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Characterization of the climatic drought indices application to the Mellah catchment, North-East of Algeria

Lina BENDJEMA^{ABCDEF} ✉, Kamila BABA-HAMED^{ACDEF},
Abderrazak BOUANANI^{ACDEF}

University of Tlemcen, Faculty of Technology, Laboratory Promotion of Hydraulic, Mining and Pedagogical Resources, Environmental Legislation and Technological Choices Tlemcen BP 119, 13000 Chetouane Tlemcen, Algeria; e-mail: lina.24206@gmail.com; kambabahamed@yahoo.fr; a_bouanani@univ-tlemcen.dz

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Abstract

Drought is one of the important phenomena resulting from variability and climate change. It has negative effects on all economic, agricultural and social sectors. The objective of this study is to rapidly detect climate dryness situations on an annual scale at the Mellah catchment (Northeast Algeria) for periods ranging from 31 years through the calculation of: the standardized precipitation index (*SPI*), the standardized Streamflow index (*SSFI*), the standardized temperature index (*STI*). Calculations made it possible to locate periods of drought more precisely by their intensity, duration and frequency, and detect years of breaks using the tests of Pettitt, rang, Lee and Heghinian, Hubert and Buishand. The use of the statistical tests for the rainfall series analyzed show all breaks, the majority of which are in 1996/1997 and 2001/2002. For the temperatures the breaks are situated in 1980/1981.

Key words: *drought, drought break, drought index, humidity, Mellah catchment*

INTRODUCTION

According to SVOBODA *et al.* [2012], drought is an insidious plague that results from a decrease in precipitation from levels considered normal. When the phenomenon lasts a whole season, or over a longer period, rainfall is insufficient to meet the needs of the environment and human activities. Drought must be considered a more relative than absolute state. It is indeed a phenomenon of regional scale and each region has its own climatic characteristics. Temperature, wind and relative humidity are also important factors in characterizing drought. This has led many researchers to study climate change in the world and in Algeria in particular [DJELLOULI *et al.* 2016; FARAH 2014; GHENIM, MEGNOUNIF 2011; 2013; GHERISSI 2018; IBRAHIM, 2012; KHOUALDIA *et al.* 2014; MERABTI 2018; OTMANE *et al.* 2018; SORO *et al.* 2014; SOUBEYROUX *et al.* 2012].

According to AOUN SEBAITI [2010], Algeria's water resources are currently relatively well known, but the drought that has been raging for more than 20 years has led water services to update their assessments of water quality rainfall in each region. Algeria has experienced many periods of drought of varying magnitude during its history. Some of them have had sometimes dramatic repercussions on the living conditions of the population, particularly in rural areas (1943–1948); the most severe and persistent droughts are those observed during the 1980s to 1990s, when the rainfall deficit was estimated at 50% for the central regions and in western Algeria and 30% in the East. The year 1988/1989 was classified as a dry year for Algeria. This drought has had a negative impact on the flow regime of the wadis, on the supply of the groundwater and on the filling level of the roadblocks. It was followed by many floods that have been marked all over the country Algerian territory [KHOUALDIA *et al.* 2014].

MEDDI and MEDDI [2009] present drought as the most recurrent climatic phenomenon in most of Africa. The northern part of Algeria is characterized by a Mediterranean climate with a relatively cold and rainy winter and a hot and dry summer, the rainfall reaches 400 mm in the West, 700 mm in the Center and 1000 mm in the East for the littoral. According to MEBARKI [2009], eastern Algeria is the most water-logged region in the country and, as a result, has the largest share of surface water resources. With an average annual flow of more than 200–300 mm in the Tell basins, it is clearly opposed to western Algeria where the dominant semi-aridity allows only mediocre flows, mostly less than 50 mm per year. The relative rainfall abundance of eastern Algeria does not exclude that this region has also experienced drought since 1980. However recent studies KHOUALDIA *et al.* [2014] show that a trend towards a return of rainfall is observed for the period 2001–2007. According to KHEZAZNA *et al.* [2017] during the period 1995–2011, a gradually return to normal precipitation is observed; moderately wet and very wet conditions were recorded in the most areas of the Seybouse watershed, with different spatial extents. Though, the deficit of rainfall persists in the center of the basin (Guelma, Ain Makhlouf) over the entire period.

In the North-East of Algeria, Wadi Mellah crosses the regions of Souk Ahras and Guelma to flow into Wadi Seybouse and participates as a water source in economic activities (agriculture, industry ...). As for Wadi Mellah, a major tributary of Seybouse, irrigates the Bouchegouf Plain (East of Guelma) and runs along the South-West study area to the North-East.

Knowledge of the climatic variability of a watershed such as the Mellah catchment, where hydraulic facilities are lacking, is necessary for the integrated management of water resources such as the design of hydraulic structures. The present work will focus on the analysis of the climate drought situation on an annual scale, in order to follow its evolution and to understand its impact on water resources

in the Mellah watershed. We will adopt revealing indices of its degree of intensity as a methodological approach to identify the relationship meteorological drought and hydrological drought.

STUDY AREA

The watershed Wadi Mellah (Fig. 1) covers an area of 552.38 km². It is located in northeastern Algeria, East of the Seybouse watershed, it constitutes the fifth sub-basin after those of: upstream Cherf, downstream Cherf, Bouhamdane and middle Seybouse. The Wadi Mellah is the main tributary of the right bank of the Seybouse with which it converges, at the mouth of the Guelma Valley (Fig. 2). It owes its name to the high salinity of the waters of the downstream catchment. This is due to the leaching of Triassic gypsum soils located in the central basin. Wadi Mellah, a tributary rises of north-west slope of the Medjerda Mountains. Wadi Mellah receives some important tributaries, among others: Wadi Zarin, Wadi Rirane, Wadi Labiod, Wadi Bouredine, Wadi El Meza, Wadi Ghanem, Wadi Chham, Wadi El Hammam and Wadi Bouzaraa. It is elongated in shape with a south-western/north-eastern orientation and a very heterogeneous topography. The basin includes all cultivated agricultural land. The region is subject to a Mediterranean climate characterized by two distinct seasons: one humid and the other dry. The average annual precipitation is about 885 mm and the average temperature is 16.5°C. The geology of the region is represented by three main formations: the permeable alluvial deposits of the Quaternary, which are of vital importance for the hydrogeology of the region, and the two impermeable or semi-permeable formations that constitute the boundaries of the natural reservoirs. These formations are represented by Numidian sandstone and Triassic formations. Alluvial deposits are groundwater reservoirs that are drained by the Mellah wadi [CHAOUÏ *et al.* 2013].

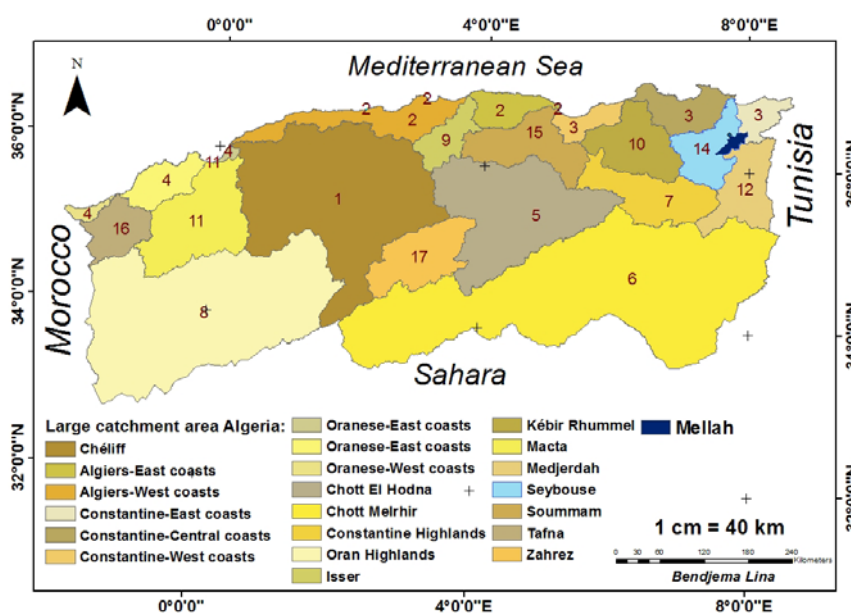


Fig. 1. Map of northern Algerian watersheds; the numbers mean the code of the watershed according to the division of the National Water Resources Agency (ANRH); source: own elaboration

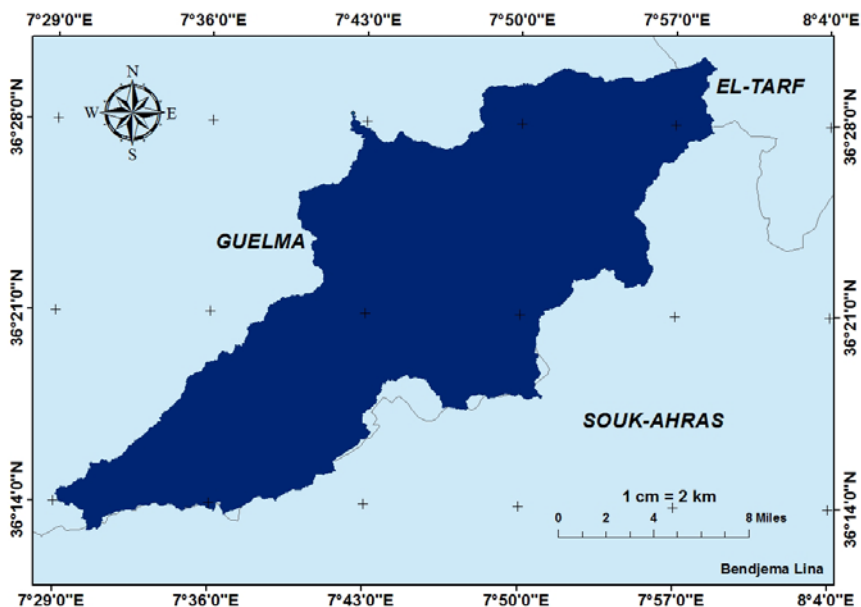


Fig. 2. Situation of the Mellah watershed; source: own elaboration

MATERIAL AND METHODS

THE DATA

To characterize the climate of the study area, we based on:

- three rainfall stations with long series of precipitation data from 1979/1980 to 2009/2010, these three stations (Mechroha, Hammam N'bail and Bouchegouf) located within the basin (Fig. 3);
- thermometric measurements are carried out at the meteorological stations of Guelma (Belkhir) and Souk Ahras (Ain Dalia) from 1979/1980 to 2009/2010;

- the Wadi Mellah watershed is controlled by a single hydrometric station at the outlet of Bouchegouf with an observation period from 1979/1980 to 2009/2010.

The rainfall and hydrometric station data used in this study come from the database of the National Agency of Hydraulic Resources (Fr. Agence Nationale des Ressources Hydriques – ANRH) in Algeria – Table 1.

The interannual variation of the runoff's depth recorded at the Bouchegouf station (Fig. 4), indicates an important irregularity. We observe an exceptional year in 2002/2003 with 493 mm, the minimum of 17 mm is recorded in 2001/2002. The interannual variation of precipitation recorded in the three stations (Fig. 4), highlights a sig-

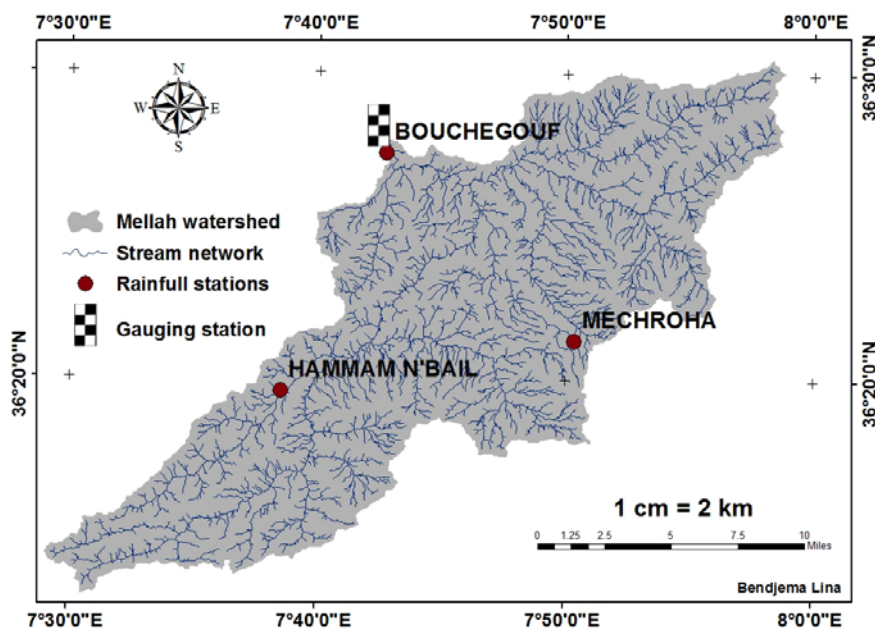


Fig. 3. Situation of the rainfall and hydrometric stations; source: elaboration by L. Bendjema

Table 1. Characteristics of Wadi Mellah catchment stations

Specification	Rainfall station			Hydrometric station	Weather station	
Station name	Mechroha	Hamam N'bail	Bouchegouf	Bouchegouf	Souk Ahras	Guelma
Station code	140502	140503	140505	140501		
Latitude N	36°21	36°19	36°28	36°28	36°37	36°37
Longitude E	7°50	7°38	7°44	7°44	7°81	7°50
Altitude (m)	750	460	110	110	626	314
Registration period	1979/1980–2009/2010					

Source: own elaboration.

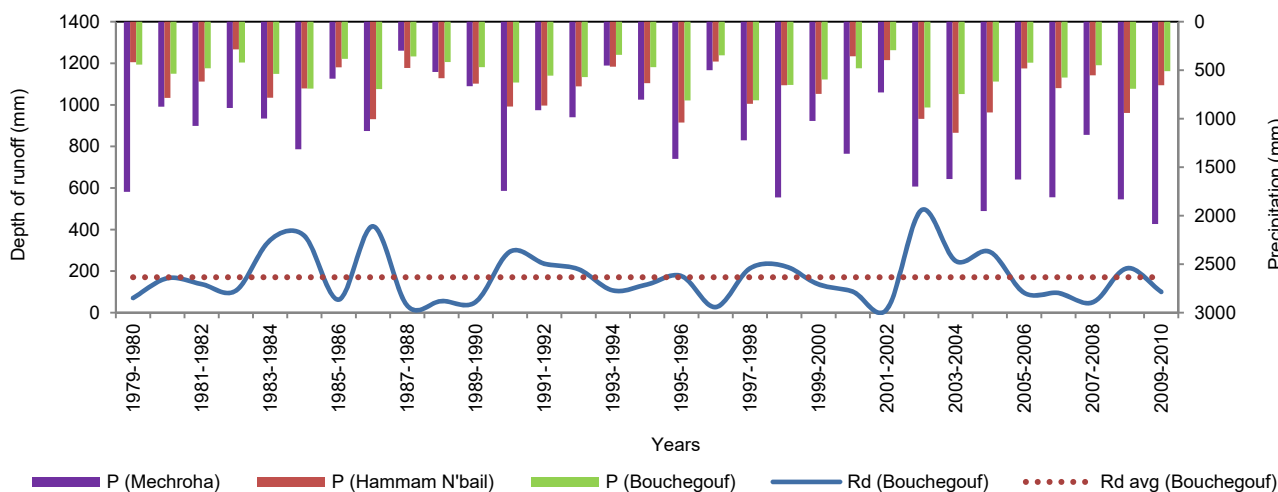


Fig. 4. Interannual variation of the runoff's depth (*Rd*) and precipitation (*P*) in the period of 1979/1980–2009/2010; source: own elaboration

nificant irregularity, indeed, we observe an exceptional year having affected the stations of Mechroha in 2009/2010, Hammam N'bail in 2003/2004 and Bouchegouf in 2002/2003. The minimum is recorded in 1987/1988 in Mechroha, Hammam N'bail in 1982/1983 and 2001/2002 in Bouchegouf.

The interannual variation in temperatures recorded at the Souk Ahras and Guelma stations during the period 1979/1980–2009/2010 (Fig. 5) shows a synchronism between the data of the two stations. The maximum temperature was recorded in 1987/1988 with 18.02°C in Souk Ahras and 17.73°C in Guelma. On the other hand, the minimum value was observed in 1979/1980 with 15.40°C in Souk Ahras and 15.17°C in Guelma.

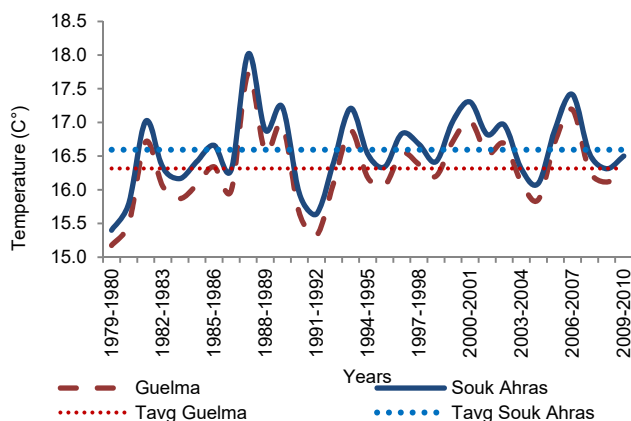


Fig. 5. Interannual temperature variation (1979/1980–2009/2010); source: own elaboration

DETECTION OF BREAKS IN ANNUAL SERIES

In hydrology, two major forms of non-stationarity are of interest: trends and breaks. It can also be noted that a break refers to a sudden change in the properties of a random process, a trend is a gradual change in the properties of a random variable. A stationary time series: its properties are invariable over time. RYBSKI and NEUMANN [2011], in time series analysis the concept of change points, indicating a change in the statistical behaviour, is of basic interest. In geoscience the cause of such events can be anthropogenic interventions to the riverbed in the case of hydrologic records, modifications of instrumentation, or climate change. Thus, it is a quest to identify whether such a point of change exists and if so, to locate it in time. At first, the usage of the term “change point” does not clarify what it really is, e.g. an abrupt change of the mean, the beginning of a linear trend, or the change of piecewise (linear) trends.

We have tried to apply to the annual series of precipitation, temperature and flow, five statistical homogeneity tests using time series statistical analysis software (Kronostat 1.01) produced by the Research Institute for IRD development and the University of Montpellier [BOYER 1998].

Pettitt test

According to FOSSOU *et al.* [2014], the Pettitt test is a modified version of the Man–Whitney test, it has been described by several authors [LUBES-NIEL *et al.* 1998; THORSTEN 2018]. It makes it possible to check the station-

ary of the rainfall series. A statistical study is defined from the two sums thus determined, and tested under the null hypothesis of membership of the two sub-samples to the same population. This test is based on the calculation of the variable Ut , defined by equation (1).

$Dij = \text{sgn}(xi - xj)$; $\text{sgn}(x) = 1$, if $x > 0$; $\text{sgn}(x) = 0$, if $x = 0$; $\text{sgn}(x) = -1$, if $x < 0$. PATUREL *et al.* [1998] presented Table 2, which indicates the probability associated with the test statistic. A qualitative ranking is made taking into account the values of this probability.

$$U_{tU} = \sum_{i=1}^t \sum_{j=t+1}^N Dij \quad (1)$$

Table 2. Level of significance of Pettitt test results

Associated probability (%)	Class
<1	very significant break
1-5	significant break
5-20	little significant break
>20	homogeneous series

Source: PATUREL *et al.* [1998], modified.

Buishand test

According to KHOUALDIA *et al.* [2014], assuming a uniform prior distribution for the position of the breakpoint t , the statistic U is defined by equation (2). For $k = 1, \dots, N$ and Dx is the standard deviation. In case of rejection of the null hypothesis, no estimate of the break date is proposed by this test. In addition to this procedure, the construction of a control ellipse makes it possible to analyze the homogeneity of the series of variable Sk , defined below which follows a normal distribution of zero mean and variance $k(N-k)N-1\sigma^2$, $k = 0, \dots, N$. It is therefore possible to define a so-called control ellipse confidence region associated with a confidence threshold containing the Sk series.

$$U = \frac{\sum_{k=1}^{N-1} (S_k/Dx)^2}{N(N+1)} \quad (2)$$

$$S_k = \sum_{i=1}^k (x_i - \bar{x}) \quad (3)$$

Bayesian method of Lee and Heghinian

The Bayesian method of Lee and Heghinian [BRUNEAU, CLAUDE 1983; LEE, HEGHINIAN 1977; LUBES-NIEL *et al.* 1998] does not express itself as a classical statistical test. However, its interpretation aims at confirming or invalidating the hypothesis of a change of mean in the series. This is a parametric approach that requires a normal distribution of the studied variables. The ε_i are independent and normally distributed, of zero mean and variance σ^2 . τ and δ represent respectively the position in time and the amplitude of a possible change of mean. The Bayesian procedure is based on the posterior marginal distribution of τ and δ . When the distribution is unimodal, the date of the break is estimated by the mode with all the more precision as the dispersion of the distribution is weak. The procedure is based on the following model:

$$X_i = \begin{cases} \mu + \varepsilon_i & i = 1, \dots, \tau \\ \mu + \delta + \varepsilon_i & i = \tau + 1, \dots, N \end{cases} \quad (4)$$

Hubert test

NDIAYE [2003], unlike Pettitt's test, presented Hubert's test which can detect several break dates in a time series. The principle of this procedure is to "split" the series into m segments so that the average calculated for the whole segment is significantly different from the average of the neighbouring segment (s). Such a method is suitable for looking for multiple changes of mean. The segmentation retained must be such that for a given order of segmentation m , the quadratic difference Dm is minimum. This condition is necessary but not sufficient for the determination of the optimal segmentation. The following constraint must be added: the averages of the two contiguous segments must be significantly different. This constraint is satisfied by application of the Scheffé test [DAGNELIE 1970]. According to HUBERT *et al.* [1989], this segmentation procedure can be interpreted as a test of stationarity, constituting the null hypothesis of this test. If the procedure does not produce acceptable segmentation greater than or equal to 2, the null hypothesis is accepted. No significance level is assigned to this test. We define: ik , $k = 1, 2, \dots, m$; $nk = ik - ik - 1$,

$$\bar{X}_k \text{ the average of the } k^{\text{th}} \text{ segment, } \bar{X}_k = \frac{\sum_{i=k-1+1}^{i=k} X_k}{n_k} \quad (5)$$

$$Dm = \sum_{k=1}^{k=m} d_k \text{ with } d_k = \sum_{j=i_{k-1}+1}^{i=jk} (X - K_K)^2 \quad (6)$$

Rang correlation test

Rang correlation test, according to KENDALL and STUART [1943], WMO [1966], OLANIRAN [1991] and LUBES-NIEL *et al.* [1998], is based on the computation of the number P of pairs (x_i, x_j) for which $x_j > x_i$ ($j > i$, $I = 1, \dots, N - 1$). Under the null hypothesis (H_0) of stationarity of the series, the variable ω , defined by:

$$\omega = \frac{4P}{N(N-1)} - 1 \quad (7)$$

follows a normal distribution of zero mean and variance equal to:

$$\sigma_t^2 = \frac{2(2N+5)}{9N(N-1)} \quad (8)$$

SIMPLE ACCUMULATION METHOD

The simple accumulation method [MERRIAM 1937] is introduced in this study to verify the homogeneity of the data and to detect changes in the behaviour of watercourses. By representing the accumulated values of a variable as a function of time, we obtain a straight line whose slope break represents a change in the relationship, either because of a metrological problem or because of a change in trend.

AVERAGE DEVIATION INDEX OR DROUGHT INDEX (SI)

Standardized precipitation index (SPI)

In order to assess the degree of rainfall drought, the SPI index is used [EDWARDS 1997; EDWARDS, MCKEE 1997; MCKEE *et al.* 1993]. It is based on the probability of

precipitation over a given period of time, and is as effective in analysing wet periods or cycles as dry periods or cycles [SVOBODA *et al.* 2012]. According to GUTTMAN [1993], in order to calculate the *SPI* index, one should ideally have monthly readings spanning at least 20 to 30 years, but preferably 50 to 60 years, see more, which constitutes the optimal period. A probability distribution is fitted to this long series of readings and then converted to a normal distribution for the average *SPI* to be zero [EDWARDS, MCKEE 1997]. Positive *SPI* values indicate precipitation above the median and negative values indicate below-median precipitation. MCKEE *et al.* [1993] used the classification system presented in the Table of *SPI* index values set out below in Table 3 to define the intensity of drought episodes based on the value of the index. They also defined the criteria for a drought episode for a time scale: X_i – annual precipitation, \bar{X} – annual average precipitation, E – standard deviation, *SPI* – standard precipitation index.

$$SPI_i = \frac{x_i - \bar{x}}{E} \tag{9}$$

Table 3. Categories of drought and humidity defined by the values of *SPI*, *SSFI*, and *STI*

Values of <i>SPI</i> and <i>SSFI</i>	Degree of humidity/drought	<i>STI</i> values	Degree of hot/cold
≥2.0	extreme humidity	≥2.0	extremely hot
1.5–1.99	high humidity	1.5–1.99	very hot
1.0–1.49	moderate humidity	1.0–1.49	moderately hot
0.1–0.99	light humidity	0.1–0.99	slightly hot
0	absolute normality	0	absolute normality
(–0.1)–(–0.99)	light drought	(–0.1)–(–0.99)	slightly cold
(–1.0)–(–1.49)	moderate drought	(–1.0)–(–1.49)	moderately cold
(–1.5)–(–1.99)	high drought	(–1.5)–(–1.99)	very cold
≤(–2)	extreme drought	≤(–2)	extremely cold

Source: own elaboration based on SVOBODA *et al.* [2012] and FASEL [2015].

Standard temperature index (*STI*)

STI is an index that represents the probability of occurrence of a temperature value over temperature values over a longer period. Positive and negative *STI* values indicate temperatures above and below the median temperature of the long-term period, respectively. This index is used to identify abnormally hot and cold periods. *STI* values are classified according to Table 3 rules [FASEL 2015].

Table 4. Results of the tests of break of the series of precipitations, runoff's depth and temperature at the annual scale with observed period 1979/1980–2009/2010

Break test	Specification	Rainfall station			Hydrometric station	Weather station	
		Mechroha code: 140502	Hammam N'bail code: 140503	Boucheougouf code: 140505	Boucheougouf code: 140501	Guelma	Souk Ahras
Pettitt	year of break	1996/1997	–	–	–	–	–
	exceedance probability ¹⁾ (%)	1.05	nd	nd	nd	nd	nd
Buishand	year of break	1996/1997	–	–	–	–	–
Rang	year of break	+	–	–	–	–	–
Lee and Heghinian	year of break	2001/2002	2001/2002	1994/1995	–	1980/1981	1980/1981
	probability density	0.4410	0.0830	0.0692	–	0.4089	0.4126
Hubert	year of break	2001/2002	–	–	–	1980/1981	1980/1981

¹⁾ The exceedance probability given only if there is a break.

Explanations: + rejected, – accepted, nd = test does not applied or no results were obtained.

Source: own study.

Standardized stream flow index (*SSFI*)

To appreciate hydrological drought, an approach similar to *SPI* is used. It is based on the standardized *SSFI* flow index introduced by MODARRES [2007]. According to GHENIM and MEGNOUNIF [2011], *SSFI* offers the advantage of controlling hydrological drought and/or water supply in the short, medium, and long term. Using the *SSFI*, the deficit and excess flow frequencies are also identified.

RESULTS AND DISCUSSION

BREAKAGE TEST OF PRECIPITATION, TEMPERATURE AND FLOW SERIES

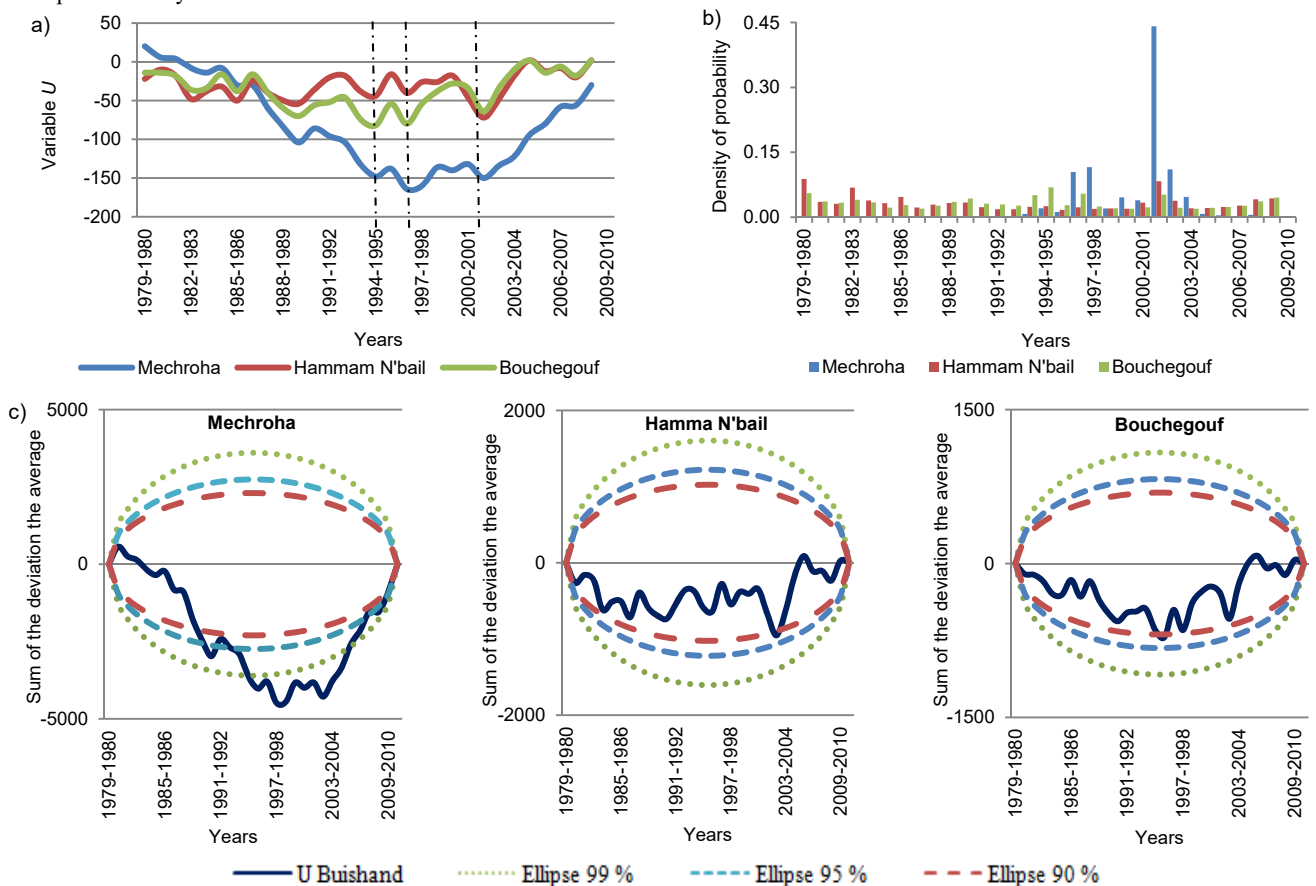
By applying the Pettitt, Buishand, Lee and Heghinian, Hubert and rang tests, we study records of river flows from gauges, precipitation and temperatures in eastern Algeria (Mellah catchment) and find significant change points. Theoretically, a change point represents a sudden change in the statistics of a record. It is said that the main series has a break at time t' if the two sub-series have different distributions. Results of break tests are presented in Table 4 and Figure 6.

The results of the Pettitt and Buishand show a break in 1996/1997 at the Mechroha station. As for the results of the segmentation of Hubert and the Lee and Heghinian break test highlight the presence of break in 2001/2002 in the series of Mechroha. Even though this test indicates that there is a break in Hammam N'bail and Boucheougouf respectively in 2001/2002 and 1994/1995, the probability density is pretty low. Hammam N'bail and Boucheougouf stations show virtually no break over 31 years, these results are confirmed by the rang test.

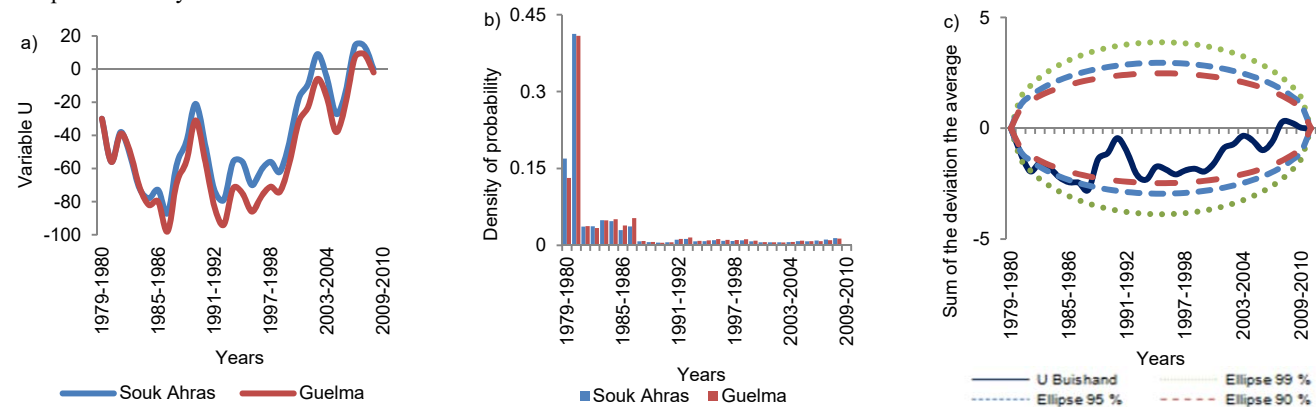
The results of the Pettitt, Buishand and rang tests recorded in Table 4 and Figure 6, do not reveal significant breaks over 31 years at the two stations Souk Ahras and Guelma. While the results of the Lee and Heghinian test and Hubert's test, show the presence of breaks in the temperature series of Souk Ahras and Guelma in 1980/1981. However, we exclude this result since the series begins in 1979/1980. However, as shown in Figure 6c, the Buishand test shows a secondary break in 1986/1987.

The results of the Pettitt, Buishand, rang and Hubert tests show that no break over 31 years is reported at the Boucheougouf station.

Precipitation study



Temperature study



Flow study

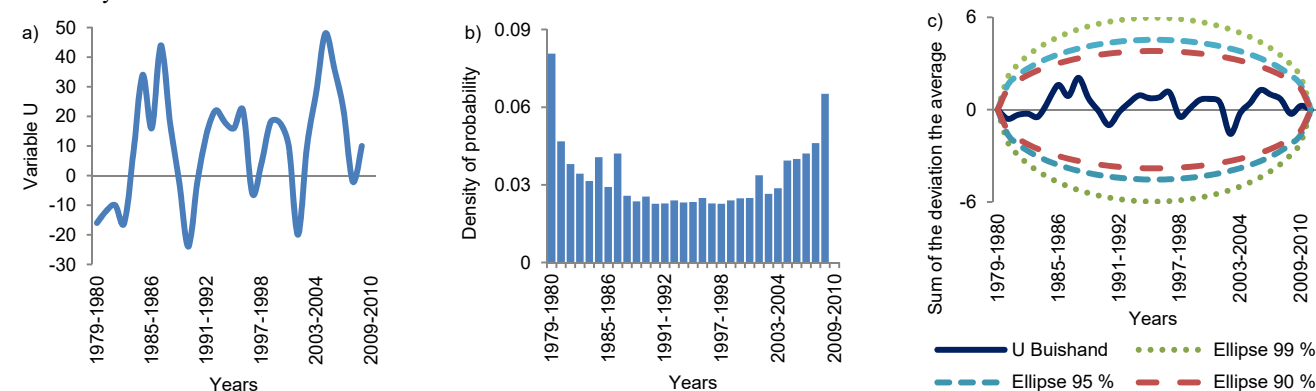


Fig. 6. Results of break tests (1979/1980–2009/2010): a) evolution of the variable U (Pettitt test), b) posterior probability density of the position of a change (Lee and Heghinian test), c) demonstration of the presence of break by the ellipse (Buishand test); source: own study

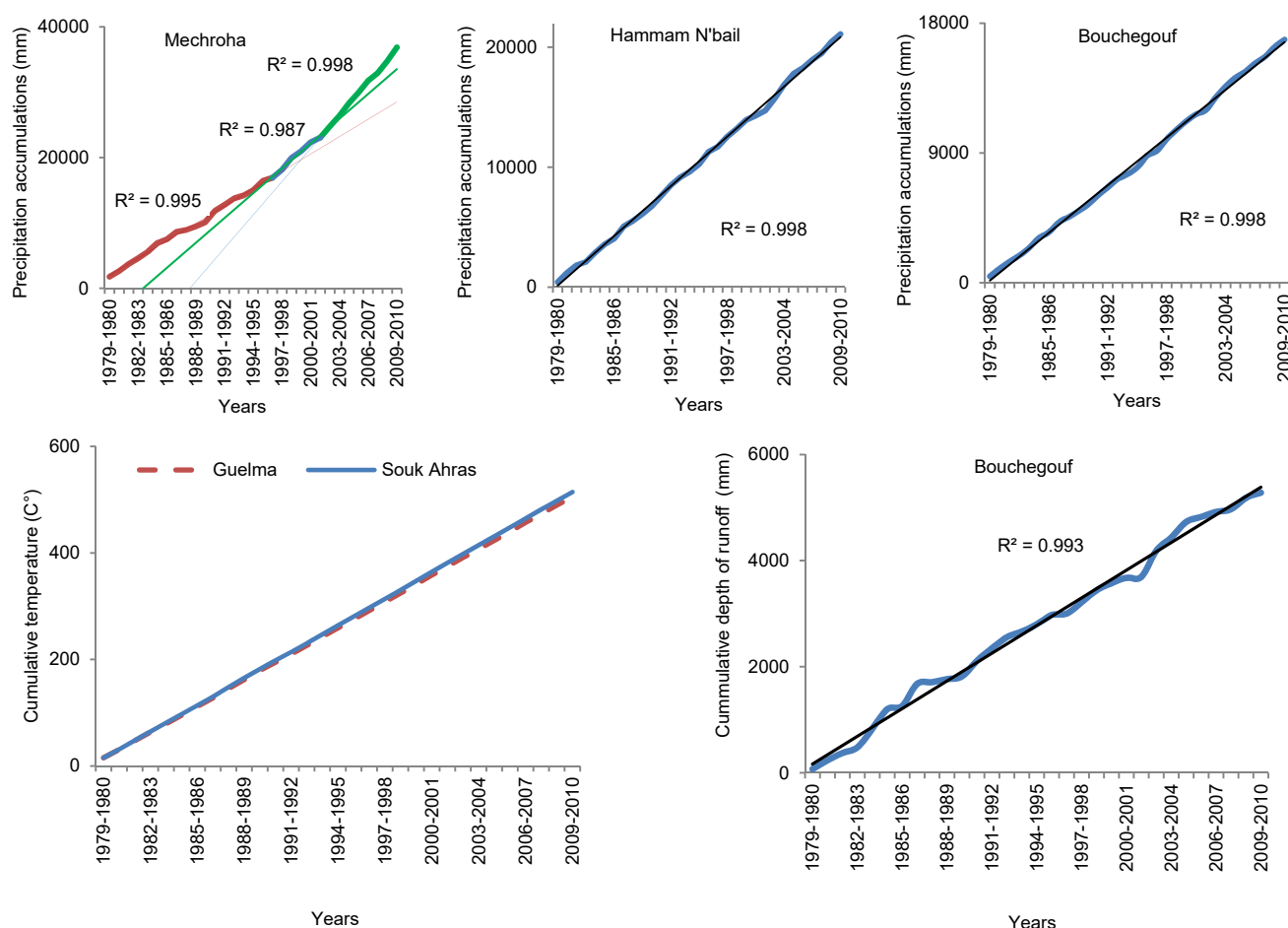


Fig. 7. Cumuls of annual rainfall, temperatures and runoff's depth; source: own study

SIMPLE ACCUMULATION

The accumulations of precipitation, temperature and runoff's depth in the annual time step (Fig. 7), show that only the series of Mechroha presents a break in 2001/2002 and 1996/1997 and virtually no break in the time series of others stations. These results are similar to the results of breakage test, and do confirm them.

AVERAGE DEVIATION INDEX OR DROUGHT INDEX (SI)

Standardized precipitation index (SPI)

Examination of Figure 8 Mechroha, shows that from 2002/2003 to 2009/2010 the degree of humidity becomes important at the Mechroha station, it is clear that in 2009/2010 and 2004/2005, the humidity is high, whereas during the period from 1979/1980 to 1996/1997, that is characterized by dry climate, the drought reached its maximum in 1987/1988.

At the Hammam N'bail station (Fig. 8), we can observe that the years between 1979/1980 and 2001/2002 mark a dry period, with its extreme recorded in 1982/1983. Yet we are witnessing a pronounced climatic irregularity in

this period. On the other hand, there is a return to humidity from 2002/2003–2009/2010.

The analysis of Figure 8 shows that at the Bouchegouf station the series begins with drought years from 1979/1980 to 1994/1995, followed by a period 1995/1996–2001/2002 with obvious variability between drought and humidity. The rest of the series is more or less humid, always marking its irregularity.

Hence, we note that the change in the general state of the climate in Mechroha was in 1996/1997 and 2001/2002, in Hammam N'bail was in 2001/2002 and in Bouchegouf in 1994/1995 and 2001/2002, as indicated by the previous results of breakage test of precipitation series.

As a result of this analysis, we can say that the three stations (Fig. 9) have the same variability of humidity and drought and that they have not suffered extreme drought during the whole study period.

Standard temperature index (STI)

Figure 5 shows a synchronism between the data of Souk Ahras station and Guelma station, so we do not have a large difference between the results from the two stations. After 1986/1987 the climate changed from cold to hot (Fig. 10). The region has generally experienced moderate temperatures (Fig. 11).

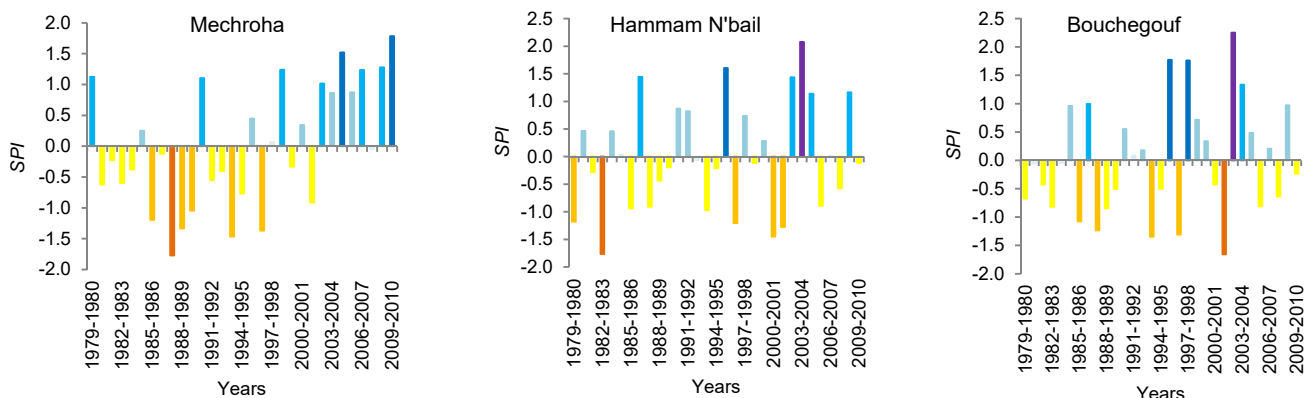


Fig. 8. Annual standardized precipitation index (SPI) during the period 1979/1980–2009/2010 at the three rainfall stations; source: own study

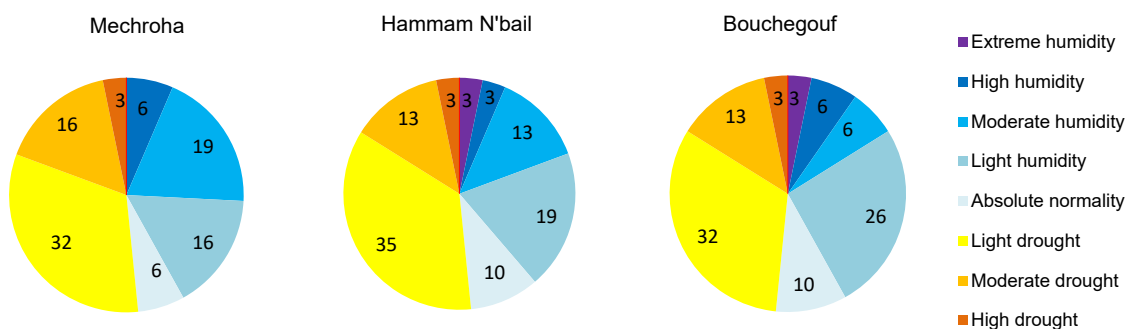


Fig. 9. Percentage share of years with a certain degree of humidity and drought during the period 1979/1980–2009/2010 at the three rainfall stations; source: own study

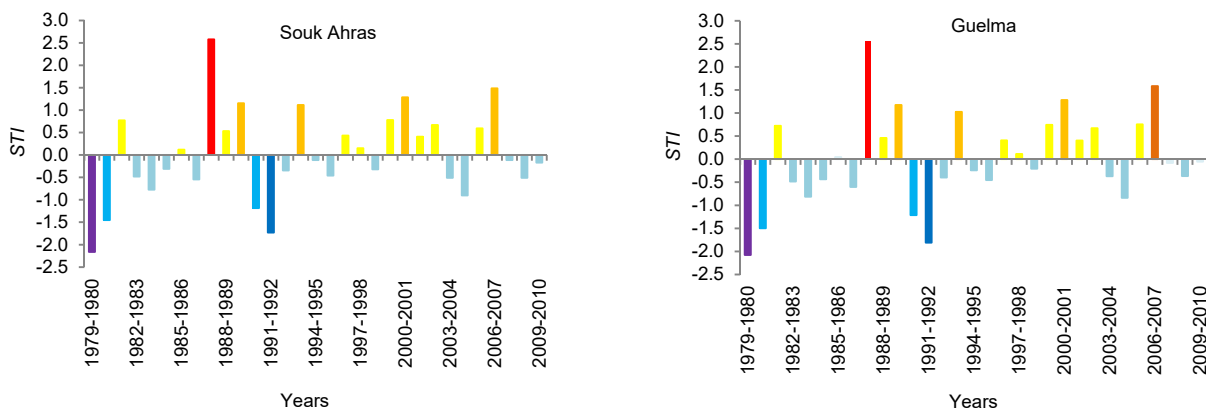


Fig. 10. Annual standard temperature index (STI) during the period (1979/1980–2009/2010) at the two weather stations; source: own study

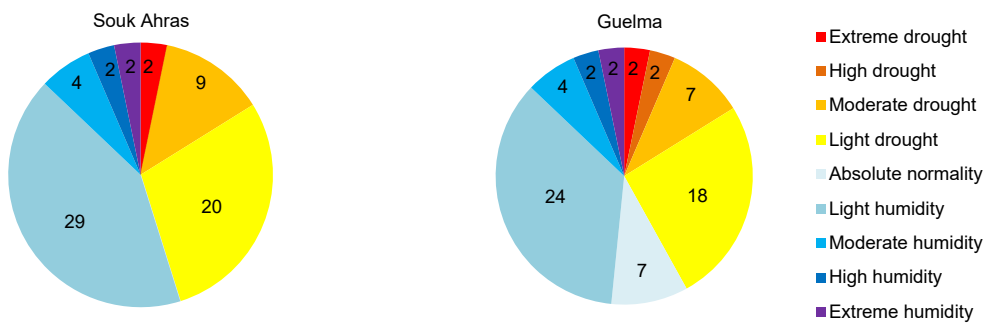


Fig. 11. Percentage share of years with a certain cold and hot degree during the period (1979/1980–2009/2010) at the two weather stations; source: own study

Standardized flow index (SSFI)

The presentation of *SSFI* (Fig. 12), in the period between 1979/1980 and 2009/2010 is characterized by 50% dry years and 50% wet years with different degrees (Fig. 13). It can also be noted that the series shows significant fluctuations over time without there being any real privileged direction. These variations reflect the intrinsic variability of hydrological series.

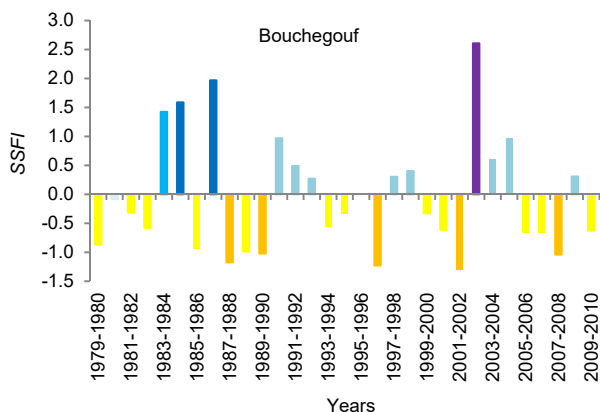


Fig. 12. Annual standardized flow index (*SSFI*) during the period (1979/1980–2009/2010) at Boucheougouf station; source: own study

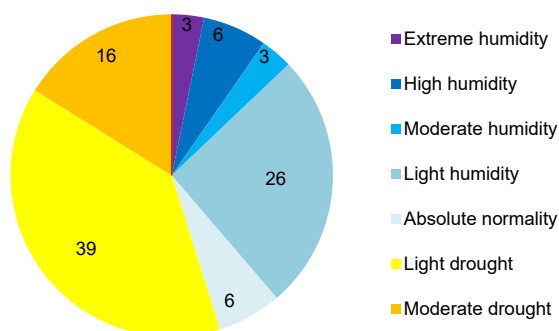


Fig. 13. Percentage share of years with a certain cold and hot degree during the period (1979/1980–2009/2010) at Boucheougouf station; source: own study

The use of statistical tests makes it possible to detect the years of break on the different series of rainfall, hydrometric and temperature observations. The rainfall series analysis over the period 1979/1980–2009/2010, of the Wadi Mellah watershed, shows that the chronicles are not stationary and that they underwent at least one break in 1996/1997 in Mechroha and in 2001/2002 in Mechroha and Hammam N'bail. These results corroborate with those of the KHOUALDIA *et al.* [2014] study where significant primary breaks are detected in the rainfall series of the Medjarda watershed, in Ain Dalia 1996/1997 and El Kouif (2001/2002). It is noted that the majority of breaks are localized in the 80's and 90's. According to NOUACEUR [2011] the last period concerns the end of the series 2002–2006. The analysis of rainfall data from this last phase showed an increase in the frequencies from wet to very

humid years. Observations made in 2007, 2008, 2009 and 2010 also confirm the predominance of wetter conditions, since the Ministry of Agriculture, Rural Development and Fisheries (Fr. Ministère de l'Agriculture, du Développement Rural et de la Pêche) in Algeria has announced for this last year, a record cereal production of 6.2 mln Mg, a figure never reached by Algerian agriculture. The figures published by the Ministry of Water Resources and Environment of Algeria (Fr. Ministère des Ressources en Eau et de l'Environnement) also report a filling rate of the various dams over 70% over the last three years. In parallel with this trend, there is also a clear upsurge of thunderstorms in almost all stations. The rains falling on the Algerian territory have thus become more intense, this argument is also supported by an unprecedented increase in floods and devastating floods in the country.

In the western region of Algeria and for all tests, the break occurred during the decade 1970–1980, according to MEDDI and MEDDI [2009b], TALIA *et al.* [2011], GHENIM and MEGNOUNIF [2013] and GHERISSI [2018], who find a tendency to dry out from the late 1970s, especially since the 1980s. On the other hand in the eastern region of Algeria according to KHEZAZNA *et al.* [2017], the results of the Pettit test show that the mean annual rainfall series for Pont Bouchet, El Kerma, Mechroha, Medjaz Ammar and Nechmaya stations show significant change points between 1982 and 2001.

On all the tests, no break was detected in the Boucheougouf hydrometric station and the simple accumulation method confirms this result. For the temperatures, secondary break is observed in 1986/1987.

Several indices relating to drought are proposed and calculated in this paper (*SPI*, *STI*, *SSFI*), most of these indices take as reference the most frequent value which is generally the climatological average, or the frequency analysis thanks to which drought thresholds can be easily calculated. In general, the drought threshold is chosen according to the desired severity since there is no prior rule. The results show that drought is a recurring phenomenon. The average deviation method gives a percentage of 20–40% light drought, 7–20% moderate drought and 0–3% sharp drought and a percentage of 16–30% light humidity, 4–20% moderate humidity and 2–6% strong humidity, 2% extremely hot and humid years according to the classification by the standardized index. It appears that the meteorological drought, characterized by a rainfall deficit, automatically results in a hydrological drought expressed by a reduction of the surface flow.

CONCLUSIONS

Drought index (*SI*) can be helpful in providing warning of drought and help to assess the drought severity. It is spatially consistent and allows comparison between different locations and climate, also its probabilistic nature gives it a historical context well suited for decision making. In this study, the use of *SPI* has helped to describe droughts throughout the basin between 1979 and 2009. The region has experienced a change in climate since 2001. Rainfall has increased significantly, particularly in the Mechroha.

The study period was divided into two sequences; a dry sequence from 1979 to 2001, and a wet sequence from 2002 to 2009. The completion of the *SPI* indicators on the entire basin shows a heterogeneous distribution of precipitation across the Mellah basin either in the dry cycle or in the wet cycle. It shows that the Bouchegouf is most affected by the continuous drought conditions. This indicator significantly reflects the runoff performance of Wadi Mellah at the Bouchegouf hydrometric station. In the water level and there was a deficit in the period 1987/1988–2001/2002 and 2005/2006–2009/2010 using the *SSFI* index. The hydrological response to rainfall events is complex, with many factors influencing flows, including aquifer recharge. Thus, after a succession of excess flows, the decrease in *SSFI* is sometimes delayed.

The results of this study provide an important database for assessing risks to climate variability. In this context, the improvement of observing systems is necessary to have reliable and sufficient data to better characterize the climate and make good forecasts that should contribute to a better adaptation to the likely adverse effects of climate variability. These results can be used to predict droughts in Mellah watersheds that allow the effective planning and management of water resources and agricultural activities, as well as the development of drought adaptation measures.

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REFERENCES

- AOUN SEBAITI B. 2010. Gestion optimisée des ressources en eau d'une nappe côtière, application à la plaine d'Annaba (Nord-est Algérien). [Optimized management of the water resources of a coastal water table application to the plain of Annaba North-East Algeria]. Phd Thesis. University Lille1 Sciences et Technologies pp. 203.
- BOYER J.F. 1998. Chronostat version 1.0. Software for statistical analysis of time series [online]. ORSTOM Ed. Paris. Montpellier. Hydrosciences, IRD-House of Water Sciences. [Access 12.12.2018] Available at: <http://www.hydrosciences.org/spip.php?article1000>
- BRUNEAU P., CLAUDE J.C. 1983. Application d'un modèle bayésien de détection de changements de moyennes dans une série [Application of a Bayesian mean change detection model in a series]. Hydrological Sciences Journal. Vol. 28. Iss. 3 341–354.
- CHAOUI W., BOUSNOUBRA H., BENHAMZA M., BOUCHAMI T. 2013. Etude de la pollution des eaux des oueds Seybouse et Mellah (Région de l'Est Algérien) [Study of water pollution in the Seybouse and Mellah wadis (Eastern Algerian Region)]. Synthèse: Revue des Sciences et de la Technologie. No. 26 p. 50–56.
- DAGNELIE P. 1975. Théorie et méthodes statistiques: Applications agronomiques. Vol. 2. Les méthodes de l'inference [Theory and statistical methods: agronomic applications. Vol. 2. The methods of inference]. Gembloux. PA de Gembloux. ISBN 978-2-87016-010-7 pp. 463.
- DJELLOULI F., BOUANANI A., BABA-HAMED K. 2016. Efficiency of some meteorological drought indexes in different time scales, case study: wadi Louza basin NW-Algeria. Journal of Water and Land Development. No. 31 p. 33–41. DOI 10.1515/jwld-2016-0034.
- EDWARDS D.C. 1997. Characteristics of 20th century drought in the United States at multiple time scales. Master Thesis. Fort Collins. Colorado State University pp. 155.
- EDWARDS D.C., MCKEE T.B. 1997. Characteristics of 20th century drought in the united states at multiple time scales. Climatology Report. No. 97-2. Fort Collins. Colorado State University pp. 155.
- FARAH A.K. 2014. Changement climatique ou variabilité climatique dans l'Est Algérien [Climate change or climatic variability in eastern Algeria]. Magister Thesis. Constantine University 1 pp. 125.
- FASEL M. 2015. Calculation of the standardized temperature index. A set of functions for computing the standardized temperature index (STI). Package 'STI' pp. 7.
- FOSSOU R.M.N., SORO N., TRAORE V.B., LASM T., SAMBOU S., SORO T., OROU R.K., CISSE M.T., KANE A. 2014. Variabilité climatique et son incidence sur les ressources en eaux de surface : cas des stations de Bocanda et de Dimbokro, Centre-Est de la Côte d'Ivoire en Afrique de l'Ouest. [Climate variability and its impact on surface water resources: The case of Bocanda and Dimbokro stations, East-Central Côte d'Ivoire, West Africa]. Africa Science Journal. Vol. 10 (4) p. 118–134.
- GHENIM A.N., MEGNOUNIF A. 2011. Caractérisation de la sécheresse par les indices *SPI* et *SSFI* (nord-ouest de l'Algérie) [Drought characterization by *SPI* and *SSFI* index (North-West of Algeria)]. Le Journal de l'Eau et de l'Environnement. Vol. 10. No. 18 p. 59–77.
- GHENIM A.N., MEGNOUNIF A. 2013. Ampleur de la sécheresse dans le bassin d'alimentation du barrage Meffrouche (Nord-Ouest de l'Algérie) [Extent of drought in the catchment area of the Meffrouche dam (North-West of Algeria)]. Géographie Physique et Environnement. Vol. 7 p. 35–49. DOI 10.4000/physio-geo.3173.
- GHERISSI R. 2018. Modélisation hydrologique d'un bassin versant en climat méditerranéen par l'approche conceptuelle globale. cas de l'oued Lakhdar (ex: Chouly) (Tafna Nord Ouest Algerien) [Hydrological modeling of a watershed in the Mediterranean climate by the global conceptual approach. Case of the Lakhdar wadi (ex: Chouly) (Tafna North-West of Algeria)]. PhD Thesis. University of Tlemcen pp. 208.
- GUTTMAN N.B. 1993. On the sensitivity of sample L moments to sample size. Journal of Climate. Vol. 7 p. 1026–1029.
- HUBERT P., CARBONNEL J.P., CHAOUCHE A. 1989. Segmentation des séries hydrométéorologiques – application à des séries de précipitations et de débits de l'Afrique de l'ouest [Segmentation of the hydrometeorological series application to series of precipitations and flows of West Africa]. Journal of Hydrology. Vol. 110. Iss. 3–4 p. 349–367.
- IBRAHIM B. 2012. Caractérisation des saisons de pluies au Burkina Faso dans un contexte de changement climatique et évaluation des impacts hydrologiques sur le bassin du Nakanbé [Characterization of the rainy seasons in Burkina Faso in a context of climate change and evaluation of hydrological impacts on the Nakanbé basin]. PhD Thesis. Paris. University Pierre and Marie Curie pp. 240.
- KENDALL S.M., STUART A. 1943. The advanced theory of statistics. London. Charles Griffin pp. 457.
- KHEAZNA A., AMARCHI H., DERDOUS O., BOUSAKHRIA F. 2017. Drought monitoring in Seybouse Basin (Algeria) over the last decades. Journal of Water and Land Development. No. 33 p. 79–88. DOI 10.1515/jwld-2017-0022.
- KHOUALDIA W., DJEBBAR Y., HAMMAR Y. 2014. Caractérisation de la variabilité climatique: cas du bassin versant de La Medjerda (Nord-Est algérien) [Climatic variability characterisation: Case of Medjerda watershed (northeastern Algeria)].

- Synthèse: Revue des Sciences et de la Technologie. Vol. 29. No. 1 p. 6–23. DOI 10.12816/0027871.
- LEE A.F.S., HEGHINIAN S.M. 1977. A shift of the mean level in a sequence of independent normal random variables – A Bayesian approach. *Technometrics*. Vol. 19 (4) p. 503–506. DOI 10.1080/00401706.1977.10489592.
- LUBES-NIEL H., MASSON J., PATUREL J., SERVAT E. 1998. Variabilité climatique et statistiques. Etude par simulation de la puissance et de la robustesse de quelques tests utilisés pour vérifier l'homogénéité de chroniques [Climatic variability and statistics. A simulation approach for estimating power and robustness of tests of stationarity]. *Revue des sciences de l'eau*. Vol. 11 (3) p. 383–408. DOI 10.7202/705313ar.
- MCKEE T.B., DOESKEN N.J., KLEIST J. 1993. The relationship of drought frequency and duration to time scales. Eighth Conference on Applied Climatology. 17–22 January 1993. Anaheim, California. Boston. American Meteorological Society, Boston p. 179–184.
- MEBARKI A. 2009. Ressource en eau et aménagement en Algérie (Les bassins hydrographiques de l'Est) [Water resources and development in Algeria (Eastern watersheds)]. Alger. OPU. ISBN 9789961012383 pp. 389.
- MEDDI H., MEDDI M. 2009a. Etude de la persistance de la sécheresse au niveau de sept plaines Algériennes par utilisation des chaînes de Markov (1930–2003) [Study of the persistence of drought in seven Algerian plains by use the Markov chains (1930–2003)]. *Courier of Knowledge Biskra*. No. 9 p. 39–48.
- MEDDI H., MEDDI M. 2009b. Variabilité des précipitations annuelles du Nord-Ouest de l'Algérie [Variability of annual rainfall in northwestern Algeria]. *Sécheresse*. Vol. 20. No. 1 p. 57–65.
- MERABTI A. 2018. Caractérisation, variabilité et prévision de la sécheresse dans le Nord-est Algérien [Characterization, variability and prediction of drought in northeastern Algeria]. Extended Abstract of PhD Thesis. Blida. Ecole Nationale Supérieure d'Hydraulique pp. 10.
- MERRIAM C.F. 1937. A comprehensive study of the rainfall on the Susquehanna Valley. *American Geophysical Union*. No. 2 p. 471–476.
- MODARRES R. 2007. Streamflow drought time series forecasting. *Stochastic Environmental Research & Risk Assessment*. Vol. 21. Iss. 3 p. 223–233. DOI 10.1007/s00477-006-0058-1.
- NDIAYE B. 2003. Impacts du climat et des aménagements sur le régime hydrologique du Mouhoun [Impacts of climate and development on the Mouhoun hydrological regime]. Master Thesis. Benin. Ecole Inter-états d'ingénieurs de l'Équipement Rural pp. 110.
- NOUACEUR Z. 2011. Vers un retour des pluies sur la rive sud du bassin méditerranéen occidental: analyse et évaluation de la tendance pluviométrique sur plus d'un demi-siècle en Algérie [Towards a return of rains on the southern shore of the western Mediterranean basin: analysis and evaluation of the rainfall trend over more than half a century in Algeria]. *The Annals of Valahia University of Târgoviște*. No. 11 p. 31–36.
- OLANIRAN O.J. 1991. Evidence of climatic change in Nigeria based on annual series of rainfall of different daily amounts, 1919–1985. *Climatic Change*. No. 19 p. 319–341.
- OTMANE A., BABA-HAMED K., BOUANANI A., KEBIR L.W. 2018. Mise en évidence de la sécheresse par l'étude de la variabilité climatique dans le bassin versant de l'oued Mekerra (Nord-Ouest Algérien) [Demonstration of drought by the study of climatic variability in the watershed of Wadi Mekerra (North-West Algeria)]. *Techniques Sciences Méthodes*. No. 9 p. 23–37. DOI 10.1051/tsm/201809023.
- PATUREL J.E., SERVAT E., DELATTRE M.O., LUBES-NIEL H. 1998. Analyse de séries pluviométriques de longue durée en Afrique de l'Ouest et Centrale non sahélienne dans un contexte de variabilité climatique [Analysis of long-term rainfall series in non-Saharan West and Central Africa in a context of climatic variability]. *Journal of Hydrological Sciences*. Vol. 43. Iss. 6 p. 937–946.
- RYBSKI D., NEUMANN J. 2011. A review on the Pettitt test. In: *Extremis*. Eds. J. Kropp, H.J. Schellnhuber. Berlin-Heidelberg. Springer p. 202–213.
- SORO G.E., ANOUMAN D.G.L., GOULA Bi T.A., SROHOROU B., SAVANE I. 2014. Caractérisation des séquences de sécheresse météorologique à diverses échelles de temps en climat de type soudanais : Cas de l'extrême nord-ouest de la Côte d'Ivoire [Characterization of meteorological drought sequences at various time scales in Sudanese-type climate: Case of the extreme north-west of Ivory Coast]. *Larhyss Journal*. No. 18 p. 107–124.
- SOUBEYROUX J.M., KITOVA N., BLANCHARD M., VIDAL J.P., MARTIN E., DANDIN P. 2012. Sécheresses des sols en France et changement climatique: Résultats et applications du projet ClimSec [Characterization of soil dryness in France and climate change: Results and applications of the ClimSec project]. *La Météorologie*. No. 78 p. 21–30. DOI 10.4267/2042/47512.
- SVOBODA M., HAYES M., WOOD D. 2012. for the standardized precipitation index. User Guide. WMO-N°1090. Geneva. World Meteorological Organization. ISBN 978-92-63-11090-9 pp. 16.
- TALIA A., MEDDI M., BEKKOUSSA B.S. 2011. Étude de la variabilité de la pluviométrie dans les hauts plateau et le Sahara algériens [Study of the variability of rainfall in the Algerian highlands and Sahara]. *Sécheresse*. Vol. 22. No. 3 p. 149–158. DOI 10.1684/sec.2007.0099.
- THORSTEN P. 2018. Non-parametric trend tests and change-point detection [online]. Technical Report pp. 18. [2.01.2018]. Available at: <https://cran.r-project.org/web/packages/trend/vignettes/trend.pdf>
- WMO 1966. Climatic change. Report of a working group of the Commission for Climatology. Technical note. No. 79. Geneva. World Meteorological Organization pp. 79.

Lina BENDJEMA, Kamila BABA-HAMED, Abderrazak BOUANANI

Charakterystyka wskaźników suszy klimatycznej w zlewni Mellah w północno-wschodniej Algierii

STRESZCZENIE

Susza jest jednym z ważnych zjawisk wywoływanych zmianami klimatu. Wywiera ujemny wpływ na gospodarkę, rolnictwo i społeczeństwo. Celem przedstawionych badań było śledzenie sytuacji suszy klimatycznej w skali roku w zlewni Mellah (północno-wschodnia Algieria) w ciągu 31 lat przez obliczenia: standaryzowanego wskaźnika opadu (*SPI*), standaryzowanego wskaźnika przepływu (*SSFI*) i standaryzowanego wskaźnika temperatury (*STI*). Obliczenia z zastosowaniem testów Petitta, rang, Lee i Heghiniana oraz Huberta i Buishanda umożliwiły dokładniejsze ustalenie okresów suszy przez analizę intensywności, czasu trwania i częstotliwości, umożliwiły też wykrycie lat przerw w ciągach suszy. Dzięki testom statystycznym dla serii analizowanych opadów wykazano okresy przerw, głównie w latach 1996/1997 i 2001/2002. Dane temperaturowe wskazywały na okresy przerw w latach 1980/1981.

Słowa kluczowe: *przerwanie suszy, susza, wilgotność, wskaźnik suszy, zlewnia Mellah*
