International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-5 Issue-5, June 2016

Assessment of Climatic Variability in Zahrez Basin (Algeria)

Fatah Bouteldjaoui, Mohamed Bessenasse, Ahmed Kettab

Abstract— The knowledge of the climatic behavior especially that one of semi-arid regions is required to optimize the management of water resources. 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 [1]. The water resources which are available in Algeria are limited[2-3]. They are also subjected to cyclical extremes variations i.e. succession of cycles of severe drought.

The drought observed during these last years in Algeria has also affected those located more to the south, characterized by semi-arid to arid climate. The decrease in rainfall and consequently that in runoff might penalize development projects linked with water supply. The Zahrez basin (Fig.1) is one of the endorheic basins of the vast steppes region in the central northern part of Algeria. The Zahrez hydrological basin covers approximately 8,989 km^2. The catchment lies between longitudes 2° 15' to 4° 08'E and latitudes 34° 35' to 35° 30'N. The area is characterized by a semi-arid climate, typically Mediterranean, with an irregular annual rainfall. The mean annual rainfall and potential evapotranspiration are 250 and 1380 mm, respectively, exceeding rainfall for most of the year [4]. The objective of this work is the identification and the consequences of climate variability, based on statistical analysis evolution of the annual rainfall series, over a period of 34 years (1973/1974 -2006/2007), a set of stations (09) covering the study area. This analysis consists of the study of the interannual evolution of Nicholson rainfall indices, and the implementation of statistical tests of homogeneity of the time series. These tests are Pettitt test, the Buishand test, the Hubert segmentation procedure and Bois control ellipse. The results of the interannual evolution of rainfall indices show that 67% of retained stations are characterized by the alternating of wet period (1974-1982) and dry (1983-2007). Moreover, the homogeneity statistical tests indicate a break in stationarity of the rainfall series in Charef, Benhafaf and Aïn Maabed stations.

Index Terms: Climate variability, water resources, semi-arid, statistic tests, Zahrez basin, Algeria

I. INTRODUCTION

Several large-scale climate events have led the world community to address climate change and its impacts on water resources. Among them include drought observed since the 1970s in the countries of the Maghreb and Algeria in particular. In Algeria this drought has been characterized by a significant rainfall deficit, and affected the entire territory. It was particularly rampant in the steppe regions and in particular, the Djelfa region, characterized by its semi-arid to arid climate [4]. In this region the water demand and the combined drought caused a decrease in groundwater resources, which play an important role in drinking water supply and irrigation of agricultural land. According to the hydrogeological investigations, the region includes several aquifers: the Mioplioquaternary, Turonian, and Albian Barremian [5-6]. This work concerns the identification and the consequences of climate variability in the Djelfa region, to better characterize the rainfall deficit. The results of this work are the first part of a study which is also interested in the impact of climate variability on water resources in this region. To carry out this study a literature review, was first allowed the selection of statistical methods often used in the studies of the stationarity of time series. The tests and procedures selected for this study are the Pettitt test, the Buishand test, Hubert's segmentation procedure, and Bois' control ellipse [7].

Manuscript published on 30 June 2016.
* Correspondence Author (s)
Fatah Bouteldjaoui, Ecole Nationale Polytechnique, Alger, Algérie.
Mohamed Bessenasse, Université Saad Dahlab, Blida, Algérie.
Ahmed Kettab, Ecole Nationale Polytechnique, Alger, Algérie.

II. STUDY AREA AND DATA SOURCES

The Zahrez basin (Fig. 1) is one of the endorheic basins of the vast steppes region in the central northern part of Algeria. The Zahrez hydrological basin covers approximately 8,989 km^2. The catchment lies between longitudes 2° 15' to 4° 08'E and latitudes 34° 35' to 35° 30'N. The hydrographic network is extremely hierarchical by rivers and conditioned by the the basin structure. It consists of the main wadis that run through the study area are: The main wadi of Djelfa , which provides the drainage throughout the western part of the Djelfa syncline and the entire area in the north to Rocher de sel on an extended approximately 1294 km^2. The Mahellem wadi, El Haoud wadi, Msekka Wadi, Benaam Wadi, and Oued Mellah [4-5].

The rainfall data used in this study are provided by the National Agency of Hydraulic Resources (ANRH) and the National Meteorology Office (ONM) . The original database comprises daily precipitation records from 09 stations (Table 1) distributed throughout the area, covering different time periods.

III. METHODOLOGY

Two types of statistical methods are commonly used in the literature to analyze the interannual variability trend of rainfall data time series, namely parametric and nonparametric

A. *Statistical tests used Pettitt test*

The Pettitt test is a nonparametric test derived from the Mann–Whitney test (Pettitt 1979) [8]. The absence of break constitutes the null hypothesis. The statistic associated with this test is follows:

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

$$K_t = \max|U_{t,T}|, 1 < T < N \quad (1)$$

$$U_{t,N} = \sum_{i=1}^{t}\sum_{j=i+1}^{N} D_{ij} \quad (2)$$

$$Dij = \mathrm{sgn}(X_i - X_j) \quad (3)$$

where sgn(X) = 1 if X > 0; 0 if X =0 and - 1 if X < 0, Using the theory of ranks, Pettitt gave "the significance probability associated with the value k of K_N
approximately by:

$$\Pr ob(KN > k) \approx 2.\exp(-6.k^2/(N^3 + N^2) \quad (4)$$

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.

Lee and Heghinian Bayesian method

The Lee & Heghinian Bayesian method proposes a parametric approach. It requires a normal distribution of the values of the series.

The basic model of the procedure is as follows:

$$X_i = \begin{cases} \mu+\varepsilon_i & i = 1,\dots,\tau \\ \mu+\delta+\varepsilon_i & i = \tau+1,\dots,\tau \end{cases} \quad (5)$$

where the ε_i, are independent and normally distributed, of zero mean and variance σ^2 . τ et δ represent respectively the position in time and the magnitude of a possible change of the mean.

The Buishand statistics

The adjusted partial sum (S_k), that is the cumulative deviation from $\bar{x}$ mean for k_{th} observation of a series x_1, x_2, x_3, ….x_k…. x_n with mean can be computed using following equation:

$$S_K = \sum_{i=1}^{k}\left(x_i - \bar{x}\right) \quad (6)$$

Buishand defines the variable U

$$U = \frac{\sum_{k=1}^{N-1} S_k / D_x}{N(N+1)} \quad (7)$$

with

$$D^2{}_X = \sum_{i=1}^{N}(X_i - X)^2/\mathrm{N} \quad (8)$$

where, Dx is the standard deviation values of the time series. Critical values of the statistic U were first given by Buishand (1982) from a Monte Carlo procedure [9]. Improved critical values are given in Buishand (1984) [10].

Bois control ellipse

In addition to these different methods, the construction of a control ellipse allows an analysis of the homogeneity variable, which is defined within the framework of the Buishand Statistic, follows a normal distribution of zero mean and variance k(N-k)N-1 σ^2 , k=0….., N , k=0,....., N under the null hypothesis of the homogeneity of the X_i series[11].

Under the null hypothesis H_0, it is possible to define a confidence region for containing a given confidence level, the S_k * series.

For a confidence level 1-α / 2, the confidence region is defined by:

$$\pm \frac{U_{1-\alpha/2}\sqrt{K(N-K)}}{\sqrt{(N-1)}} D_x \quad (9)$$

This confidence region is a control ellipse, when the values of S_k * out of this ellipse H_0 is rejected at a confidence level 1-α / 2 is a risk α 1st species [11-12].

Hubert's segmentation procedure

The partition of the original series in m segments is a segmentation of order m of this series. Is a segmentation of particular m order is defined ik avec k = 1, …, m rank in the initial series of the terminal end of the k_{th} segment by convention with i_0 = 0, et N_k = i-i_{k-1} is the length of the k_{th} segment with:

$$x_k = \frac{1}{N_K}\left(\sum_{i=1+i_{k-1}}^{i=i_k} x_i\right) \quad (10)$$

The standard deviation D_m between the series and the segmentation considered of order m allows to appreciate the proximity of the series and segmentation which is applied as:

$$D_m = \sum_{k=1}^{k=m} d_k \quad (11)$$

and $$d_k = \sum_{i=1+i_{k+1}}^{i=i_k}(x_i - x_k)^2 \quad (12)$$

To determine the best segmentation of hydro meteorological series, this is to minimize the gap criterion D_m [13-14].

IV. Results and Discussion

A. *Climate context*

Several parameters are used to characterize the climate of the study area and assess its degree of aridity. These parameters include, the index of Martone, using annual precipitation (P in mm), and the mean annual temperature (T ° C): I = P / (T + 10), for the bioclimatic arid zone (I <10), semi-arid (10 <I <20) and wet (I> 20) [4].

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

One obtains I = 12.93; which allows to classify the study area in the semi-arid bioclimatic zone. On the other hand, the Bagnouls-Gaussen diagram of the study area during the period (1995-2004) (Fig. 2) allows to highlight dry season with a period of 3 months (June, July, August). And a wet period of 7 months, from January to May, and from October to December. With very irregular rainfall that do not exceed 200 mm / year on average. The average temperature during the period (1995-2004) is generally between 0.65° C and 34.4° C. The results of the statistical analysis of climatic parameters measured at the meteorological station of Djelfa, are summarized in Table 2.

These results indicate that the precipitation ranges from 8.06 mm to 38.12 mm with a mean of 26.47 mm, the values of the standard deviation and coefficient of variation (CV) are 8.59 and 0.31 respectively. On the other hand, the temperature values range from 4.60 ° C to 26.56 ° C and have a mean of 14.66 ° C, the values of the standard deviation and coefficient of variation are 7.91 and 0.54 respectively. Moreover, the evaporation values range from 45.70 to 291.97 mm with a mean of 145.03 mm, the values of the standard deviation and coefficient of variation are 84.81 and 0.58 respectively.

B. Temporal variation of annual precipitation

The data of average annual precipitation recorded at nine rainfall stations are illustrated by the graphs in Fig. 3. The data of average annual precipitation recorded at nine rainfall stations are illustrated by the graphs in Figure 3. The interannual variations in precipitation show that rainfall values observed during the period (1974-2007) range from 1.17 mm to 405.91 mm in Ain mouilah to Benhafaf. In order to characterize the interannual variability of rainfall, mean, standard deviation and coefficient of variation were calculated at different stations that make up the study area. The results are summarized in Table 3.

These results indicate that the values of interannual average of the precipitation varies from 70.80 mm (Ain Mouilah) to 199 mm (Zaafrane). Also the values of the standard deviation range between 48.60 (Ain Mouilah) mm and 98.90 (Benhafaf).

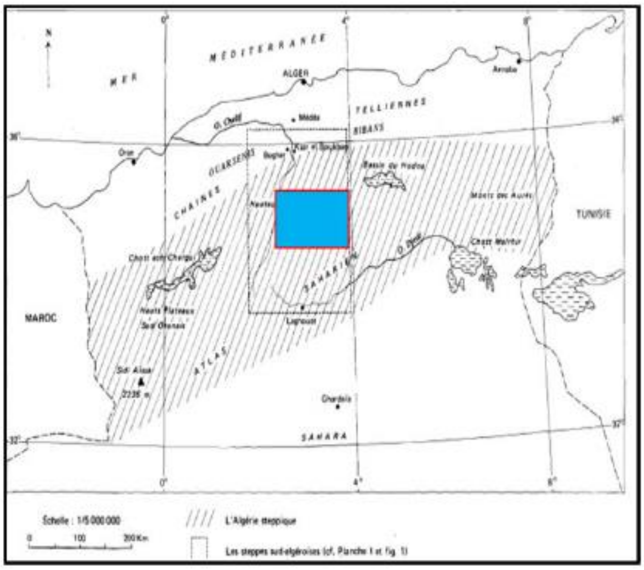


Fig.1. Location map of the study area

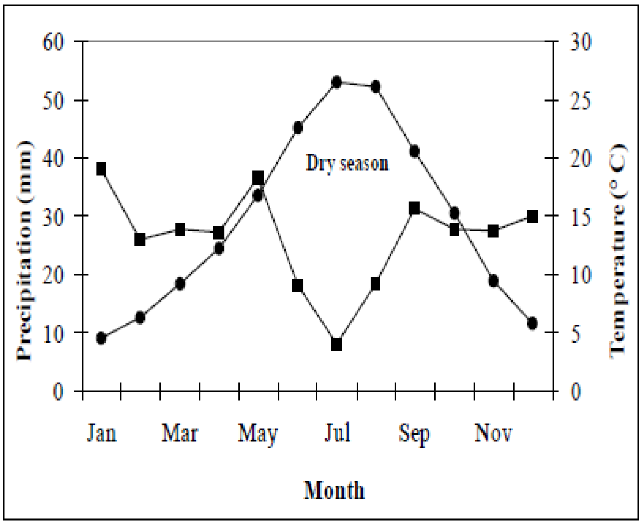


Fig.2. Ombrothermic diagram at the station of Djelfa (1974-2007)

In addition, the interannual variability of rainfall phenomenon modules is expressed by the coefficient of variation (CV), reflecting the relative dispersion of rainfall values. The values of the coefficient of variation during the period (1974-2007), are between 0.33 and 0.68, indicating a relatively high variability. It is notable that the 2007), are between 0.33 and 0.68, indicating a relatively high variability. It is notable that the variability is more important for the stations of Charef, Benhafaf, Arara , and Ain Mouilah station, with a coefficient of variation exceeds 0.5.

C. Analysis of the interannual variability of rainfall

Annual rainfall indices

Different approaches can be used to monitor interannual changes in precipitation are: rainfall index, the low pass filter of Hanning of order 2, the correlation test of rank and segmentation procedure of Hubert [15]. The annual rainfall indices (reduced centered variable) is calculated using the formula proposed by Nicholson [15].

$$Ip = \frac{(X_I - Xm)}{\sigma i} \qquad (13)$$

Ip: Rainfall Index

Xi (mm): total rainfall of a station for a year i

Xm (mm): average annual rainfall of a station during the study period

σ: Standard deviation of annual rainfall.

These indices highlight the interannual variability, and the periods of deficits and excessive rainfall [14-15]. Fig. 4 shows the evolution of interannual rainfall indices for the period (1974-2007) at the rainfall stations. The results show that the stations of Djelfa, Aïn Maabed, Rocher de sel, Charef, Ain Mouilah, and Benhafaf and are characterized by the alternation of wet period followed by a deficit period 1983-2007.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Table 1. Geographic coordinates and altitudes for rainfall stations used

Code	Station	Geographical coordinates in Lambert system (km)		Altitude (m)	Observing period
		X	Y	Z	
170208	Djelfa	551	153	1160	1974-2007
170204	Ain Maabed	539.6	167.4	1040	1970-2007
170201	Rocher de Sel	533.65	174,65	1020	1972-2007
170102	Charef	509.50	147.25	1200	1970-2007
170207	ZAAFRANE	514.45	172.15	854	1974-2007
170219	Benhafaf	594.90	178.20	1070	1968-2007
170503	Dar Chioukh	572.00	178.00	1100	1965-2007
170401	AIN MOUILLAH	572	162.5	1117	1972-2007
170501	Arara	590.1	203.6	875	1970-2007

Table 2. Statistical summary of climatic data over the period 1974–2007

Meteorological variables	Maximum	Minimum	Mean	Standard deviation	Coefficient of variation (%)
Precipitation (mm)	38.12	8.06	26.47	8.29	0.31
Temperature (° C)	26.56	4.60	14.66	7.91	0.54
Relative humidity (%)	75.65	36.78	58.43	13.06	0.22
Evaporation (mm)	291.97	45.70	145.03	84.81	0.58
Wind speed (km/h)	4.79	3.37	4.01	0.45	0.11
Sunshine hour (hr)	321.70	168.87	244.32	53.00	0.22

Stations	Minimum	Maximum	Moyenne	Ecart type	Coefficient de Variation
Rocher de Sel	78	327	184	65.8	0.36
Ain Maabed	68.0	327	186	63.3	0.34
Djelfa	42	280	169	56.4	0.33
Charef	11	233	110	58.8	0.53
Zaafrane	79	325	199	59.5	0.30
Arara	7	355	134	84.5	0.63
Ain Mouilah	1	170	70.80	48.6	0.68
Dar Chioukh	54	379	197	69.4	0.35
Benhafaf	19	407	181	98.9	0.55

Table 3. Statistical summary of annual rainfall data over the period 1974–2007

Moreover, the interannual fluctuation of rainfall in Zaafrane, Dar Chioukh, and Arara station and is characterized by the succession of wet period from 1974 to 1991 followed by a deficit period from 1992 to 2007. On the other hand, the interannual variability of rainfall indices reveals a significant rainfall deficits, ranging from 57.43% for Rocher de sel station, and 97.63% in the Ain Mouilah station, observed in 1982 and 1988 respectively. It is noteworthy, that 1983 was characterized by a significant rainfall deficit at stations: Rocher de sel, Djelfa, Aïn Maabed, Arara, Zaafrane and Benhafaf station.

D. Application of homogeneity tests on time series rainfall

The statistical tests of homogeneity were applied to the rainfall time series of selected stations; using Khronostat software developed by Maison des Sciences de l'Eau (MSE), Montpellier [16]. These are: the test of Pettitt, Buishand test, the segmentation procedure of Hubert and ellipse Bois test. If there is a rupture of the relative percentage of variation in average rainfall interannual between the two periods was calculated. It is the ratio:

$$\frac{(\text{Average annual rainfall after rupture} - \text{Average annual rainfall before rupture}) \times 100}{\text{Average annual rainfall before rupture}} \quad (14)$$

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

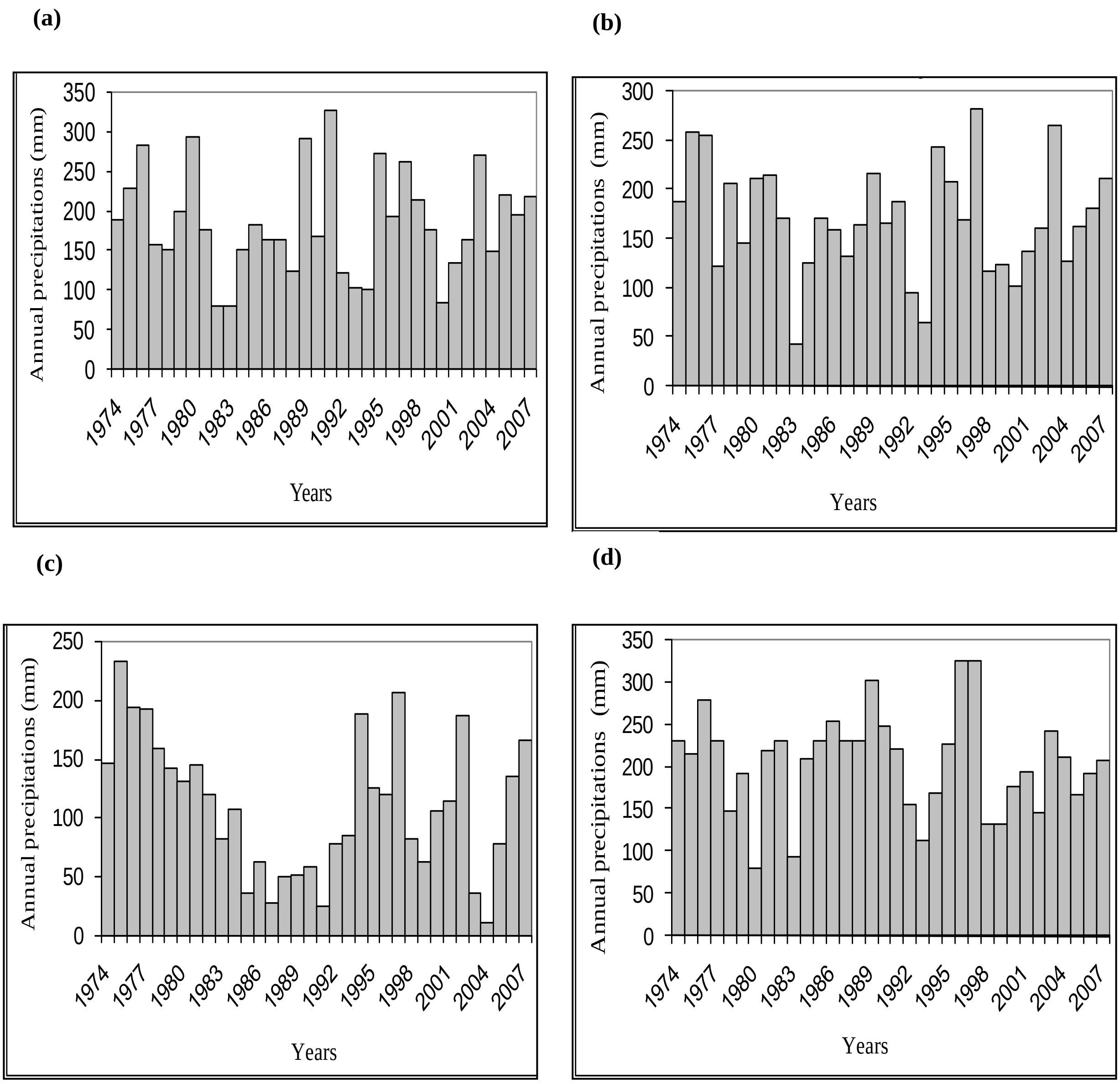
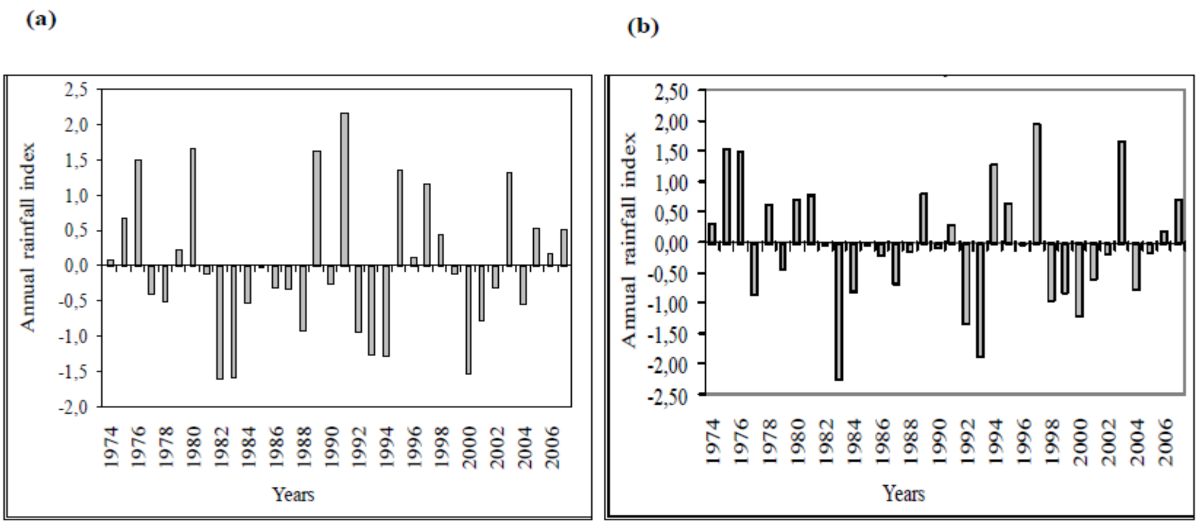


Fig. 3. Interannual variability of annual precipitation over the period (1974-2007). (a) Rocher de sel , (b) Djelfa,(c) Charef, (d) Zaafrane



Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

(c)

(d)

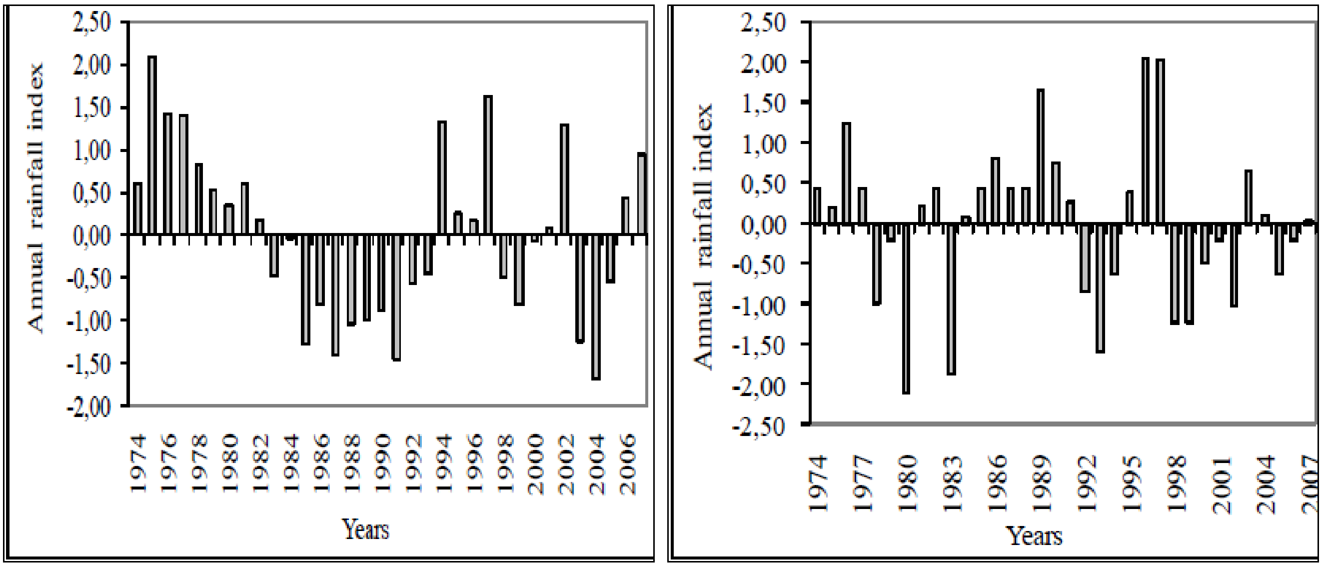


Fig. 4. Interannual variability of annual rainfall index variation over the period (1974-2007) (a) Rocher de sel, (b) Djelfa, (c) Charef, (d) Zaafrane

Pettitt test:

The results of the Pettitt test applied to rainfall time series of nine stations are shown in Fig. 5. These results indicate that the hypothesis of no break in series (H0) is accepted at confidence thresholds of 90%, 95%, 99% for rainfall time series of Djelfa, Aïn Maabed, Rocher de sel, Dar Chioukh, Arara, Ain Mouilah, and Zaafrane station. However, the application of the Pettitt test allowed the detection of a break in stationarity in 1982, at the confidence thresholds of 90% and 95% in the time series of annual rainfall of Charef and Benhafaf.

Buishand test:

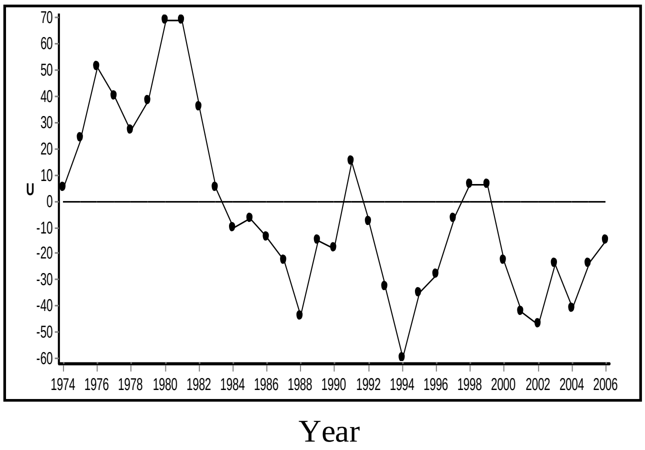
The results of Buishand test indicate that the null hypothesis of no break is accepted at the confidence threshold of 90%, 95%, and 99%, on the rainfall time series of stations of Djelfa, Aïn Maabed, Rocher de sel, Ain Mouilah and Zaafrane station . Moreover, the application of this test shows that the rainfall time series of Charef and Benhafaf station present a break at the confidence threshold of 90% and 95%.

Table 4. Summarized results of Hubert's segmentation procedure for rainfall time series of over the period1974–2007

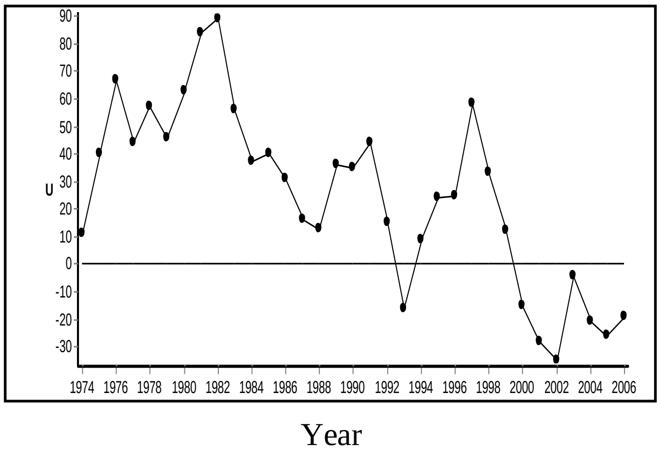
Station	Start year	Complete year	Mean	Standard deviation	Relative variation of average (%)
Charef	1974	1981	168.14	35.06	-44.84
	1982	2007	92.75	53.15	
Arara	1974	2007	128.30	75.09	-
Zaarfrane	1974	2007	199.31	59.44	-
Ain Mouilah	1974	2007	70.74	48.59	-
Benhafaf	1974	1982	269.08	73.50	-44.51
	1983	2007	149.30	87.65	
Dar chioukh	1974	2007	196.74	69.41	-
ONM Djelfa	1974	1997	342.66	77.22	
	1998	2007	258.10	66.20	
Rocher de sel	1974	2007	184.87	65.74	-
Ain Maabed	1974	1976	283.43	62.39	-37.66
	1977	2007	176.68	55.73	
Djelfa	1974	2007	169.42	56.41	

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

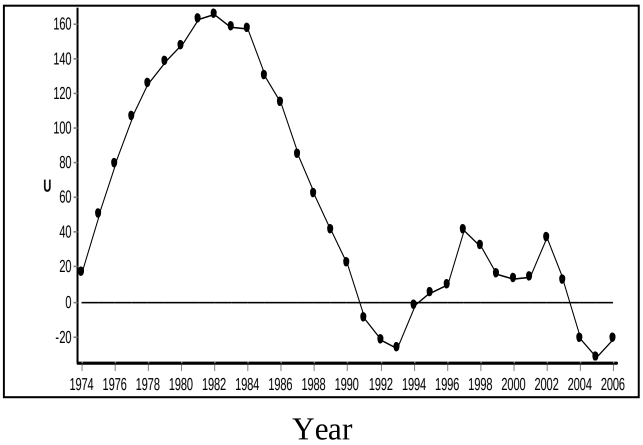
(a)



(b)



(c)



(d)

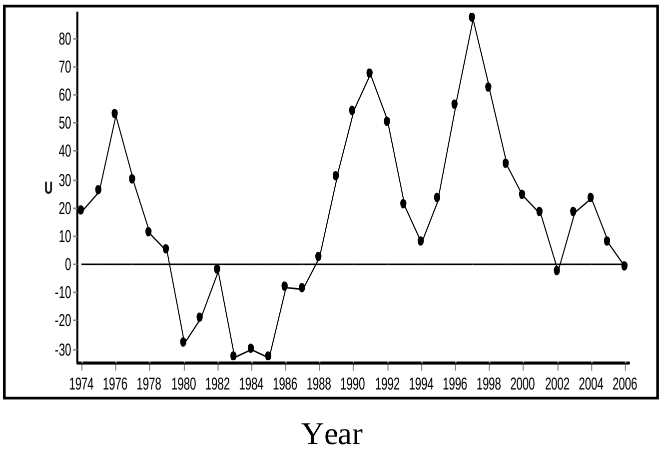
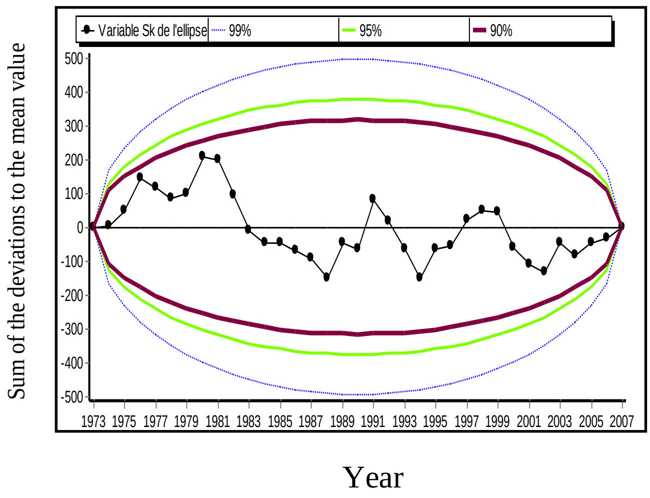
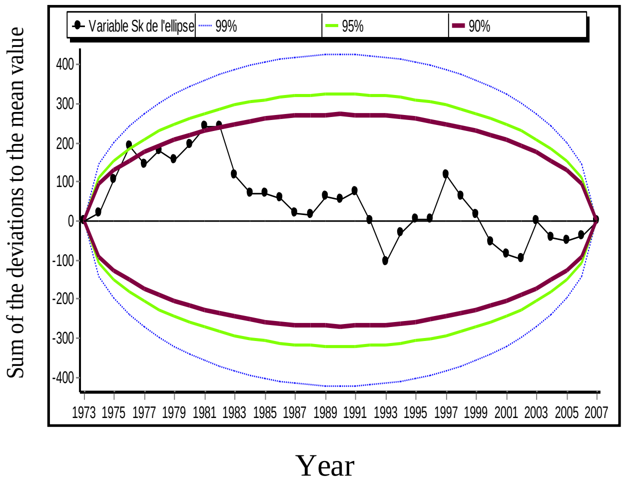


Fig. 5. Pettitt test results. (a) Rocher de sel, (b) Djelfa, (c) Charef, (d) Zaafrane

(a)



(b)



(c) (d)

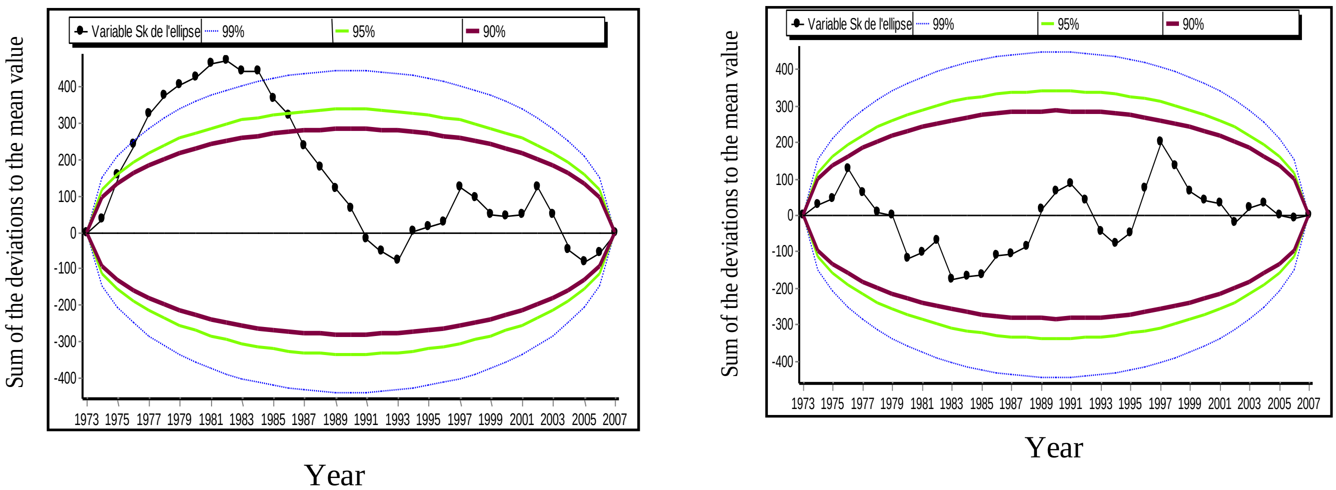


Fig. 6. Bois'ellipse results. (a) Rocher de sel, (b) Djelfa, (c) Charef, (d) Zaafrane

Hubert segmentation procedure

The results of the Hubert segmentation procedure of Charef station (Table 4) propose the division of the time series of annual rainfall in two segments: from 1974 to 1981 and from 1982 to 2007, with an average values of 168.14 mm and 92.75 mm respectively. Moreover, it is found that the application of this procedure to the rainfall series of Benhafaf station , allowed the detection of a rupture in 1982, allowing the division of the time series into two segments: from 1974 to 1982, and from 1983 to 2007, characterized by average values of 269.08 mm and 149.30 mm respectively. Furthermore, the results of the statistical test which reveals a point of rupture in 1976, on the series of annual rainfall of Aïn Maabed station; with an average of 283.43 mm (1974-1976) and 176.68 mm (1977 to 2007) respectively. It is noteworthy that the average relative variations in rainfall time series of Charef, Benhafaf, and Aïn Maabed station are -44.84%, -44.51% , and -37.66% respectively.

Ellipse control

The results of the control ellipse in the confidence threshold of 99.95% and 99% for the nine rainfall stations are shown in Fig. 6. This figure shows that the null hypothesis of no break at confidence threshold of 90% and 99.95% is accepted for rainfall time series of Zaafrane and Rocher de sel station. Furthermore, Djelfa, Aïn Maabed, and Ain Mouilah station present a rupture at the confidence threshold of 95 and 90%. It is noteworthy that the rainfall time series of charef and of Benhafaf station present significant rupture at the confidence threshold of 99,95 and 99%. Fig. 6 illustrates this, many points are outside the ellipse Bois.

V. Conclusion

This study focused on climate variability characterization in the Djelfa region. Using the method of reduced centered variable of Nicholson and statistical methods of detecting breaks in the stationary time series (Pettitt tests, Buishand test, Hubert segmentation procedure, and the ellipse control). The evolution of the annual rainfall indices shows that 67% of retained rainfall stations are characterized by a succession of rainfall excess and deficit rainfall periods. The first period from 1974 to 1982 and the second period from 1983 to 2007. It is noteworthy that 1983 is characterized by a significant deficit of up to 89%. Moreover, the Pettitt test applied to the time series of annual precipitation to a confidence levels 90% and 99.95% revealed that no rupture of the stationary was detected during the period (1974-2007) on 78 % retained rainfall series. Moreover, the Buishand test allows detection of break for confidence levels 90% and 95% of the rainfall series of Charef and Benhafaf. Moreover, the use of the method of control ellipse shows that 56% of the rainfall stations studied, have a break in the time series of annual precipitation for confidence levels of 90% and 95%. On the other hand, the null hypothesis of no break is accepted at the confidence level 99% for 56% of rainfall data retained.

References

1. M. Meddi, "Impact des Changements Climatiques sur les Eaux Souterraines (Cas du Bassin Hydrographique Cheliff-Zahrez) ", conference Groundwater& Climate in Africa, Kampala, Uganda, 2008.
2. Kettab, "Water resources in Algeria : strategies, investments, and vision" , Desalination, vol.136, no.1-3, pp.25-33, 2001.
3. Kettab, "Water for all with quality and quantity: it is the concern of all", Desalination and Water Treatment, vol.52, pp.1965–1966, 2014.
4. F. Bouteldjaoui, M. Bessenasse, and A. Gendouz, "Etude comparative des différentes méthodes d'estimation de l'évapotranspiration en zone semi-aride (cas de la région de Djelfa) ", Revue Nature & Technologie, no.07, Juin, pp.109-116, 2012.
5. M. F. Sidi Moussa, and M.Deramchi, "Synthèse des études et exploitation des données existantes sur le Synclinal de Djelfa", Agence Nationale des Ressources Hydrauliques (ANRH), Rapport Technique, 40P, 1993.
6. M. F. Sidi Moussa , "Ressources Hydrauliques de la zone du projet GTZ-HCDS. Coopération Algero-Allmande", Agence Nationale des Ressources Hydrauliques (ANRH). Rapport Technique, 176 P, 2000.
7. N. H. Lubès, J.M. Masson, J.E. Paturel, E. Servat, and B.Kouamé, "De différents aspects de la variabilité de la pluviométrie en Afrique de l'Ouest et Centrale non sahélienne", Rev. Sci. Eau, 12(2), pp 363-387, 1999.
8. A.N. Pettitt, "A non-parametric approach to the change-point problem", Appl. Statist, vol. 28, no. 2, pp.126-135,1979.
9. T. A. Buishand, "Some methods for testing the homogeneity of rainfall records", Journal of Hydrology,vol. 58, pp.11–27. 1982.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

10. T. A. Buishand, "Tests for detecting a shift in the mean of hydrological time series", Journal of Hydrology, vol. 73, pp.51-69, 1984.
11. N. H. Lubès, J.M. Masson, J.E. Paturel, and E. Servat, " Variabilité climatique et statistiques. Etude par simulation de la puissance et de la robustesse de quelques tests utilisés pour vérifier l'homogénéité de chroniques", Revue des Scienes de l'Eau, no. 3, pp. 383-408, 1998.
12. D. Sighonou, " analyse et redéfinition des régimes climatiques et hydrologiques du Cameroun : Perspective d'évolution des ressources en eau", Thèse de Doctorat, Université de Yaoundé, Faculté des sciences, 173 P, 2004
13. P. Hubert., J.P. Carbonnel, and A. Chaouche, "Segmentation des séries hydrométéorologiques - Application à des séries de précipitations et de débits de l'Afrique de l'Ouest", J. Hydrol, vol.110, pp. 349-367, 1989.
14. Chrystelle A, " Impact du changement climatique sur la ressource en eau en région Langueduc Roussillon. Thèse DEA, Université Pierre et Marie Curie, Université Paris Sud, Ecole des Mines de Paris, 49 P, 2002.
15. Kouakou, A. Goula Bi Tié, S. Issiaka, "Impacts de la variabilité climatique sur les ressources en eau de Surface en Zone Tropicale Humide : Cas du Bassin Versant Transfrontalier de la Comoé (Côte d'ivoire –Burkina Faso) ", European Journal of Scientific Research, vol. 16, n°.1, pp. 31-43, 2007.
16. JF. Boyer, "Khronostat statistical time series analyses software", Montpellier, UMR 5569 Hydrosciences, IRD-Maison des sciences de l'eau, 1998.