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; (iii) 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 Africa 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 westemand 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 sequence from 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 (iii) 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 km² 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 m³·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

<table>
<thead>
<tr>
<th>Stations</th>
<th>x</th>
<th>y</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pont Bouchet</td>
<td>387676.538</td>
<td>4075860.31</td>
<td>140631</td>
</tr>
<tr>
<td>Ain Barda</td>
<td>374436.463</td>
<td>4061429.10</td>
<td>160606</td>
</tr>
<tr>
<td>Nechmeya</td>
<td>366951.782</td>
<td>4052869.16</td>
<td>140605</td>
</tr>
<tr>
<td>Boukamouza</td>
<td>387853.440</td>
<td>4049493.79</td>
<td>140607</td>
</tr>
<tr>
<td>Bouchegouf</td>
<td>384626.796</td>
<td>4033289.75</td>
<td>140505</td>
</tr>
<tr>
<td>Guelma (Fendjel)</td>
<td>360987.538</td>
<td>4033719.82</td>
<td>140412</td>
</tr>
<tr>
<td>Heliopolis</td>
<td>361718.010</td>
<td>4041294.87</td>
<td>140403</td>
</tr>
<tr>
<td>Mechrouha</td>
<td>396191.581</td>
<td>4024729.98</td>
<td>140502</td>
</tr>
<tr>
<td>El Karma</td>
<td>381949.053</td>
<td>4060154.17</td>
<td>140609</td>
</tr>
<tr>
<td>Medjaz Amar</td>
<td>349708.384</td>
<td>4033499.41</td>
<td>140313</td>
</tr>
<tr>
<td>Ain Makhlouf</td>
<td>344190.352</td>
<td>4012483.12</td>
<td>140205</td>
</tr>
<tr>
<td>Charef (El Khenga)</td>
<td>357146.418</td>
<td>3990797.14</td>
<td>140105</td>
</tr>
<tr>
<td>Ain Sabath</td>
<td>324651.829</td>
<td>4032145.71</td>
<td>140302</td>
</tr>
</tbody>
</table>

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 coefficient 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

<table>
<thead>
<tr>
<th>Station</th>
<th>Mean rainfall (mm)</th>
<th>Median (mm)</th>
<th>Minimum (mm)</th>
<th>Maximum (mm)</th>
<th>Standard deviation</th>
<th>Coefficient of variation</th>
<th>Coefficient of skewness</th>
<th>Sen’s slope</th>
<th>p value of MK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pont Bouchet</td>
<td>602.64</td>
<td>590.40</td>
<td>349.64</td>
<td>933.60</td>
<td>155.84</td>
<td>0.26</td>
<td>0.37</td>
<td>5.170</td>
<td>0.010</td>
</tr>
<tr>
<td>Ain Berda</td>
<td>630.88</td>
<td>595.80</td>
<td>368.20</td>
<td>973.00</td>
<td>153.14</td>
<td>0.24</td>
<td>0.22</td>
<td>3.425</td>
<td>0.114</td>
</tr>
<tr>
<td>Bouceguen</td>
<td>547.96</td>
<td>537.65</td>
<td>279.30</td>
<td>884.00</td>
<td>150.22</td>
<td>0.27</td>
<td>0.42</td>
<td>1.926</td>
<td>0.343</td>
</tr>
<tr>
<td>Boukamouza</td>
<td>685.07</td>
<td>675.40</td>
<td>380.50</td>
<td>1212.91</td>
<td>174.97</td>
<td>0.29</td>
<td>0.21</td>
<td>6.921</td>
<td>0.004</td>
</tr>
<tr>
<td>Medjaz Amar</td>
<td>661.68</td>
<td>534.00</td>
<td>309.10</td>
<td>946.40</td>
<td>170.42</td>
<td>0.29</td>
<td>0.85</td>
<td>24.84</td>
<td>0.001</td>
</tr>
<tr>
<td>Nechmeya</td>
<td>593.66</td>
<td>527.17</td>
<td>264.30</td>
<td>1353.46</td>
<td>239.79</td>
<td>0.40</td>
<td>2.01</td>
<td>6.654</td>
<td>0.013</td>
</tr>
<tr>
<td>Bordj Sabath</td>
<td>542.19</td>
<td>538.75</td>
<td>264.30</td>
<td>928.50</td>
<td>151.70</td>
<td>0.28</td>
<td>0.76</td>
<td>3.740</td>
<td>0.048</td>
</tr>
</tbody>
</table>

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–Kendall 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]:

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

(1)

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

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

(2)

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

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

(3)

where: $m$ = the number of tied groups; $t_i$ = the size of the $i^{th}$ 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]:

$$\beta = \text{median} \left[ \frac{x_j - x_i}{j-k} \right] \text{ for all } k < j$$

(4)

where: $1 < k < j < n$, and $\beta$ 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 \( H_a \) is that change-point exists at time \( t \), in which \( t = 1, \ldots, n \) 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 \( p < 0.05 \).

### 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 [AWANGA 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 a distribution of data. This test has been widely used to test the mean annual rainfall of (Heliopolis) to 24.844 (Mechrouha). The change points that occurred between 1982 and 2001 (Fig. 2), the hypothesis of homogeneity 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.

### RESULTS AND DISCUSSION

#### HOMOGENEITY ANALYSIS

The results of the Mann–Kendall test (Tab. 2) indicated that the null hypothesis \( H_0 \) 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.

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).

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

<table>
<thead>
<tr>
<th>Drought category</th>
<th>SPI classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely wet</td>
<td>SPI ≥ 2</td>
</tr>
<tr>
<td>Very wet</td>
<td>1 ≤ SPI &lt; 2</td>
</tr>
<tr>
<td>Moderately wet</td>
<td>0 ≤ SPI &lt; 1</td>
</tr>
<tr>
<td>Moderately dry</td>
<td>−1 &lt; SPI &lt; 0</td>
</tr>
<tr>
<td>Severely dry</td>
<td>−2 &lt; SPI ≤ −1</td>
</tr>
<tr>
<td>Extremely dry</td>
<td>SPI ≤ −2</td>
</tr>
</tbody>
</table>

Source: McKee et al. [1993], modified.

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

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

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>-0.43</td>
<td>-0.21</td>
<td>-0.003</td>
<td>-0.54</td>
<td>-0.07</td>
<td>0.12</td>
<td>0.46</td>
<td>0.06</td>
<td>0.85</td>
<td>0.03</td>
</tr>
<tr>
<td>Minimum</td>
<td>-1.19</td>
<td>-0.73</td>
<td>-0.72</td>
<td>-1.06</td>
<td>-0.60</td>
<td>-0.42</td>
<td>-0.88</td>
<td>-0.73</td>
<td>-0.32</td>
<td>-1.19</td>
</tr>
<tr>
<td>Maximum</td>
<td>0.61</td>
<td>0.94</td>
<td>0.92</td>
<td>0.07</td>
<td>0.68</td>
<td>1.16</td>
<td>1.88</td>
<td>2.14</td>
<td>2.81</td>
<td>2.81</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.46</td>
<td>0.52</td>
<td>0.47</td>
<td>0.31</td>
<td>0.39</td>
<td>0.44</td>
<td>0.63</td>
<td>0.76</td>
<td>0.89</td>
<td>0.19</td>
</tr>
<tr>
<td>Average deviation</td>
<td>0.32</td>
<td>0.42</td>
<td>0.37</td>
<td>0.25</td>
<td>0.30</td>
<td>0.32</td>
<td>0.41</td>
<td>0.54</td>
<td>0.64</td>
<td>0.09</td>
</tr>
</tbody>
</table>

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 into 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 Khoualidia 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 heterogeneous 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. 3. Annual standardized precipitation index SPI values in the Seybouse basin (1970–2011); source: own study
Fig. 4. Spatiotemporal monitoring of drought using standardized precipitation index (SPI), 1970–2011; source: own study
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A. KHEZAZNA, H. AMARCHI, O. DERDOUS, F. BOUSAKHRIA

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 znaczące 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 Seybouse 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