, and between the North 34°15′ and 35°30′. It covers an area of 63,785 km^2, including the catchments of Chéliff (01), Oraneese coast (4), Macta (11) and Tafna (16) (the numbers in brackets "()" indicate catchment codes). The area is limited to the North by the Mediterranean Sea, in the West by the Algerian-Moroccan border, in the South by high plains, and in the East by the prolongation of the mountainous massif of Ouarsenis (Fig. 1).

The climate of north-western Algeria is influenced by various factors such as topography and atmospheric circulation. During the rainy season (December–February), the winds are W-NW. To reach north-western Algeria, these winds have to cross the very narrow arm of the Sea separating the study area of Spain. And before leaving Spain, they unload parts of their moisture on the high summits of the Sierra Nevada. The air masses do not have time enough to accumulate enough water vapor and reach north-western Algeria

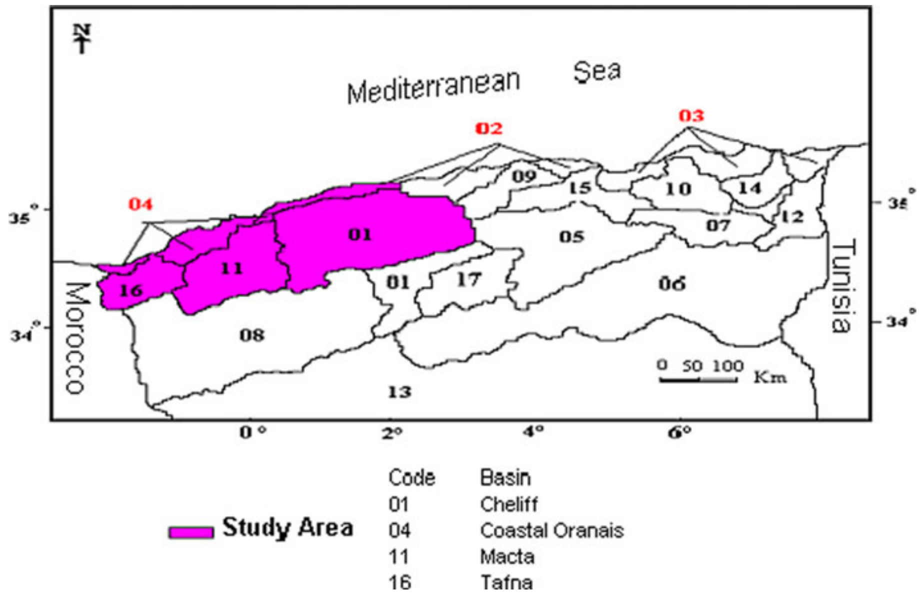


Fig. 1 The study area (ANRH, 1974) (01, 04, 11 and 16 are codes of the catchments of the study area)

relatively dry. Eastern winds charged with water during their long course over the Mediterranean Sea favor the occurrence of heavy precipitation, but they are scarce in winter.

The area is characterized by strong heterogeneity. The West Tellian Atlas has a very fragmented relief. The high west plains are arid steppes.

North-western Algeria is sheltered by the dorsal of the Middle Atlas Rif of Morocco. It has a complex topography with a parceled out mountainous character. This increases the zones of shelter and exposure toward Sea influences and the disturbed flux. Fig. 2 shows the location and geographical features of this region. All mentioned factors contribute to the reduction in precipitation and consequently to the reduction of the surface and subsurface water resources of the study area.

The climate of the north-western Algeria is also influenced by the atmospheric circulation which is characterized by cells with latitudinal extensions. Among these cells we can cite:

- The Azores anticyclone, a zone with a permanent high pressure which extends to the central Atlantic in the area of the Azores islands. Its extension to the Maghreb zone deviates the meteorological disturbances toward Europe.
- The Saharan anticyclone: it is much more stable than the previous one, in the general circulation point of view.

Irregularity is the essential character of precipitation: the spatial and temporal irregularity from one region to another, and especially an inter-annual irregularity. Outside of the summer period frequently no rain falls during more than a month. Some years may have heavy precipitation, provoking catastrophic floods. Most of the region has precipitation totals between 200 and 800 mm. The south-western area is the driest one with annual rates below 100 mm. Another relevant aspect of the region is the low number of rainy days (between 14 and 21 %).

The rainfall data used in this study are provided by the National Agency of Hydraulic Resources (ANRH). The original database comprises daily precipitation records from 220 stations distributed throughout the area, covering different time periods and with more than

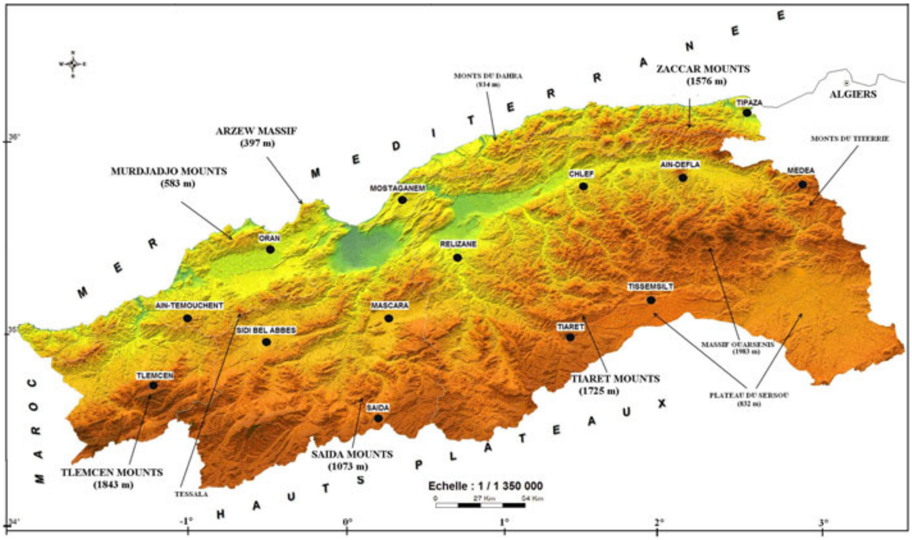


Fig. 2 Elevation map of Western Algeria with the principal mountains (Medjerab 2005)

20 years of observations. The analysis of the variability of precipitations requires long high-quality data series. Moreover, a common period for all stations must be chosen in order to analyze the spatial distribution. For this reason, we had to balance between the length of the periods and the number of included stations. It should be also noted that precipitation analyses are sensitive to the number of missing data, and therefore, only series with <10 % of missing values were selected.

A quality control was performed on the selected data series, which had two main stages. The first stage identified possible errors and suspicious precipitation records. In the second stage, data series were subjected to a homogeneity test. The aim of data homogenization is to adjust observations, if necessary, so that the temporal variations in the adjusted data are caused only by climate processes. The most common causes of a lack of homogeneity in climate data are changes in the location of the stations, alterations in screen designs, or environmental changes around the station. The cumulative residuals were tested in order to detect such anomalies in the series. The test allows for a qualitative evaluation at a given significance level of the homogeneity of rainfall series with regard to proven homogeneous series, by comparing the cumulative residuals of a linear regression to an elliptic confidence interval ('ellipse de Bois'). Detailed descriptions of this test can be found in Bois (1986).

Only series that did not present heterogeneities were accepted. Finally, 21 annual precipitation time series passed the quality control described above, which were also acceptably distributed throughout the study area, covering the period 1914–2004 and presenting <10 % of missing values (Table 1, Fig. 3).

The missing values were interpolated by linear regression based on a series from adjacent stations. Linear regression equations were established separately with complete series of 1 or 4 adjacent stations as independent variables and incomplete series as the dependent variable. The relative error in evaluating the interpolation was obtained by averaging 5 relative errors calculated from 5 observed and predicted values near missing data. The linear regression equation with the least relative error was the chosen equation for predicting missing data. We checked that the maximum relative error did not exceed 15 %.

3 Methodology

A number of parametric and nonparametric tests have been applied for trend detection. Parametric trend tests are more powerful than nonparametric ones, but they require data to be independent and normally distributed. On the other hand, nonparametric tests require only that the data are independent and can tolerate outliers in the data.

We decided to use, for detecting trends in rainfall time series, the nonparametric tests that allow us to get rid of constraints by other methods. The widely used nonparametric tests for detecting trends in time series are the Mann–Kendall test (Mann 1945; Kendall 1975) and the Spearman's test. Their efficiency and power were already demonstrated for similar applications (Lubes-Niel et al. 1998; Sheng et al. 2002).

Moreover, the Mann–Kendall test applied in a sequential version lends itself particularly well to locate the time from which the trend appears. To reinforce the results of these two tests, we performed another nonparametric test, Pettitt test, which also has the particularity to locate the break point in the serial mean at a significance level that represents the real magnitude of the detected trend.

To identify periodicities in the rainfall time series, a spectral analysis is performed (Kottegoda et al. 2004). A principal components analysis is then performed to deduce a spatiotemporal regionalization of the rainfall variability.

Table 1 Meteorological stations used

		Geographical coordinates in Lambert system (km)		Characteristics		
	Station	*X*	*Y*	Elevation (m)	Mean annual precipitation (mm)	Variation coefficient (SD/Mean) (%)
01	Ain Ouessara	518.05	239.03	690	220.2	35.87
02	Khemisti	434.15	263.03	928	395.3	41.09
03	Derrag	472.00	289.85	1160	531.4	37.45
04	Bordj El Emir AEK	461.09	385.03	1081	467.8	33.18
05	Tiaret	373.40	232.80	1100	512.2	31.96
06	Zemoura	324.15	270.70	320	389.4	34.11
07	Ghriba	423.08	334.25	229	501.9	29.90
08	Zoubiria	513.05	312.08	940	492.8	29.19
09	Tenes	376.85	350.00	5	496.4	31.01
10	Meurad	473.08	349.09	315	660.9	30.04
11	Mostaganem	264.08	296.25	80	380.8	26.58
12	Oran	196.36	271.03	82	403.2	27.91
13	Tamzourah	195.45	299.09	189	398.4	33.14
14	Hammam Bouhadjar	167.02	237.45	153	410.0	34.37
15	Cheurfa	232.01	238.03	215	344.8	29.82
16	Benbadis	170.85	190.08	720	462.5	45.23
17	Saida	266.08	173.03	867	393.1	27.43
18	Matemore	273.97	228.85	590	441.0	42.05
19	Sfisef	233.75	218.08	525	450.6	35.55
20	Sidi ali Ben Youb	186.55	192.02	635	428.0	40.12
21	Beni Bahdel	115.02	165.05	880	475.5	27.22

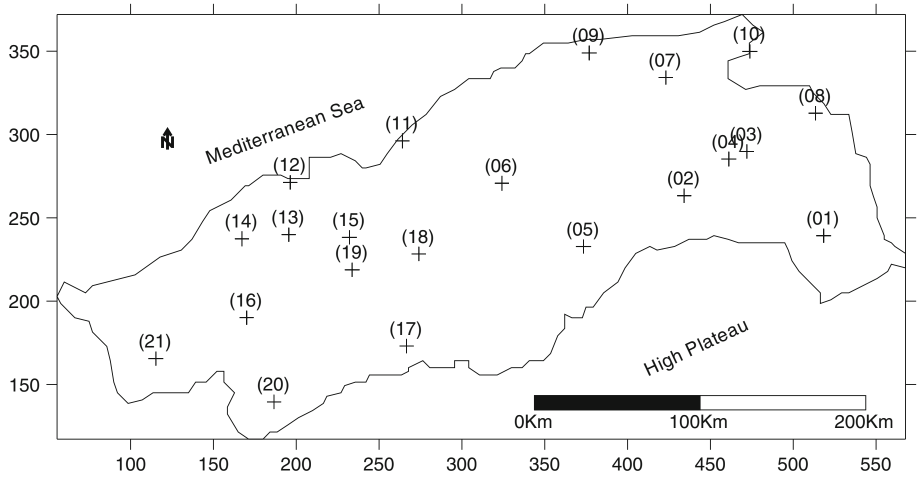


Fig. 3 Station positions in the study area (number in brackets corresponds to stations in Table 1)

3.1 Spearman's test

The spearman's test is a rank-based nonparametric statistical test that can be used to detect monotonic trends in a time series (Lehmann 1975; Sneyers 1975). Spearman's test has been used in hydro-meteorological trend analysis by Pilon et al. (1985), McLeod et al. (1991) and Hipel and McLeod (1994).

For a given sample of data (X_i, $I = 1, 2, \ldots, N$), the null hypothesis H_0 states that all the X_i are independent and identically distributed; the alternative hypothesis is that X_i increases or decreases with i, that is, a trend exists. The test statistic r_s is given by Sneyers (1975) as follows:

$$r_s = 1 - \frac{6}{N(N^2-1)}\sum_{i=1}^{N}(y_i - i)^2 \tag{1}$$

where y_i is the rank of the ith observation X_i in a sample of size N.

Under the null hypothesis, the distribution of this statistic is asymptotically normal with the mean and variance as follows:

$$E(r_s) = 0 \text{ and } \quad \operatorname{var}(r_s) = \frac{1}{N-1} \tag{2}$$

The exceedance probability α_1 is computed using the normal cumulative distribution function with zero mean and variance Var(r_s):

$$\begin{aligned} \alpha_1 &= P(|u| > |u(r_s)|) \\ u(r_s) &= r_s\sqrt{N-1} \end{aligned} \tag{3}$$

The null hypothesis is accepted or rejected at a significance level α_0 depending on whether $\alpha_1 > \alpha_0$ or $\alpha_1 < \alpha_0$. Significant values of $|r_s|$ indicate a downward or upward trend.

3.2 Mann–Kendall test

The Mann–Kendall test is also a rank-based nonparametric test which associates a number n_i to each x_i; x_i being the number of elements such as $i > j$ and $x_i > x_j$. The Mann–Kendall's statistic is

$$t = \sum_{i=1}^{N} n_i \tag{4}$$

Under the null hypothesis, the statistic is, for large sample size, normally distributed with mean and variance given by

$$E(t) = \frac{N(N-1)}{4} \tag{5}$$

and

$$\operatorname{var}(t) = \frac{N(N-1)(2N+5)}{72} \tag{6}$$

Its reduced form is then

$$U(t) = \frac{t - E(t)}{\sqrt{\operatorname{var}(t)}} \tag{7}$$

The null hypothesis is then rejected for large values of the reduced statistic. Positive values of $U(t)$ indicate increasing trends while negative $U(t)$ show decreasing trends. When testing either increasing or decreasing monotonic trends at α significance level, the null hypothesis was rejected for an absolute value of $U(t)$ greater than $U_{1-\alpha/2}$, $U_{1-\alpha/2}$ is the critical value obtained from the standard normal cumulative distribution tables. In this research, a significance level of 0.05 was applied.

The sequential version of the test (on a forward and a backward sense) enables to identify the start of a trend within the data series.

Note that $U(t)$ is the forward sequence; the backward sequence $U'(t)$ is calculated with the same function but with the reverse data series.

In the absence of any trend, the graphical representations of the $U(t)$ and $U'(t)$ curves overlap several times. When the null hypothesis is rejected (i.e., when any of the points in $U(t)$ exceeds the confidence interval ± 1.96), an increasing or decreasing trend is indicated. The test statistic used in the present study enables the detection of the approximate time of trend occurrence by locating the intersection of the $U(t)$ and $U'(t)$ curves. An intersection point within the confidence interval indicates a change point. The parts of the curves that exceed the confidence lines represent the time domain of an abrupt change. Detailed descriptions of this nonparametric test can be found in Sneyers (1975).

3.3 Pettitt test

The Pettitt test is a nonparametric test derived from the Mann–Whitney test (Pettitt 1979). The absence of break constitutes the null hypothesis. Pettitt defines the variable $U_{t,N}$

$$U_{t,N} = \sum_{i=1}^{t} \sum_{j=i+1}^{N} \mathrm{Sgn}(Z) \tag{8}$$

$$Z = X_i - X_j \tag{9}$$

$\mathrm{Sgn}(Z) = 1$ if $Z > 0$, 0 if $Z = 0$ and -1 if $Z < 0$.

He suggested to test the null hypothesis by using the statistic K_N defined by the maximum absolute value of $U_{t,N}$ for $t = 1,\ldots, N-1$. From rank theory, Pettitt demonstrates that if k indicates a value of the K_N series, under the null hypothesis, the exceedance probability of the k value is given by:

$$\text{Prob } (K_N > k \approx 2\exp\left(-6k^2/\left(N^3 + N^2\right)\right) \tag{10}$$

for a type I error α, if the exceedance probability estimated is less than α, the null hypothesis is rejected. The time series demonstrate a trend at the time t where the K_N appears.

3.4 Principal component analysis

Principal components analysis (PCA) is a classical factorial method. PCA transforms a number of (possibly) correlated variables (here the 21 stations of annual precipitations) into a (smaller) number of uncorrelated synthetic variables called *principal components* (*PC*). A temporal chronicle (factorial score) is associated with each principal component. PCA ensures the detection of coherent and recurring modes in the total domain. Rotation methods allow us improving the interpretability of the results through a linear transformation of the PC. Compared to the nonrotated solution, orthogonal rotations (preserving noncorrelation between the PC) are less affected by the domain form, the subdomanial instability (the fact that PCA is carried out on only a part of the field leads to results different from those of the PCA of the whole field) and the sampling errors between the PCs. The rotation used in this work is the varimax rotation. It is the most commonly used rotation (Richman 1986). Its goal is to maximize the variance of the factorial weights between each component for a given variable, increasing the segregation between the various principal components.

3.5 Spectral analysis

The spectral density captures the frequency content of a stochastic process and helps to identify periodicities.

The spectral density function corresponds to a change from a time mode to a frequency mode through a Fourier transformation of the auto-correlation function. The interpretation of the spectral density function, $S(f)$, through the identification of the different peaks representing periodical phenomena, leads to the characterization of the system:

$$S(f) = 2\left[1 + 2\sum_{k=1}^{m} D(k) r(k)\cos(2\pi fk)\right], \tag{11}$$

$$D(k) = \frac{\left(1 + \cos\pi\frac{k}{m}\right)}{2} \tag{12}$$

where $f = j/2m$; $j = 1$ to m, f is the frequency and $D(k)$ ensures that the estimated values $S(f)$ are not biased (Tukey filter). $r(k)$ is the auto-correlation function expressed by

$$r(k) = \frac{C(k)}{C(0)} \tag{13}$$

$$C(k) = \frac{1}{n}\sum_{t=1}^{n-k}\left(x_t - \overline{X}\right)\left(x_{t+k} - \overline{X}\right) \tag{14}$$

where k is the time lag ($k = 1,\ldots, m$), n is the length of the time series, x is a single event, $\overline{X}$ is the mean of the events and m is the cutting point. The cutting point is usually determined based on the interval of the analysis and the given circumstances.

4 Results and discussions

4.1 Temporal analysis

The tests of Spearman and Mann–Kendall were applied to the data series of annual rainfalls of the 21 selected stations and detected a significant decreasing trend at a significance level of 5 % for 15 stations (Fig. 4). Four series did not show any significant trend. Only the Ghriba station, in the eastern zone of the studied domain, presents a significant increasing trend at 5 % significance level. This station is hind of isolated in the region. Thus, this result does not indicate any specific regional behavior. Also measurement problems might be responsible for the positive trend.

The gradual application of Mann–Kendall's test on the forward and backward sense for the series which have no trends, namely those of Khemisti, Derrag, Zoubiria and

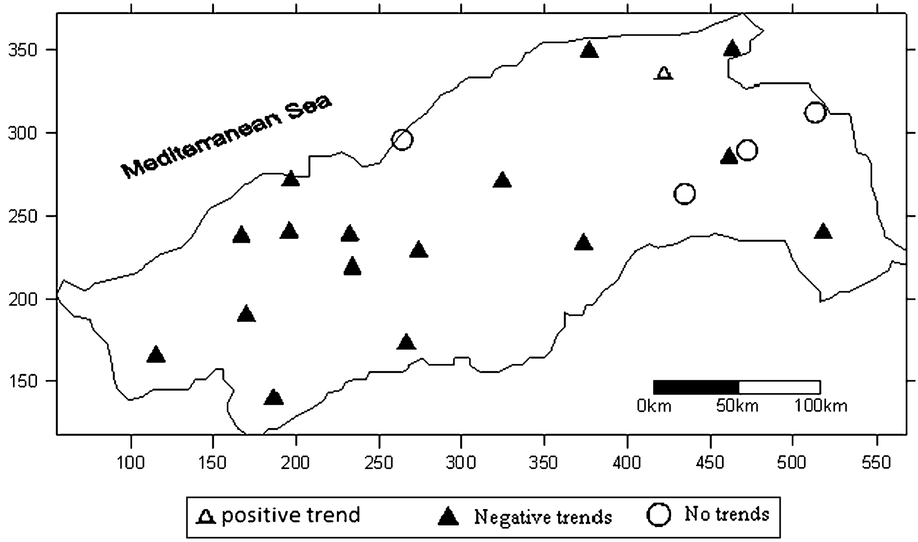


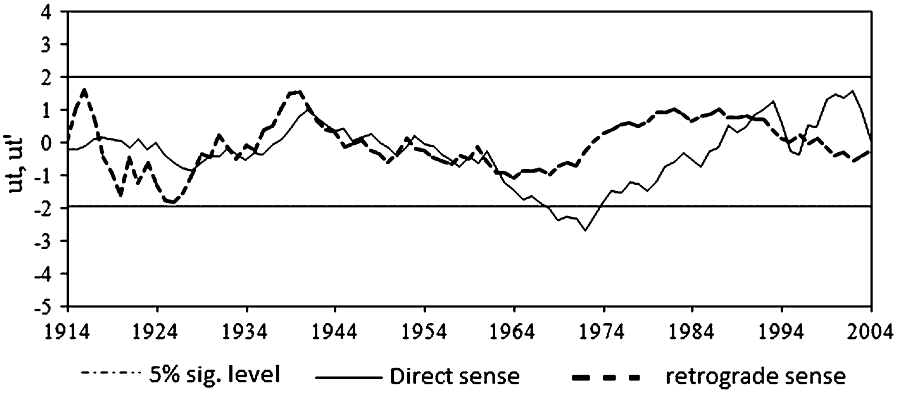
Fig. 4 Trends in annual total precipitation during 1914–2004 detected by the Mann–Kendall method

Mostaganem stations, indicates a steady trend. The curves overlap (e.g. Fig. 5a for Zoubiria station), and the statistical values do not overpass the limits of the critical significance levels, except for the series of Derrag which presents significant variations of the statistic indicating the presence of dry periods. The test revealed that the other series present important positive or negative variations indicating the alternating presence of very rainy and very dry periods. The intersection point between both curves (forward and backward) within the confidence interval indicates approximately the change point that corresponds to the break date. The graph shown in Fig. 5b shows the forward and backward results of the test for the Beni Bahdel station. The intersection of both curves indicates that a change occurred around 1981.

The analysis of the whole series using Pettitt's test allows us to confirm the results obtained previously and to locate the years of break with different significance levels. Indeed, the results show that an abrupt change (decrease of rainfall) within the time series is mainly observed from the end of the 1960s up to the beginning of the 1990s. For six stations, the beginning of the trend was detected between 1960 and 1975 so that 10 stations lead to a very significant decreasing trend between 1975 and 1996, the other ones appear to be stationary and confirm the previous results. Thus, one can deduce the existence of a rainfall deficit in the eastern zone from the beginning of the 1960s and is accentuated during the 1970s and 1980s by its extension to the whole region. Most of the significant negative trends have magnitudes of about 20–30 % (for 10 stations). The abrupt changes that occur between 1988 and 2000 were more intense and presented magnitudes exceeding 40 %.

Trends can be detected using Pettitt's and Mann–Kendall's tests. However, these tests cannot detect more than one break date. This represents the drawback of these tests while investigating rainfall time series which could have multiple increasing and decreasing trends and/or breaks, especially for long series. In addition, a limitation is due to the difficulty in interpreting the results at a regional scale, mainly when the number of used stations is not very important. These suggest that further investigation is needed; we tried then to perform a spectral density analysis to seek possible periodicities and to carry out a

(a) Zoubiria



(b) Derrag

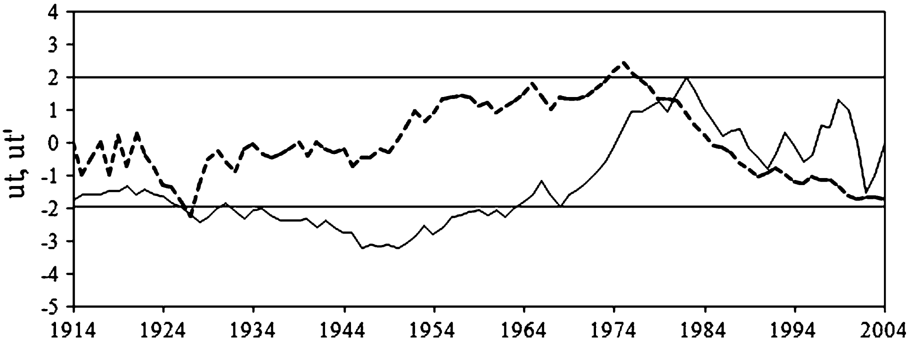


Fig. 5 Mann–Kendall progressive test applied to stations of a/Zoubiria (08) and b/Beni Bahdel (21)

principal component analysis (PCA), in order to supplement this study and to perform regionalization of rainfall variability.

4.2 Spatiotemporal rainfall variability: search for a regionalization

This part of the work is devoted to regionalize the precipitation spatiotemporal variability by a multivariate analysis, the principal component analysis (PCA) without and with rotation, and to identify regions having the same variation mode. The PCA is performed with the stations as variables and the 92 annual precipitation values. The results of PCA without and with rotation underline that the first four components account for most of the total variance (61.7 %) as shown in Table 2.

Table 2 Explained variances by the four first principal components before and after rotation (F: Factors)

	PC (without rotation)				RPC (rotated)			
	F1	F2	F3	F4	F1	F2	F3	F4
% variance	41,334	13,135	7,189	5,600	22,521	18,465	10,146	14,636
% cumulatif variance	41,334	54,470	61,659	67,258	22,521	40,986	51,132	65,768

The first component accounts for the largest part (41.33 %) of the variance; it describes the inter-annual variability of the precipitation for the whole region (opposing humid years and dry years). All stations are positively correlated with this component, with correlation coefficients varying between 0.47 and 0.82. The greatest coefficients are registered in the center of the region (Fig. 6).

This spatial consistency can be particularly explained by the large homogeneity of the weather regimes (winter rains and summer drought), but it denotes especially that a large number of years presents large deficits or excesses over the whole region. This confirms the result found by the nonparametric statistical tests of trend detection as shown in section 4.1.

The time series of the amplitudes of first component (Fig. 7) highlights particularly wet years (1928, 1952) and the succession of several particularly dry years that most stations of the region affected. Obvious is a decreasing trend with a significant determination

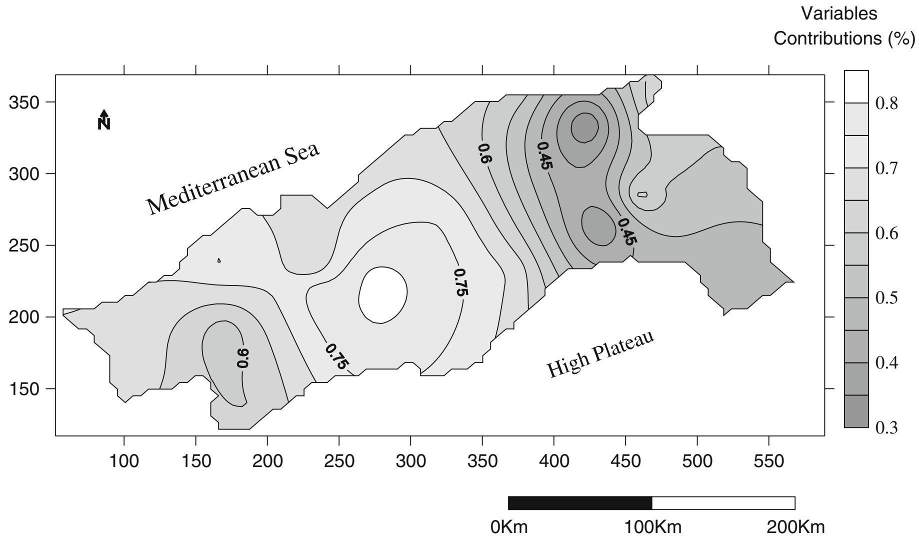


Fig. 6 Spatial distribution of the first principal component (PC1) fields in the area of study (PCA without rotation)

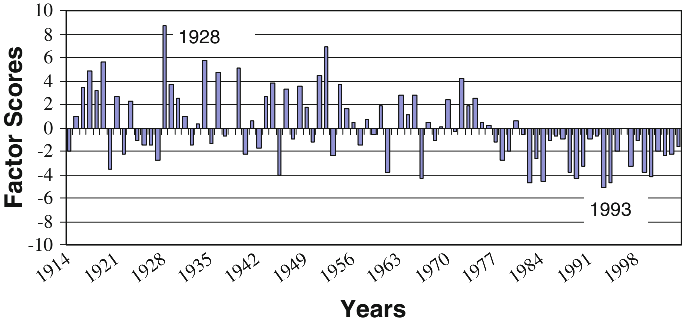


Fig. 7 Temporal factorial scores of the first component without rotation. The straight line represents the chronicle trend

coefficient of 0.218, starting from the end of years 1970 till the year 2004 (with an absolute minimum in 1993).

The following components (Fig. 8) account for smaller proportions of the variance. The second component accounts for only 13 % of the variance (Table 2); it shows opposite amplitudes between parts of the eastern region (correlated positively) (strong rainfall) and the west and southwest (area affected by the Foehn phenomenon and distant from the marine influences and the rainy fluxes and consequently with low rainfall).

The third component accounts for 7.2 % of the variance; it opposes the South West and southern parts to the North and the Center of the study area.

The first component accounts for the largest amount of the total variance; however not all of the stations are significantly correlated with this component. We performed a rotation of the factorial axes according to the varimax method that better models independent spatial structures. Varimax orthogonal rotation is the option used to avoid some of the domain shape dependence (Richman 1986) and to obtain stable and physically meaningful pattern. The principle is then to determine the components that correlate the best with the variables (Camberlin 1994; Douguedroit 1994).

We retained the first four components accounting for 65.77 % of the variance. The percentage of the explained variance by the eigenvalues is different from the one of PCA without rotation with less variance explained by the first component, and more variance explained by the other patterns.

The first component describes the western and the central part of the region (littoral plains). The stations most correlated with this component are those for which the altitude varies between 5 and 215 m. The eastern region is characterized by a weak relief and weak rainfall (annual rainfall <500 mm) with a weak explained variability (variation coefficients <0.30) (Fig. 9a).

The second component characterizes the eastern part of the study area (Dahra mounts). This is a well-watered region; it expresses the simultaneous influence of topography and atmospheric circulation on rainfall (Fig. 9b).

The third component characterizes more the variability of the western part of the study region (Fig. 9c).

The fourth component represents the Tellian plateau and the high plains in the East, characterized by weak rainfall not exceeding the 450 mm with a very irregular character due to the shelter effect reducing the influences of the rainy systems covering West and North West (Fig. 9d).

The time series associated with the first component (Fig. 10a) reflects an evolution mode identical to the one described by the component of PCA without rotation, with some differences like excesses less accentuated during the period of 1930–1950. However, the

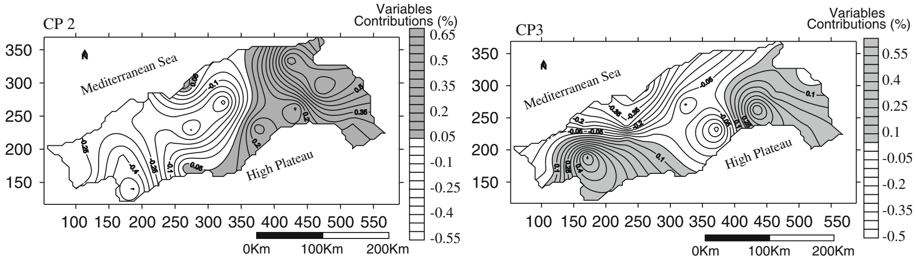


Fig. 8 Spatial distribution of PC2 and PC3 fields in the area of study (PCA without rotation)

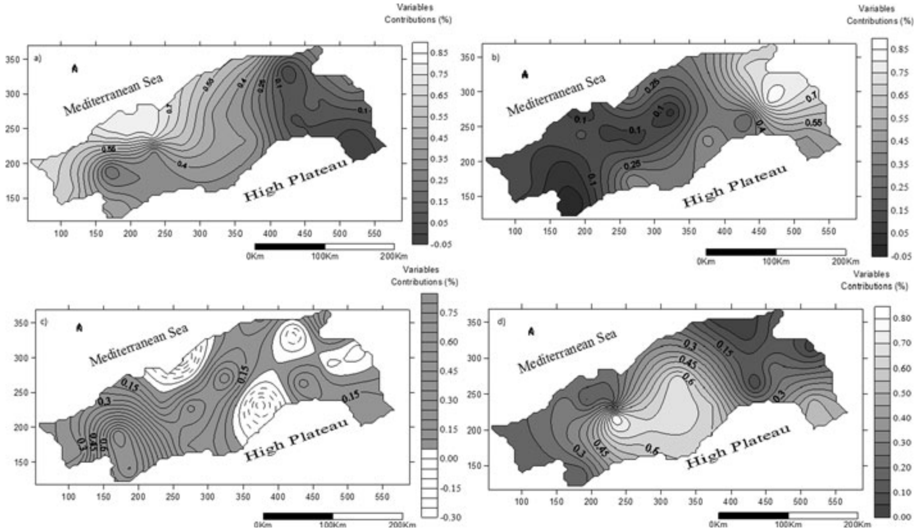


Fig. 9 Spatial distribution of **a** PC1, **b** PC2, **c** PC3 and **d** PC4 fields in the study area (PCA with Varimax rotation)

other three components also present more appreciable differences. The second component (Fig. 10b) presents some more accentuated surpluses during the years 1930 and 1950 as well as at the beginning of the years 1970 (an absolute maximum in 1939). The same dry period between 1960 and 1970 is represented in addition to years with low rainfalls (1984, 1994 and 2002). The third component (Fig. 10c) is characterized by a very humid period during the years 1960 (with an absolute maximum in 1963) followed by a period showing a deficit spreading out from the end of the 1970s years to the beginning of 2000, nevertheless less marked than for the first component. Finally, the same deficit period, as the one the third component is revealed by the fourth component (Fig. 10d).

The analysis of the chronicles revealed the existence of two dry periods found for the first component. One beginning in 1920, and the other beginning in 1978, that is to say 58 years later. The last one is longer and more severe (with more accentuated deficits).

The second component also indicates two dry periods: the former starting from 1914 and the later extending from 1958 to 1970.

The third component also reveals two periods the first starts in 1918 and the second in 1970.

There are two periods visible for the fourth component: a humid period spreading out until 1967 and a dry period beginning in 1968.

The results obtained on the basis of the temporal chronicle of the principal components analysis allow us to separate the study area in the four main zones. (1) a north band including the Cheliff and Harba plains characterized by a persistent drought that began relatively late around 1978; (2) a neighboring northeast area including a large part of Dahra and Ouarsenis massifs experienced a drought which started in 1958 and lasted until the 1970s years. This area registered a drought earlier than the other zones, but with less intensity in the later years; (3) a third lateral zone, opposite to the second, situated southwest of the domain, containing the Tlemcen mounts and the surrounding high

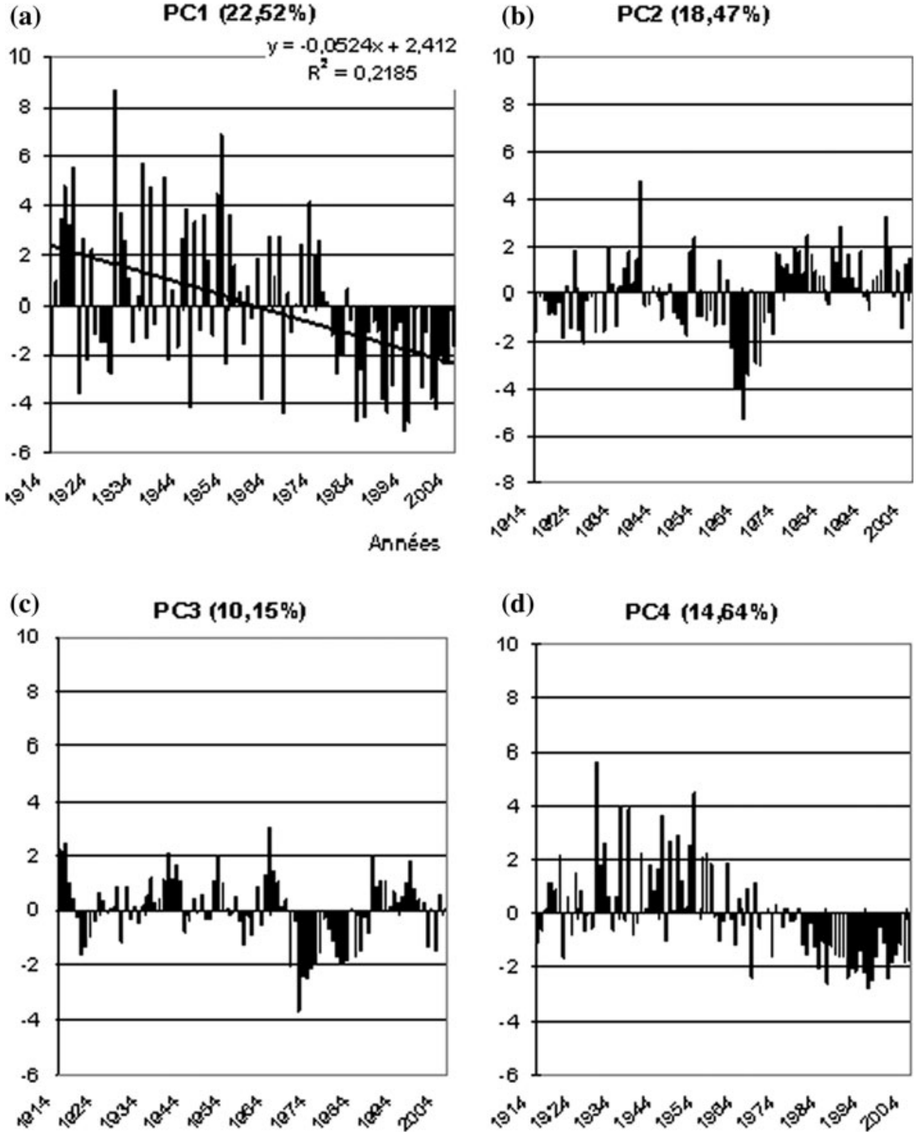


Fig. 10 Temporal factorial scores of the four principal components (with rotation)

agricultural plains, also registered a drought between 1970 and 1990; (4) a fourth zone which is a band situated in the south of domain and facing the first, experienced drought starting from 1968 and lasting until now.

It appears from the above that the lateral parts of domain are not more affected by drought. The registered drought could be considered as momentary. Thus, the central part of domain consisting of both North and South streaks experiences persistent drought. The North part of domain is the last that knew this phenomenon of drought, but it presents the most severe trend. This trend continues up today.

4.3 Spectral analysis

Annual rainfall varies significantly from year to year. The objective of this section is to investigate whether these fluctuations are random or follow a cyclical pattern. For this purpose, a spectral analysis over all the rainfall time series is performed and checked whether their characteristics are common to the whole region.

Figure 11 illustrates the spectral density function of the Sfisef station time series. It shows the existence of a period of about 30 years. The same phenomenon is observed for all stations. Furthermore, the trends revealed in all the obtained spectra let us think of the existence of another period, of low frequency, which cannot, however, be detected with small sample size.

Note that the semi-arid character of North Algeria, especially of the western zone, can be partly explained by variation in the atmospheric general circulation. Indeed, several studies link the reduction in precipitation to the Northern Atlantic Oscillation (NAO) which influences the Mediterranean climate (Xoplaki et al. 2004; Trigo et al. 2000, 2008; Combourieu Nebout et al. 2009).

The NAO phenomenon is quantitatively described by the NAO index, which is a normalized pressure difference between measurements at Azores and Iceland. The index varies from year to year, but also exhibits a tendency to remain in one phase for intervals lasting for several years (Hurrell 1995).

Interest in the NAO has been recently renewed, particularly because of two concurrent trends observed in the winter season over the last three decades: a trend toward a positive phase of NAO, and a trend toward warmer Northern Hemisphere winters (Hurrell 1995). Positive NAO winters are associated with higher than usual pressures in the subtropics and a lower pressure in the Arctic. As a result, winters are warm and dry in Southern Europe, warm and wet in northern Europe, and cold and dry in Greenland. Conversely, during negative phases of the NAO, winters are usually cold in northern Europe, moist and wet in southern Europe, and milder in Greenland.

Climatic anomalies associated with NAO have impacts on North African precipitation as it was revealed in several studies such as those of Lamb and Peppler (1991), Khaldi (2005), Meddi et al. (2010), and recently that of Brandimarte et al. (2011). Then, one can link the periodicity revealed for this part of the study area to 25 years of the positive

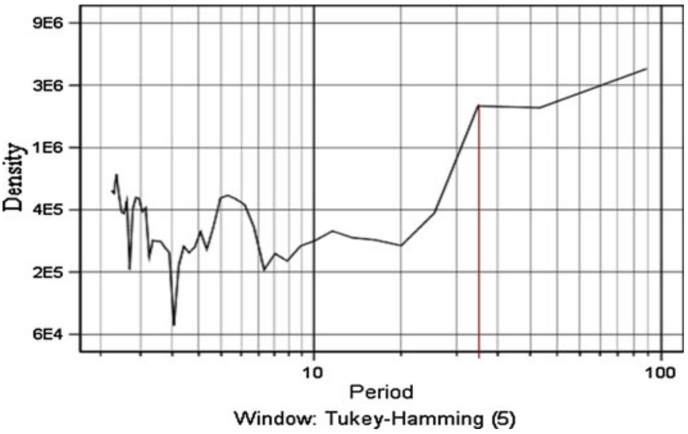


Fig. 11 Spectral density function of Sfisef (19) stations time series

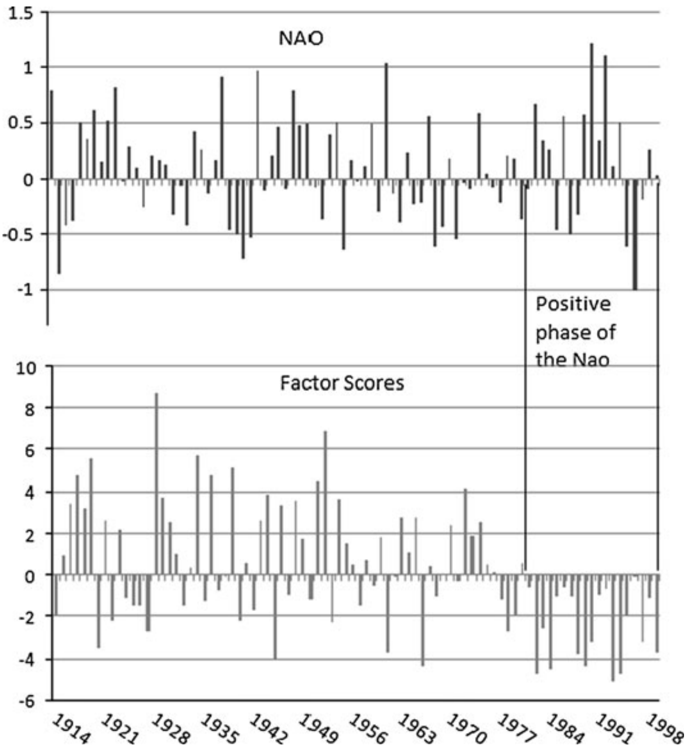


Fig. 12 Temporal evolution of the annual NAO index and the factorial scores of the first principal component

observed phase of the NAO (as it was depicted by the correlation analysis performed by Lopez et al. 2010). Thus, a study taking into account the observation period of 2005–2011 could reveal that the negative phase of NAO could have led to an increase in precipitation.

Figure 12 shows that from the middle of 1970 to 2000, the NAO annual index enters a positive phase, and the regional precipitation regime, represented by the first component, presents a decreasing trend. Furthermore, a negative significant correlation (Pearson's $r = -0.36$) was found between the first component and NAO for the period 1975–2000. This will be more apparent at a seasonal scale because the NAO phenomenon affects winters precipitation.

5 Conclusion

The use of principal component analysis allowed us to evidence four significant geographical regions with coherent precipitation variability and to show that the investigated area is under the influence of two regimes:

- A central zone that is from North toward South; this is always affected by the rainfall deficit; and
- Two lateral zones which do register no more deficits.

The relief of the investigated area being mainly of high mountainous plateau type suggests that the observed phenomena are less dependent on the intrinsic characteristics of the domain. But it would greatly depend on the meteorological variations in a more widened domain, defining thus the transit corridors of the rainy currents. It overtakes the sole effect of the proximity of mountainous chain of Morocco Atlas.

If one has to pronounce about a climate change, the central region of domain would be the more concerned.

The nonparametric statistical tests applied to series of annual rainfall reveal a decrease trend in most of the investigated stations. This is in good agreement with the results obtained in many trends analysis studies.

One of the recommendations that one can propose to describe more accurately the sequence of wet and dry sequences is the study of the rainfall time scales within the year. This will also enable to observe the possible shifting of rainy and dry months.

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