Drought monitoring in the Seybouse basin (Algeria) over the last decades

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Abstract

Algeria is amongst the African countries most affected by climate change impacts especially by drought which caused considerable economic losses in the past decades. In this paper, drought monitoring for the period between 1970 and 2011 was conducted in the Seybouse watershed by analysing annual rainfall data in terms of variability and trends along with the calculation of the standardized precipitation index (*SPI*). The results indicated important inter-annual rainfall fluctuation and a significant increasing trend. The estimated drought indices indicated that the Seybouse watershed experienced in the past a long dry period with a moderate severity followed by a long wet period at the majority of the study area. Moreover, the interpolation of the standardized precipitation indices (*SPI*) on the entire Seybouse basin in GIS allowed visualizing and evaluating the spatial-temporal evolution of drought in the region which should help the decision-makers in the management of water resources, agriculture and other activities that may be affected by drought.

Key words: *climate change, drought, GIS, Seybouse watershed, standardized precipitation index (SPI)*

INTRODUCTION

Drought is one of the most important natural hazards that presented a serious problem for human societies and ecosystems across generations. According to WILHITE and GLANTZ [1985] drought is classified into four categories: (i) Meteorological drought; defined as a lack of precipitation for a period of time over the affected area; (ii) Hydrological drought defined as an insufficiency in surface and subsurface water resources supply; (iii) Agricultural drought refers to a period with soil moisture deficit, which affects the crop productivity; (iiii) Socioeconomic drought is associated with insufficient water resources

supply to satisfy the economic needs in the affected region.

To face this hazard, men tried to appreciate the phenomenon by trying to understand the climate cycles through the study of the variability and the trends of different climatic variables especially rainfall and temperatures [BALLING *et al*. 1998; HE, GAUTAM 2016; NICHOLSON 1989; VINNIKOV *et al*. 1990; ZHAI, PAN 2003].

Since 1900, several indices were developed to identify and to assess the severity of drought, such as the rainfall anomaly index (*RAI*) [VAN ROOY 1965], the Palmer drought severity index (*PDSI*) [PALMER 1965], and the standardized precipitation index (*SPI*) [MCKEE *et al*. 1993; 1995] this latter is recommended

by many organizations such as the World Meteorological Organization (WMO) and the United States National Oceanic and Atmospheric Administration (NOAA) for characterizing meteorological droughts as well as the other categories of droughts [MOREIRA *et al.* 2016] due to its simplicity ,its robustness, and flexibility for drought analysis as it can be used at different time scales (e.g., weekly, monthly, yearly) [HAYES *et al.* 1999].

The last century in African was marked by drought phenomenon which affected many counties and caused colossal economic loss [OBA, LUSIGI 1987; SIRCOULON 1976] Algeria was not an exception, according to the studies of MEDJERAB, HENIA *et al.* [2005] the North West of Algeria experienced in the two last decades a severe drought characterized by rainfall deficits varying from 12% to 20%.

The studies of KETTAB *et al.* [2004] conducted for the period between 1980 and 1990 noted a rainfall deficit of about 50% in the central regions of Algeria, while it come up to 30% in the westernand the eastern parts.

At a larger regional scale, LABORDE [1993] studied rainfall data of 120 stations Northern Algeria, the results indicated an alternation of wet and dry sequences; (i) a long wet sequence from 1922 to 1938 characterized by rainfall excess of about 6%. (ii) A dry sequencefrom 1939 to 1946 in the eastern and the centre parts of Algeria with a rainfall deficit of about 11%. (iii) A wet sequence from 1947 to 1972 (iiii) and a long dry sequence that starts from 1973.

This paper aims at assessing the spatial and temporal evolution of drought over the Seybouse watershed (North-eastern Algeria) for the period between 1970 and 2011 by analysing precipitation series using a number of tests (Mann–Kendall, Sen's slope estimator, Pettitt) and by calculating and mapping the standardized precipitation index (*SPI*).

STUDY AREA AND DATA

STUDY AREA

The Seybouse watershed which covers an area of 6471 km^2 is located in the North East of Algeria between the latitudes 36°15' and 37°00' North and the longitudes 7°15' and 7°55' East, it is part of the Hydrographic Region Constantine – Seybouse – Mellegue, bordered North by the Mediterranean Sea and south by the high plateaus of Constantine (Fig. 1). The study area is characterized by a Mediterranean climate with hot and dry summer, and cold and rainy winter. The mean annual rainfall ranges from 1167.96 mm at Mechrouha to 507.97 mm at Ain Makhlouf (Tab. 2), which indicates a heterogeneous spatial distribution of rainfall over the study area. The Seybouse watershed has three main watercourses which are the Bouhamdane, the Charef and the Seybouse rivers. The Seybouse River begins in Medjaz Amar at the confluence of the two other rivers and runs for about 225 km
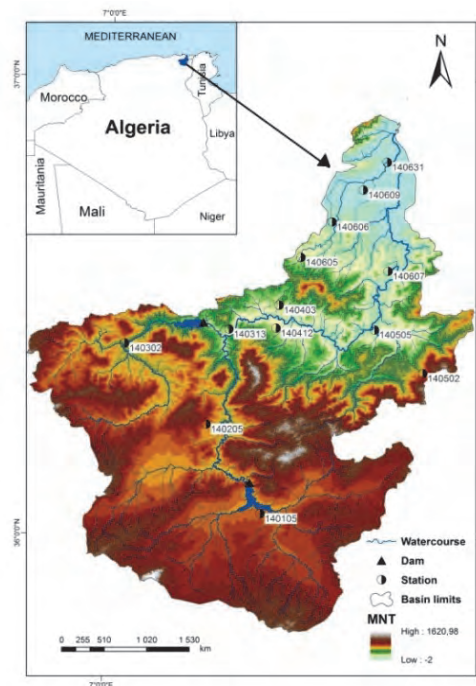

Fig. 1. Map of the Seybouse watershed
and hydrometric station; source: own elaboration

North ending in the South-East of Annaba city into the Mediterranean Sea with an average annual flow of 11.5 m^3·s^{-1}.

RAINFALL DATA

The study of climate requires long and many series of observations. The quality of data represents a major element in these studies [MEDDI, HUBERT 2003]. In this study, 13 rainfall stations (Tab. 1) managed by the National Agency of Water Resources (ANRH) was used to create as possible the most complete and representative annual data-base of the zone of study (Fig. 1). The data collected from these stations follow the criteria of quality and quantity. The series of observations taken into account spread over 42 years between 1970 and 2011.

Table 1. Characteristics of rainfall stations in the Seybouse watershed

Stations	x	y	Code
Pont Bouchet	387676.538	4075860.31	140631
Ain Barda	374436.463	4061429.10	160606
Nechmeya	366951.782	4052869.16	140605
Boukamouza	387853.440	4049493.79	140607
Bouchegouf	384626.796	4035289.75	140505
Guelma (Fendjel)	360987.538	4035719.82	140412
Heliopolis	361718.010	4041294.87	140403
Mechrouha	396191.581	4024729.98	140502
El Karma	381949.053	4069154.17	140609
Medjaz Amar	349708.384	4035499.41	140313
Ain Makhlouf	344190.352	4012483.12	140205
Charef (El Khenga)	357146.418	3990797.14	140105
Ain Sabath	324651.829	4032145.71	140302

Source: National Agency of Water Resources [ANRH 2009].

The principal statistical characteristics of the rainfall series are presented in the Table 2.

The statistical analysis conducted on the annual rainfall series shows that their distribution is Asymmetric. We noted also a significant difference between the position's parameters (average, median). The co-efficient of variation for annual rainfall is characterized by high fluctuations especially at the stations Mechrouha and Nechmeya where the coefficient of variation is at 43% and 40% respectively, while it ranges from 24% and 33% at the other stations.

Table 2. Statistical characteristics of the rainfall data

Station	Mean rainfall	Median	Minimum	Maximum	Standard deviation	Coefficient of variation	Coefficient of skewness	Sen's slope	p value of MK
	mm								
Pont Bouchet	602.64	590.40	349.64	933.60	155.84	0.26	0.37	5.170	0.010
Ain Berda	630.88	595.80	368.20	973.00	153.14	0.24	0.22	3.425	0.114
Bouchegouf	547.96	537.65	279.30	884.00	150.22	0.27	0.42	1.926	0.343
Boukamouza	685.07	675.40	380.50	1212.91	198.55	0.29	0.49	4.019	0.187
El Kerma	608.43	601.54	296.30	976.08	174.97	0.29	0.21	6.921	0.004
Guelma	531.68	530.00	222.60	802.00	141.95	0.27	0.00	2.219	0.262
Heliopolis	581.26	547.05	279.10	1100.20	170.42	0.29	0.85	0.219	0.863
Mechrouha	1167.96	1066.40	298.60	2158.24	498.30	0.43	0.10	24.844	0.001
Medjaz Amar	561.68	534.00	309.10	946.40	1593.01	0.28	0.40	5.503	0.005
Nechmeya	593.66	527.17	264.95	1353.46	239.79	0.40	1.10	6.654	0.013
Ain Makhlouf	507.97	490.60	107.19	1176.10	166.03	0.33	1.56	–0.461	0.763
Charef	574.24	546.03	343.90	1065.60	165.87	0.29	1.14	1.145	0.682
Bordj Sabath	542.19	538.75	264.30	928.50	151.70	0.28	0.76	3.740	0.048

Source: own study.

METHODS

ANALYSES OF THE HOMOGENEITY OF THE RAINFALL DATA

Homogeneity of rainfall data was performed to define the trends and the change points in the annual rainfall time series using: (i) the Mann–Kendal test, (ii) Sen's slope, and (iii) the Pettitt test.

MANN–KENDALL TEST

The non-parametric Mann–Kendall (MK) test proposed by MANN [1945] and extended by KENDALL *et al.* [1975] is used in this study to detect trends in rainfall data. This technique recognizes any trend in a given time series, without specifying whether the trend is linear or not [HISDAL *et al.* 2001]. The MK test was widely used to test the trend of meteorological and hydrological data as it accepts missing values in the time series [PATRA *et al.* 2012; PINGALE *et al.* 2015; 2016; WU *et al.* 2008].

Test statistic S defined as [TAXAK *et al.* 2014]:

$$S = \sum_{i-1 j}^{n-1} \sum_{i+1}^{n} \text{sgn}(x_j - x_i) \qquad (1)$$

where: x_j = the sequential data values; n = length of the data set

$$\text{sgn}(y) = \begin{cases} 1... \text{if } y > 0 \\ 0... \text{if } y = 0 \\ -1... \text{if } y < 0 \end{cases} \qquad (2)$$

It has been documented that when $n \geq 8$, the statistic S is approximately normally distributed with the mean $E(s) = 0$ and variance as

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i-1}^{m} t_i(t_i - 1)(2t_i + 5)}{18} \qquad (3)$$

where: m = the number of tied groups; t_i = the size of the ith tied group.

Monte Carlo simulation was used to assess the statistical significance of the trends at a significance level of 5%. At this level, a positive trend is significant when p-value > 0.05, and a negative trend is significant when its p-value < 0.05 [FINIGURE *et al.* 2016; YUE, PILON 2004]. The null hypothesis H_0 assumes that there is no trend in the series, which means that they are homogeneous [DOUGLAS *et al.* 2000].

SEN'S SLOPE ESTIMATOR

The trend magnitude is estimated using a non-parametric median based slope estimator proposed by SEN [1968] and HIRSCH *et al.* [1984]. The Sen's slope is given by the following expression [SALARIJAZI *et al.* 2012]:

$$\beta = \text{median}\left[\frac{x_j - x_k}{j - k}\right] \text{ for all } k < j \qquad (4)$$

where: $1 < k < j < n$, and β is considered as median of all possible combinations of pairs for the whole data set.

CHANGE POINT TEST

The change point test proposed by PETTITT [1979] derived from the Mann–Whitney statistical test is adopted in this study to identify the presence and timing of non-stationarity in the form of an abrupt

shift in the mean annual rainfall series. It is a non-parametric test that requires no assumption about the distribution of data. This test has been widely used to detect change points in the observed meteorological and hydrological time series [TAXAK *et al.* 2014].

The change point *t* is detected by determining if the mean time series can be divided in two statistically different series before and after *t*. The null hypothesis H_0 states that no shift exists in the time series at time *t* which means that both means of the subseries are consistent. The alternative hypothesis *Ha* is that change-point exists at time *t*, in which *t* = 1, …, *n* as all possible subdivisions of the time series are measured, since t is unknown here [ISHAK 2014].

In the present study, the significance of the test is assessed using the Monte Carlo resampling procedure which computes the corresponding *p*-values at the level of significance of 5%. At this level, a change-point exists when *p*-value < 0.05.

ANALYSIS OF THE RAINFALL DATA BY PLUVIOMETRIC INDICES

The standardized precipitation index (*SPI*) method proposed by MCKEE *et al.* [1993; 1995] was employed in this study to analyse the rainfall data by identifying dry and wet sequences and assessing the severity of drought. As over-mentioned the *SPI* method is a highly recommended technique, as well it was employed in several researches all around the world [AWANGE *et al.* 2016; BONACCORSO *et al.* 2003; HAYES *et al.* 1999; ZHOU, LIU 2016].

The calculation of *SPI* requires at least 30 years of rainfall data which allow evaluating the probability distribution function, this latter is normalized to have the mean of zero. The values of *SPI* are expressed in standard deviations where positive *SPI* indicating greater than median rainfall designate wet condition, while negative values indicating less than median rainfall designate wet condition [EDWARDS *et al.* 1997].

Mathematically the *SPI* is calculated using the following expression:

$$SPI = \frac{1(P_i - P_m)}{\sigma} \qquad (5)$$

where: P_i = the actual rainfall (mm), P_m = the mean rainfall, σ = the standard deviation.

Drought severity is identified through *SPI* values according to the classification scheme (Tab. 3) pro-

Table 3. Classification of drought severity based on *SPI*

Drought category	SPI classification
Extremely wet	$SPI \geq 2$
Very wet	$1 \leq SPI < 2$
Moderately wet	$0 \leq SPI < 1$
Moderately dry	$-1 < SPI < 0$
Severely dry	$-2 < SPI \leq -1$
Extremely dry	$SPI \leq -2$

Source: MCKEE *et al.* [1993], modified.

posed by MCKEE *et al.* [1993], and used in several studies in the Maghreb region [ALI, LEBEL 2009; ARDOIN-BARDIN 2004; ARDOIN-BARDIN *et al.* 2003; BERGAOUI, ALOUINI 2002].

RESULTS AND DISCUSSION

HOMOGENEITY ANALYSIS

The results of the Mann–Kendall test (Tab. 2) indicated that the null hypothesis *Ho* is accepted for Ain Berda, Bouchegouf, Boukamouza, Guelma, Heliopolis, Ain Makhlouf, and Charef stations (*p*-value > 0.05), with magnitudes of trends equal, respectively, to 0.1141, 0.3426, 0.1875, 0.2617, 0.8633, 0.7631, 0.6824. The mentioned stations present certain homogeneity of annual rainfall data at 5% level of significance. On the other hand, the probability of the null hypothesis is rejected for Pont Bouchet, El Kerma, Mechrouha, Medjaz Amar, Nechmeya and Bordj Sabath stations with magnitudes of trends equal, respectively, to 0.0099, 0.0038, 0.0004, 0.0054, 0.0129 and 0.0482.

According to Sen slope estimates at 5% level of significance (Tab. 2), only Ain Makhlouf station showed a negative trend (–0.461). The other stations showed significant positive trends ranging from 0.219 (Heliopolis) to 24.844 (Mechrouha).

Table 4 illustrates the results of the change point test of Pettitt conducted on the mean annual rainfall of the 13 stations of the Seybouse watershed.

Table 4. Results of Pettitt test

Station	*p*-value	Year	Trend
Pont Bouchet	0.0472	2001	Ha
Ain Berda	0.1255	2001	Ho
Bouchegouf	0.3865	1994	Ho
Boukamouza	0.2941	2000	Ho
El Kerma	0.0044	2001	Ha
Guelma	0.6165	2001	Ho
Heliopolis	0.7774	2001	Ho
Mechrouha	0.0001	1996	Ha
Medjaz Amar	0.0116	1982	Ha
Nechmeya	0.0113	1989	Ha
Ain Makhlouf	0.9056	–	Ho
Charef	0.1645	–	Ho
Bordj Sabath	0.1063	2001	Ho

Explanations: Ha = heterogeneous series, Ho = homogenous series.
Source: own study.

The results show that the mean annual rainfall series of Pont Bouchet, El Kerma, Mechrouha, Medjaz Ammar and Nechmaya stations have significant change points that occurred between 1982 and 2001 (Fig. 2), the hypothesis of homogeneity is rejected for these stations at 5% level of significance. The test indicated also that the hypothesis of homogeneity is valid in the other stations as Non-significant change points were detected in their rainfall series (*p* value ≥ 0.05).
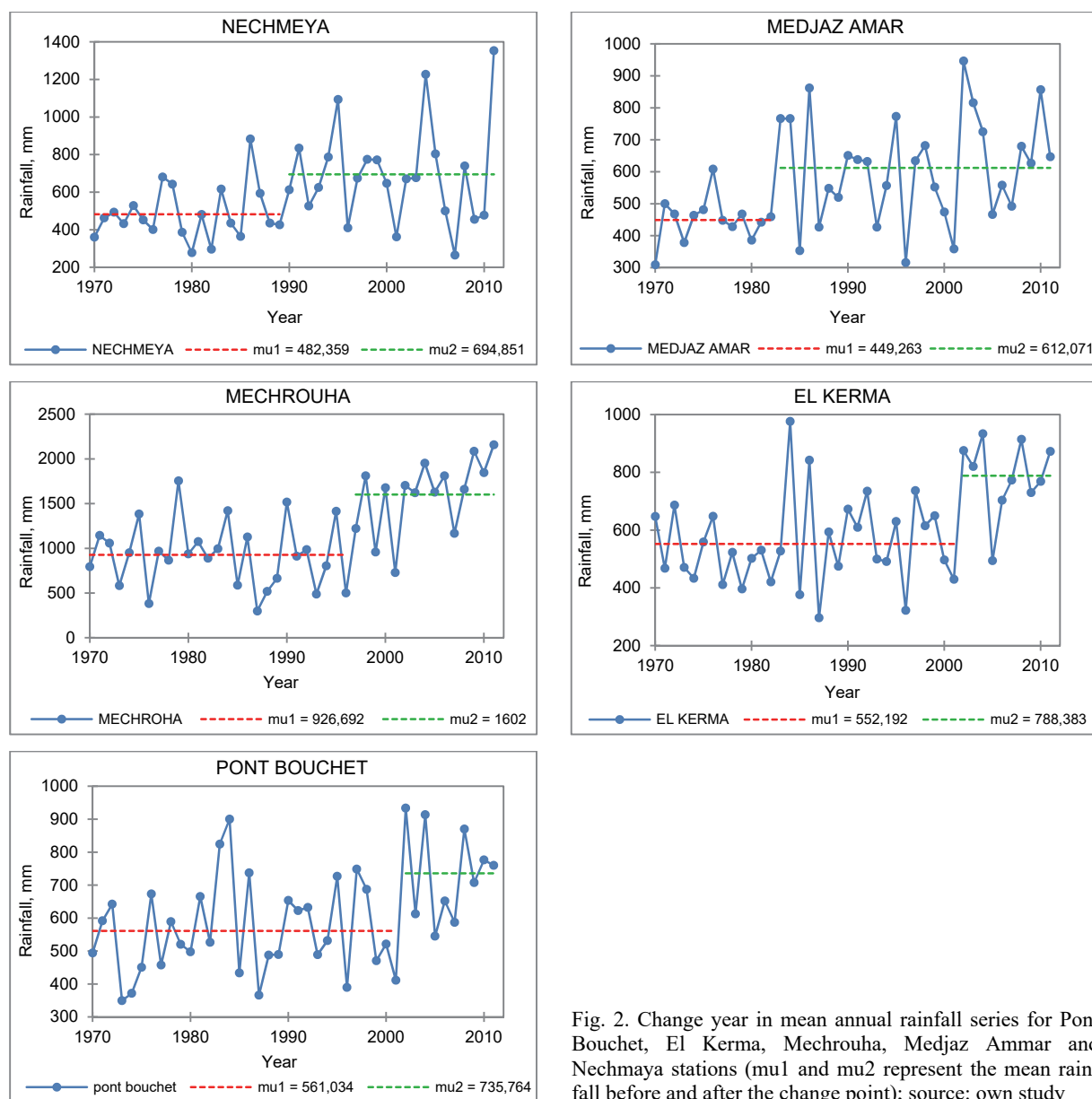
Fig. 2. Change year in mean annual rainfall series for Pont Bouchet, El Kerma, Mechrouha, Medjaz Ammar and Nechmaya stations (mu1 and mu2 represent the mean rainfall before and after the change point); source: own study

RAINFALL ANALYSIS BY PLUVIOMETRIC INDEX

The *SPI* indices were calculated for the 13 rainfall stations of the Seybouse basin in order to differentiate dry, normal, and wet periods and to better evaluate the variations in the annual rainfall over the Seybouse basin.

In the 70s, the 80s and early 90s, with the exception of Mechrouha station, we observed mostly negative SPI values which are often less than –1 (Fig. 3).

In the mid-90s until 2011, with the exception of Ain Makhlouf and Guelma stations, we observed mostly positive SPI values which are often greater than 1, negative SPI values are less frequent (Fig. 3).

According to the table below which presents the statistical characteristics of the 5 years average *SPI* indices, the studied period can be divided in two sequences; a dry sequence that begins in 1970 and ends in 1994 with negative average *SPI* values that range

from –0.54 to –0.07, and a wet sequence from 1995 to 2011 with positive average *SPI* values that range from 0.06 to 0.85.

Figure 4 illustrates the spatial and temporal variability of the pluviometric indices over the Seybouse basin; the maps were created in geographic information system (GIS) environment by interpolating SPI values of the 13 stations using a Kriging interpolation type.

According to the *SPI* maps, during the period 1970–1994, deficit of rainfall associated with (i) moderately dry conditions were widely observed through the Seybouse watershed, (ii) and with extremely dry conditions recorded in some limited areas (Medjaz Ammar in 1970–1974 and Charef in 1985–1989). This period was also marked by an excess of rainfall associated with moderately wet conditions which was persistent in the central-eastern area (Mechrouha).
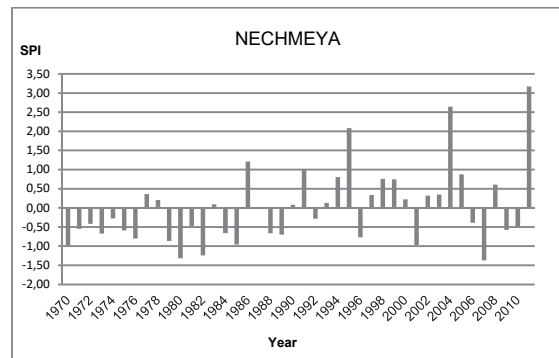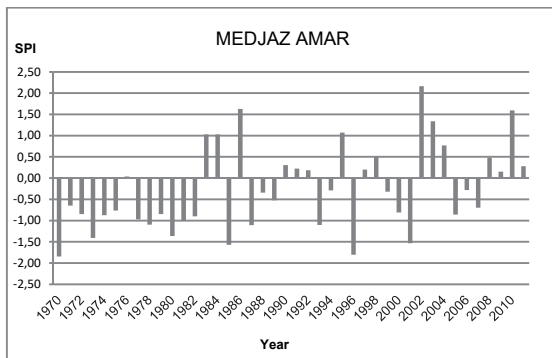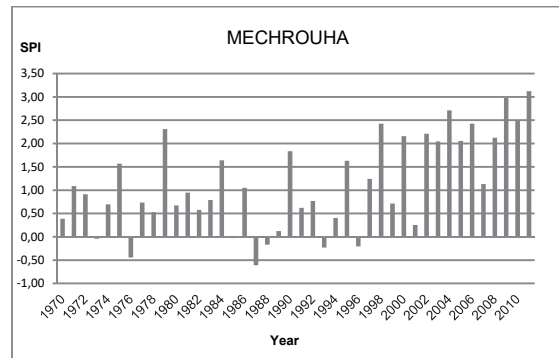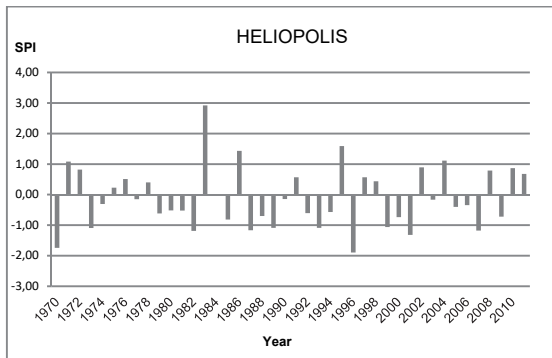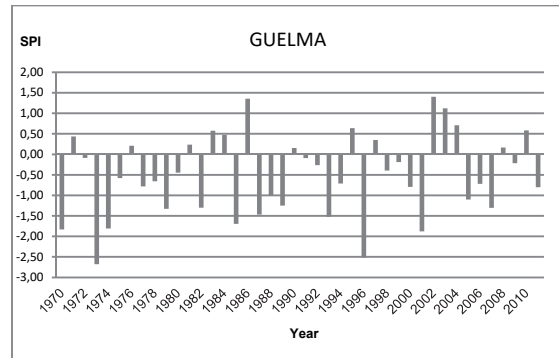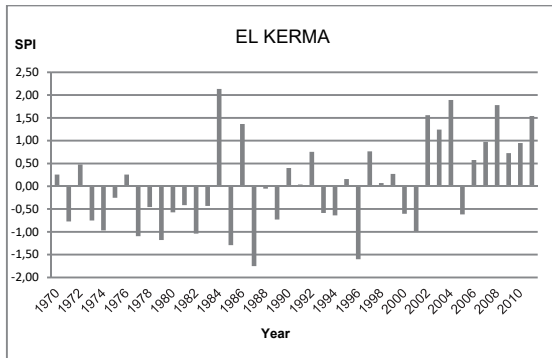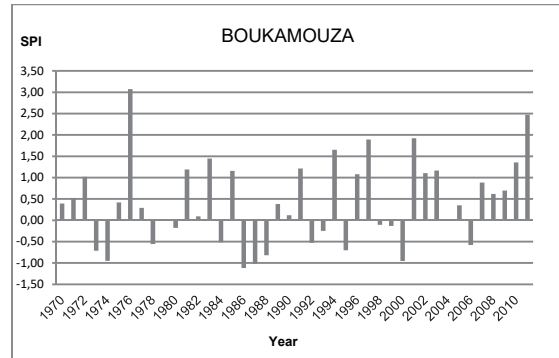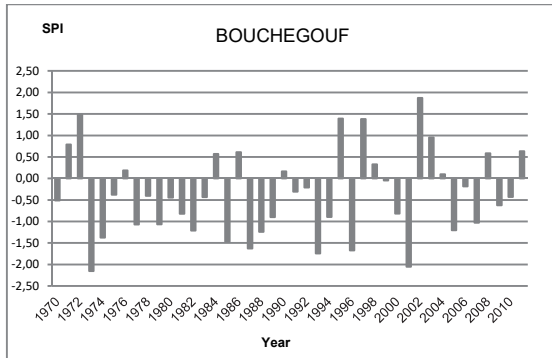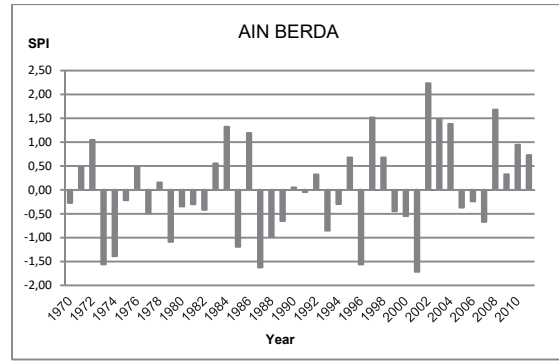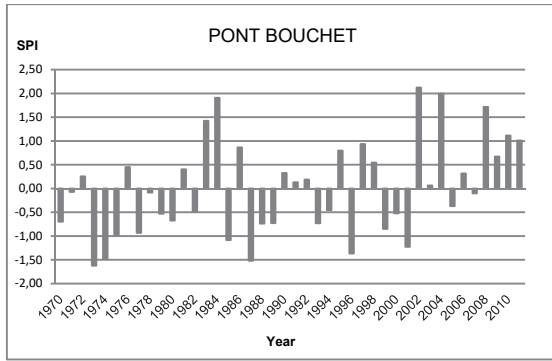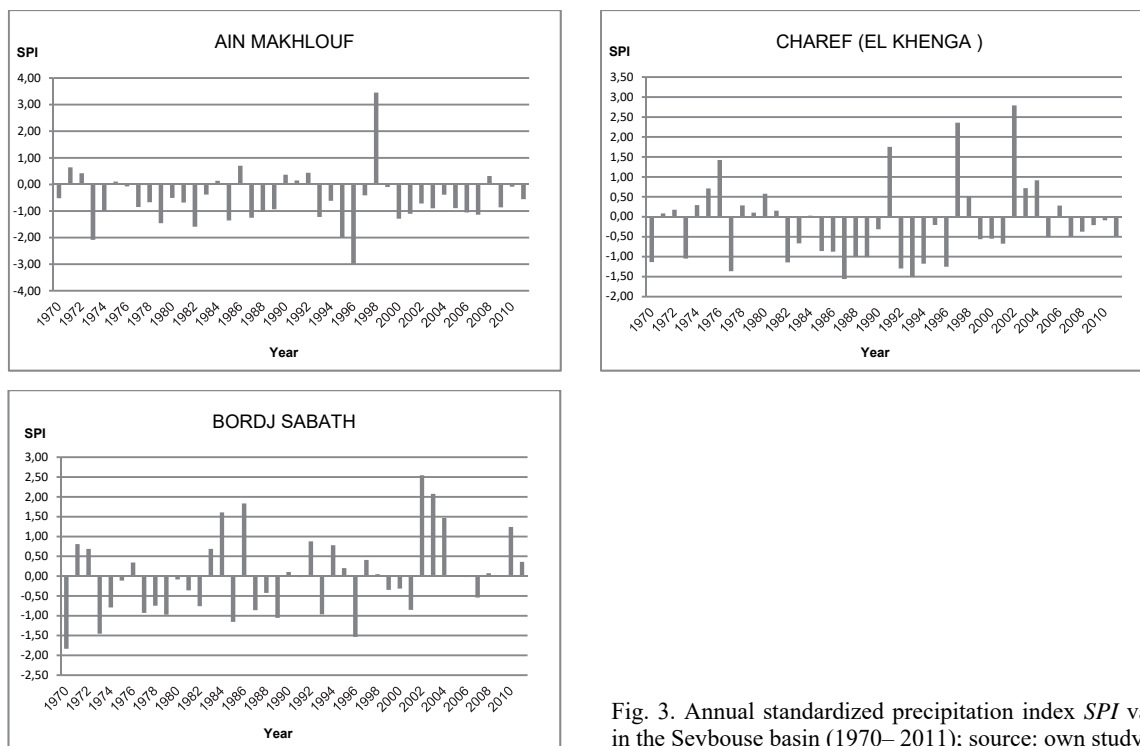
Fig. 3. Annual standardized precipitation index *SPI* values in the Seybouse basin (1970– 2011); source: own study

Table 5. Statistical characteristics of the 5 years average *SPI* values for the study area

Characteristics	Dry cycle					Wet cycle				1970–2011
	1970–1974	1975–1979	1980–1984	1985–1989	1990–1994	1995–1999	2000–2004	2005–2009	2010–2011	
Average	–0,43	–0,21	–0,003	–0,54	–0,07	0,12	0,46	0,06	0,85	0,03
Minimum	–1,19	–0,73	–0,72	–1,06	–0,60	–0,42	–0,88	–0,73	–0,32	–1,19
Maximum	0,61	0,94	0,92	0,07	0,68	1,16	1,88	2,14	2,81	2,81
Standard deviation	0,46	0,52	0,47	0,31	0,39	0,44	0,63	0,76	0,89	0,19
Average deviation	0,32	0,42	0,37	0,25	0,30	0,32	0,41	0,54	0,64	0,09

Source: own study.

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.

CONCLUSIONS

In this study drought analysis was conducted in the Seybouse watershed for the period between 1970 and 2011 by analysing rainfall data using non-parametric tests and the *SPI* method.

The statistical analysis of the rainfall data indicated that the evolution of the mean annual rainfall series is characterized by significant irregularities expressed by significant coefficients of variation and a statistically significant increase in the mean annual rainfall. As well, the climatic variability in the study area was confirmed by the Pettitt test which detected the presence of shifts in the mean annual rainfall series. These shifts were significant at 5 stations from the 13 stations under study.

According to the standardized precipitation index calculations the studied period was divided in two sequences; a dry sequence from 1970 to 1999, and a wet sequence from 1999 to 2011, which is in good agreement with the results obtained by LABORDE [1993]. Which noted a significant rainfall downward in the North of Algeria after the 70s and agrees as well with the studies of KHOUALDIA *et al.* [2014] which indicated the return of normal precipitation between 2001 and 2007

The interpolation of *SPI* indices on the entire basin shows a heterogonous distribution of rainfall through the Seybouse basin either in the dry cycle or in the wet cycle and showed that the central part of the Seybouse basin was affected by persistent drought conditions.

The study results constitute valuable material that can be used in forecasting droughts in the Seybouse watershed which permits effective planning and management of water resources and agriculture activities, and moreover, elaborating adaptation measures to face drought periods.
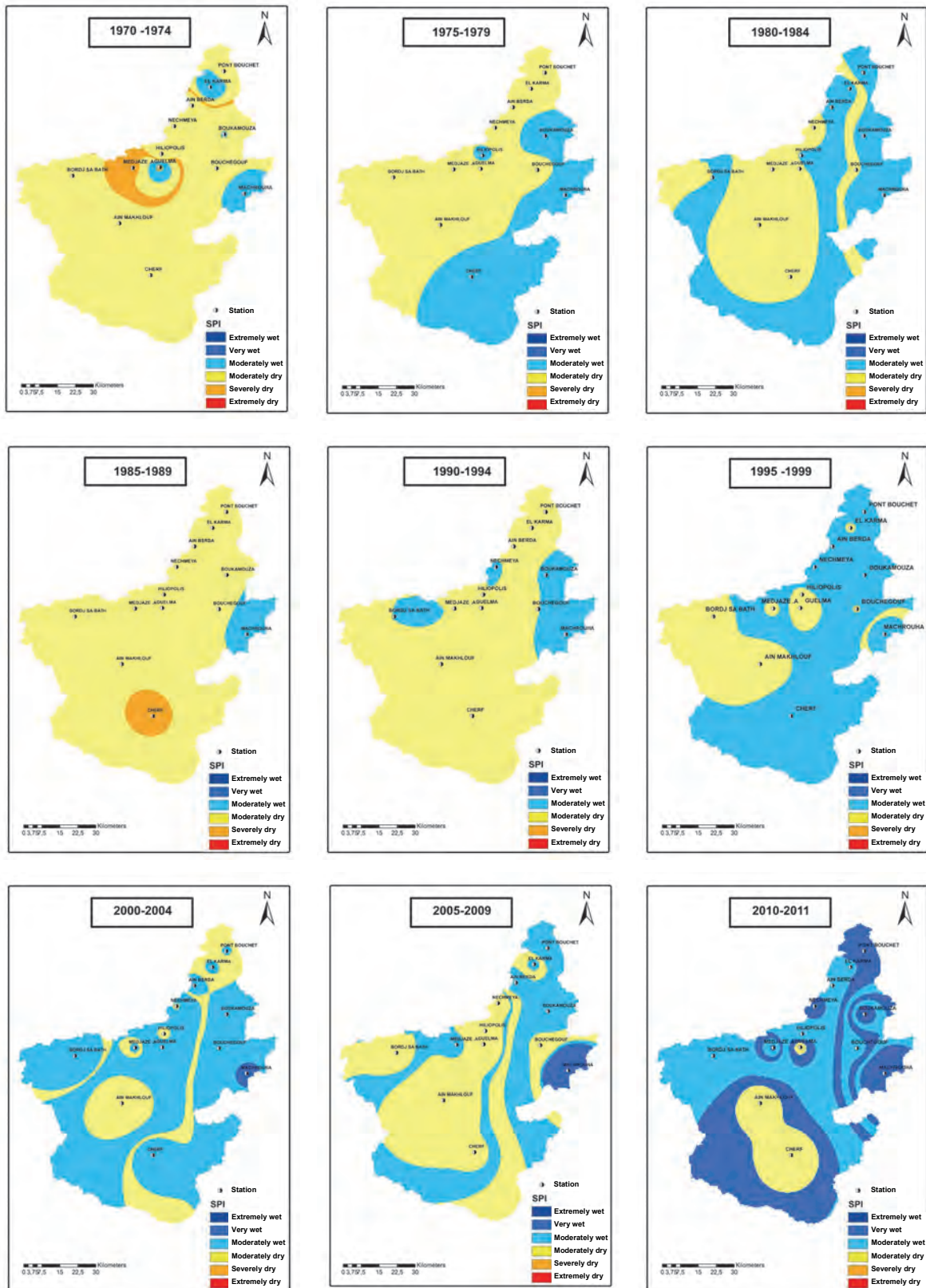
Fig. 4. Spatiotemporal monitoring of drought using standardized precipitation index (*SPI*), 1970–2011; source: own study

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Monitorowanie suszy w basenie Seybouse w Algierii w ciągu ostatnich dziesięcioleci

STRESZCZENIE

Algieria jest jednym z krajów Afryki najsilniej doświadczanych przez wpływ zmian klimatu, w szczególności przez susze, które w minionych dziesięcioleciach powodowały znaczne straty gospodarcze. W prezentowanych badaniach przeprowadzono monitoring susz w latach 1970–2011 w zlewni rzeki Seybouse, analizując zmienność i trendy rocznych opadów oraz obliczając standaryzowany indeks opadów (SPI). Wyniki dowodzą dużej zmienności opadów między latami i ukazują istotną tendencję wzrostową. Oszacowane wskaźniki suszy wskazują, że zlewnia Seybouse doświadczała w przeszłości długich okresów umiarkowanej suszy, po których następował długi okres wilgotnej pogody na większości badanych obszarów. Ponadto, interpolacja standaryzowanego wskaźnika opadu na całą zlewnię Sebouse za pomocą GIS umożliwiła wizualizację i ocenę rozwoju suszy w regionie. Powinno to pomóc decydentom w zarządzaniu zasobami wodnymi, rolnictwem i innymi rodzajami działalności, które mogą być zależne od suszy.

Słowa kluczowe: *GIS, standaryzowany indeks opadu (SPI), susza, zlewnia Seybouse, zmiany klimatu*