Characterization of the interannual variability of precipitation and runoff in the Chelif and Medjerda basins (Algeria)

ABDERRAHMANE KHEDIMALLAH1,*, MOHAMED MEDDI1 and GIL MAHE2

1Ecole Nationale Supérieure d’Hydraulique de Blida, Laboratoire GEE, Blida, Algeria.
2University of Montpellier UMR HydroSciences Montpellier/IRD, 34095 Montpellier, France.
*Corresponding author. e-mail: a.khedimallah@ensh.dz

An analysis of rainfall and hydrometric regimes was carried out over the period from 1968 to 2013 on the Chelif basin situated in the west and the Medjerda basin in the east of Algeria. The Mann–Kendall and Pettitt tests have shown significant downward trends for rainfall, about 30% for the Chelif basin, and 36% for the Medjerda basin, and about 61% and 43% for the flows at the level of the Chelif and Medjerda basins, respectively. The continuous wavelet method, used during the study period, has shown three major discontinuities from the wavelet spectrum for the decades 1970s, 1980s and 1990s. Several modes of variability for different stations have been observed: annual (1 yr), interannual (2, 2–4 and 4–8 yrs), and multi-decadal (8–16) yrs. The different scales of precipitation and runoff variability seem to be clearly related to the NAO with different degrees of correlation. Continuous wavelet coherence indicates a strong correlation between the NAO climate index and precipitation with correlations ranging from 60 to 84%, and a strong relationship between the NAO and the runoff with correlations ranging from 67 to 74% for both watersheds.

Keywords. Precipitation; runoff; NAO; wavelet method; Chelif basin; Medjerda basin.

1. Introduction

The risk of water scarcity is very high in North Africa (Bekkoussa et al. 2008; Hallouz et al. 2013, 2018; Yazdanpanah et al. 2014; Jemai et al. 2017; Cramer et al. 2018; Zeroual et al. 2019). Since the 1950s, wadis infrastructures and water extractions for the purpose of irrigation as well as for other uses have rapidly developed and, together with climate change, have modified the natural functioning of Mediterranean rivers (Meddi et al. 2009; Remini 2010; Hallouz et al. 2013). In fact, precipitation is the primary source of water for rivers and streams. It has a direct influence on the variability of runoff at all time scales. However, the construction of new dams in watersheds certainly influences this runoff also. The assessment report of the Intergovernmental Panel on Climate Change (IPCC) concluded that climate change is due to an increase in the atmospheric greenhouse effect (IPCC 2014; Brousseau 2016). The rainfall regime of a region may be affected by a mode of circulation at a large scale (Di Mauro et al. 2008; Fritier et al. 2012; Taibi et al. 2013; Jemai et al. 2017; Zeroual et al. 2017). One of the consequences of climate change, in the Mediterranean basin, is the decline in rainfall regime. This is characterized by a significant decline during the last decades in the Mediterranean basin (New et al. 2001; Knippertz et al. 2003; Rodrigo and Trigo 2007; Benassi 2008;


Furthermore, it is difficult to interpret and describe the variability of precipitation using conventional methods, which have several limitations because of their disadvantage of not highlighting non-stationary processes (Massei et al. 2007). For this reason, wavelet transforms have been introduced to overcome these shortcomings. The wavelet method is an excellent tool for the analysis of non-stationary phenomena as well as for signal and image processing (Morizet 2006; Mateescu and Haidu 2007). It allows the study of the periodicities directly and can discover latent aspects hidden in a chronological series (Mateescu and Haidu 2007). It is often used to study the hydrological variability of the main rivers of the world (Labat 2006; Massei et al. 2011).

Moreover, several researchers have based their rainfall and hydrometric studies on the wavelet method (Labat 2006; Mateescu and Haidu 2007; Laignel et al. 2010; Massei et al. 2011; Dieppois et al. 2012; Frittier et al. 2012; Zamrane et al. 2016). It has the advantage of highlighting non-stationary processes and the location of disturbances at both time and frequency scales.

Our study focuses on the two basins of Chelif and Medjerda, which are the largest watersheds in Algeria, each located at one end of the country, Chelif to the west and the Medjerda to the east. These basins are greatly influenced by the effects of climate and anthropogenic changes that have undergone very significant regime modifications due to the existence of dams (Ladjal 2013; Kotti et al. 2016; Mehaiguene et al. 2017). Our work consists in analysing the interannual variability of precipitation and runoff rates and their relationship to the North Atlantic Oscillation NAO climate index. This analysis will be carried out using the wavelet technique to determine the different bands of energies existing in the series of rains, runoff and the climatic index. We will try to shed light on the existence of relationship between the NAO climate index and the rainfall and hydrometric data in the basins of the study. According to available literature, Meddi et al. (2010) have shown the existence of relationships between seasonal rainfall and the NINO4 and NAO indices using the canonical correlation at the far west of Algeria. Zamrane et al. (2016) have found a relationship between the runoff and rainfall with the NAO climate index in Morocco by applying the wavelet technique. Moreover, Jemai et al. (2017) have discovered a good correlation between the NAO – Rain using wavelets in Tunisia. Di Mauro et al. (2008) have shown the presence of a significant negative correlation of the NAO with the Standardized Precipitation Index (SPI) series during the last three decades in Italy. Brandimarte et al. (2011) have revealed the presence of significant links between the NAO, winter precipitation and runoff rates of rivers in Italy and Egypt by analysing Pearson’s lag-zero cross correlation.

2. Presentation of the study area

The Chelif basin is located in the center-west of Algeria, between longitudes 0°12″–3°87″E and 33°91″–36°58″N latitude (figure 1). It is bordered to the north by the Algerian coastal watershed and the Mediterranean Sea, to the south by the Sahara basin, to the east by the Algerian Hodna Soummam basin and to the west by the Oranie Chergui basin. It is characterized by a semi-arid climate with annual rainfall varying between 300 and 500 mm going from the south to the north. The Chelif basin comprises two main mountain ranges; the Tellian atlas in the north and the Saharan atlas in the south (figure 1).

To the north of the basin, the relief reaches an altitude of 1885 m represented by the Ouarsenis mountains, reaching 1550 m, to the south by the Dahra mountains and to the east by the schistose-bearing metamorphic massifs of Daoui and Temoulga. Wadi Chelif and its tributaries drain an area of 43,750 km². It flows over a length of 700 km. It is the largest wadi in Algeria. This watershed experiences significant inter-annual irregularities
in the hydrological regime. The climate of the basin is Mediterranean (semi-arid) with relatively cold and rainy winters and hot, dry summers. It should be noted that the basin is characterized by the existence of 17 dams in operation.

The Medjerda watershed between Algeria and Tunisia occupies an area of 23,700 km², of which 7600 km² is in the Algerian territory. It is located in the northeastern region of Algeria. It extends between 7°18′–8°39′E longitude and 35°18′–36°47′N latitude (figure 1). It is bordered to the north by the coastal basin of Constantine, to the south by the Melghir basin, to the east by Tunisia and to the west by the Seybouse wadi basins and the highlands of Constantine. The basin is characterized by a relief (Atlas Tellien in the North) with an altitude which varies between 1400 and 700 m, and in the south, by the Saharan Atlas. This basin is crossed by the main wadis: Wadi Medjerda to the north and Wadi Mellegue to the south (figure 1). This zone is characterized by a continental climate with both Mediterranean and desert influence with an annual rainfall total exceeding 1000 mm at north of the Medjerda watershed and decreases gradually to the south 300 mm/year. The wadi of the Medjerda flows for 482 km including 350 in Tunisia (Rodier et al. 1981). It should be noted that the Algerian basin is characterized by the existence of a single dam operating on the wadi Medjerda.

3. Data and method

3.1 Data

The data used for this study are mainly precipitation, runoff rates and the North Atlantic Oscillation (NAO) climate index. Precipitation data and runoff rates were obtained from the National Agency of Water Resources of Algiers and Blida (ANRH) (tables 1 and 2). Thus, 31 rainfall stations
spread over the whole of the Chelli basin and 15 for the whole of the Medjerda basin were selected for a good representation of the spatial variability of precipitation (table 1 and figure 1). The two basins are equipped with 21 and 5 hydrometric stations, respectively. Only six hydrometric

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stations were selected for the Chellif and three for the Medjerda basins. For all selected stations, the observed period of rainfall and flow is from 1968 to 2013 (table 2 and figure 1). For rainfall, the 31 selected stations were used to calculate the average rainfall for the six hydrological sub-basins of the Chellif basin. For the Medjerda catchment, we have used the 15 rainfall stations to estimate the average rainfall for three hydrological sub-basins.

The choice of positions was based on the data quality criteria and the length of the rainfall and hydrometric series (tables 1 and 2).

The NAO is defined as ‘monthly sea level pressure anomaly difference between the two stations’ the Azores and Iceland, according to Rogers (1984) and Cassou (2004). Monthly time series of NAO data were obtained from ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/nao_index.tim.

### 3.2 Method

This study is based on the indices and techniques described below.

#### 3.2.1 The standard index (SI)

The standardized index (SI) has been used by many researchers to study hydrological variability (Giddings et al. 2005; Meddi et al. 2009; Rodriguez-Puebla and Nieto 2010; Taibi et al. 2013; Zemrane et al. 2016; Merabti et al. 2018). It was employed to determine the dry and wet periods and their alternations. This index is characterized by its simplicity in detecting anomalies. It is applied for rainfall and hydrometric series as part of this study where

\[
SI = \frac{x_i - X}{\sigma},
\]

\(x_i\) is the pluviometry/runoff rate for a given year, \(X\) is the average pluviometry/average runoff rate for the interannual period, and \(\sigma\) is the standard deviation of precipitation/runoff rate standard deviation for the interannual period.

#### 3.2.2 Mann–Kendall and Pettitt test

The Mann–Kendall and the Pettitt tests were used to successfully determine the trend and break date of a time series.

The non-parametric Mann–Kendall test (Mann 1945; Kendall 1975) is recommended to identify the trend of series. It allows to study the presence or absence of trend in a given time series. The Mann–Kendall \(S\) statistic is defined as: (Yue and Wang 2002)

\[
S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(x_j - x_k),
\]

where

\[
\text{sgn}(X) = \begin{cases} 
+1, & X > 0 \\
0, & X = 0 \\
-1, & X < 0 
\end{cases}
\]

where \(x_j\) and \(x_k\) are of the time series, \(n\) is the length of the data sequence. The variance of \(S\) and test statistic \(Z\) is given by:

\[
\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n-1} t_i(i-1)(2i+5)}{18},
\]
where $m$ is the number of tied groups and $t_i$ is the size of the $i$th tied group:

$$Z_{MK} = \begin{cases} \frac{S - 1}{\sqrt{\text{Var}(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S + 1}{\sqrt{\text{Var}(S)}}, & S < 0 \end{cases}$$

(5)

The null hypothesis is accepted or rejected at $a$ depending on whether $a_t > a$ or $a_t < a$. Generally, the 0.05 level is largely used. In this study, analysis in precipitation and runoff variability, 0.05 and 0.1 levels were employed. When the statistical value of $z$ is positive, the trend is increasing and when it is negative, it indicates a decline trend.

This test is recommended by the World Meteorological Organization (Mitchell et al. 1966; Sirois 1998). Many researchers have used this test in their studies (Lana et al. 2004; Norrant and Douguedroit 2006; Maheras et al. 2008; Chaouch et al. 2010; Tramblay et al. 2013; Elmeddahi et al. 2016; Halouz et al. 2019) to detect trends in rainfall series and test their significance. Renard et al. (2008) and López-Moreno et al. (2010) applied the Mann–Kendall test for the analysis of hydroclimatic time series trends.

The Pettitt (1979), test may be used to determine the significance probability associated with the various statistics: the probability of detecting a shift in the mean where no such shift occurs in the series. Hence, it may be used to estimate, at a given confidence level, whether or not a population shift did occur. Several researchers have used this test in their studies (McCane et al. 1994; Tarhule and Woo 1998; L’Hôte et al. 2003; Wijngaard et al. 2003; Meddi et al. 2010; Zin et al. 2010; Kang and Yusof 2012; Chang et al. 2017; Emmanuel et al. 2019).

Given $x_1, ..., x_t, ..., x_T$, is a sequence of random events (measurements). This sequence shows a shift in population at $t$, if the set of events (measurements) $x_1, ..., x_t$ has a distribution function $F_1(x)$ whose mean is significantly different from that of $F_2(x)$, the distribution function over $x_{t+1}, ..., x_T$, the goal being to test is the null hypothesis, which is the absence of a shift in the trend of the variable.

The statistics associated with this test is as follows:

$$k_t = \max_{1 \leq i \leq T} (|U_{i,T}|),$$

(6)

where

$$U_{i,T} = \sum_{i=1}^{t} \sum_{j=i+1}^{T} \text{sgn}(x_i - x_j),$$

(7)

$$\text{sgn}(X) = \begin{cases} +1, & \text{if } X > 0 \\ 0, & \text{if } X = 0. \\ -1, & \text{if } X < 0 \end{cases}$$

(8)

If a shift in only one direction (positive or negative) is considered, it is as follows:

$$k_T^+ = \max_{1 \leq i \leq T} U_{i,T},$$

(9)

or

$$k_T^- = \min_{1 \leq i \leq T} U_{i,T}.$$  

(10)

### 3.2.3 Continuous wavelets transform (CWT)

In the Fourier analysis, the signal is decomposed into sinusoidal functions of different frequencies. This method allows the frequency spectrum of the signal to be obtained, but not its location over time. The size of the window during the Fourier analysis of a signal does not give us all the information; therefore, we have to choose between the location of high frequencies and the location of low frequencies. It was therefore necessary to find a tool that induced a reconstruction method that was independent of the scale of analysis. To overcome this difficulty, a new approach, called ‘wavelet transformation’, has been introduced (Meyer et al. 1987). Because of their non-stationarity, Meyer et al. (1987), Benner (1999), and Moriset (2006) have already highlighted the ability of wavelet analysis to show that most climate oscillations are non-stationary and do not persist throughout the time series. Among the numerous available techniques (Ghil et al. 2002), powerful wavelet analysis is much preferable to classical Fourier analysis, due to the natural non-stationarity of the hydrological series (Labat et al. 2000). Currently, the studies based on time series analysis are leading to important results, Anderson and Woodhouse (2005) consider the wavelet transform as ‘elegant and appropriate’ for the analysis of climate time series.

In hydrology, several applications of wavelets to disseminate time series of rainfall and flows have already been presented in America (Coulibaly and Burn 2004; Xu et al. 2019), in Europe (Lafraneri and Sharp 2003; Pekárová et al. 2003; Andreo et al. ...
CWT shows the distribution of spectral content over time and at different scales. Continuous wavelet spectra have a colour scale that represents increasing power from blue to red. The continuous spectrum of wavelets in the time series highlights the existence of several modes of variability in the form of energy bands covering certain frequency ranges; for more details an elaborated presentation of continuous wavelet analysis techniques has been done by Torrence and Compo (1998).

A wavelet mother $\psi$ will serve as a basic prototype to generate a family $\psi_{a,b}$ called daughter wavelet. They are dilated, compressed and translated copies of the mother wavelet. Hence the following formula of a daughter wavelet:

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right), \quad a \in R^+, \ b \in R, \quad \text{(11)}$$

where $\psi$ is the Mother wavelet, $\psi_{a,b}$ is the Daughter wavelet, $a$ is the scale parameter (acts on the compression or dilation of the daughter wavelet), $b$ is the position parameter (allows the translation of the daughter wavelet to the left or to the right along the signal analyzed), and $\frac{1}{\sqrt{a}}$ is the factor that keeps the same energy at each scale.

The continuous wavelet transform consists in transforming an original function $f(t)$ which depends on time into a new function $C_f(a, b)$ which, in turn, depends on both scale and time; hence the following formula of the function $C_f(a, b)$:

$$C_f(a, b) = \int_{-\infty}^{+\infty} f(t) \psi_{a,b}(t) dt, \quad \text{(12)}$$

where $C_f(a, b)$ is the wavelet coefficients.

### 3.2.4 Wavelet coherence

The purpose of the wavelet coherence is to compare the spectral structuring of the signals so as to see the percentage of correlation between its variables.

In this study, a comparison is made between the climate index (NAO) and the rainfall and hydrological variables.

$$WC_{n}^{XY}(s) = \frac{W_n^{XY}(s)}{\sqrt{W_n^{X}(s) \ast W_n^{Y}(s)}}, \quad \text{(13)}$$

where $W_n$ is the wavelet, $S$ is the signal, and $X$ and $Y$ correspond to two studied variables.

The wavelet phases are also plotted to show the amount of delay between the two signals. They allowed us to test the meaning of the relationship between two time series. The wavelet coherence spectrum (WCO) has values between zero and one, characterizing a disappearance or perfect linear relation respectively (Maraun and Kurths 2004).

The computation of the continuous wavelet coherence between the different variables (climatic indices, rainfall and runoff rates) is thus used in order to precisely determine the modalities of their correlation, and to verify the observations made previously from the continuous wavelet spectra. It expresses the linearity relation between the input and output signal, thanks to the use of the simple energy spectra $S_x$ and $S_y$ and the energy spectrum of the intercorrelation function $S_{xy}$. The result of the coherence spectrum characterizes the degree of linearity between two processes (Maraun and Kurths 2004; Maraun et al. 2007).

### 4. Results and discussion

#### 4.1 Hydrological variability from the standardized variables

**4.1.1 Rainfall 1968–2013**

The application of the Mann–Kendall trend test over the period from 1968 to 2013 has shown a significant downward trend in annual rainfall at the threshold of 5% for all the sub-watersheds of the Chelif and Medjerda, which has been observed with maximum $z$ values of $-3.74$ at Melegue station, and minimum $z$ values of $-1.70$ at Ch-b station (table 3). The Pettitt test has given a break during the 1970–1980 decade (table 3), where rainfall decrease is about 30% on average for the Chelif basin and 36% on average for the Medjerda basin. The period of observation (1968–2013) is characterized by an alternation of wet and dry periods with a return to wet conditions observed from 2008 for the Chelif basin and from 2003 for the Medjerda basin; and this is consistent with the results found in Algeria by Nouaceur et al. (2014).

Rainfall in the Chelif basin has experienced excess periods, particularly from 1968 to 1973 and in the years 1995, 2003 with maximum standardization indices ($> 3$). The largest deficits were recorded during the years from 1982 to 1984; between 1992 and 1993, 1999 to 2001, and in 2004 with a maximum standardized index ($> -1$) (figure 2).
Rainfall in the Medjerda basin has experienced excess periods, particularly from 1968 to 1973, sometimes until 1976 and during the years 1995, 1999 and 2003–2004, with a maximum standardized index (> 2.5). The most noticeable deficits are showed by figure 2, where the maximum standardized indices (> –1) are recorded.

For the most significant deficit periods with an index greater than −1, only the years 1993 and 2001 are similar for both basins.

This shows a general downward trend with an increase in dry years. Peaks were recorded after 1980 in both basins. The same observations were made in Morocco and Tunisia (Taibi et al. 2013; Zamrane et al. 2016).

Numerous studies have also highlighted the decrease in rainfall in Maghreb countries (Mahé et al. 1998, 2013; Meddi et al. 2002, 2010; Knippertz et al. 2003; Mahé and Paturel 2009; Laborde et al. 2010; Singla et al. 2010; Sebbar et al. 2011, 2012; Taibi et al. 2013, 2017; Zamrane et al. 2016; Jemai et al. 2017; Hallouz et al. 2018). Western Algeria is the most affected region by drought (Meddi et al. 2002; Taibi et al. 2013) where rainfall deficit varies between 16 and 43%.

### 4.1.2 Runoff rates 1968–2013

A high variability of annual mean flow rates has been observed at all gauging stations in the Chelif and Medjerda basins. Significant changes detected include a downward trend in mean flow rates in the Chelif basin which has been observed with maximum z values of −8.34 at Ch-g station, and minimum z values of −0.0867 at Mina station (table 4). Only the Mina station shows a significant downward trend for the Mann–Kendall test (P value < 0.1) with a significant rupture detected around 1986 by the Pettitt test. These same tests, applied to the flow data of the Medjerda basin in the period 1968–2013, revealed a significant trend (P value < 0.05) with maximum z values of −0.6438 observed in the Mellegue station and minimum z values −0.3604 observed in the Zergua station, with a break detected in the mid-1970s (table 4). Only the Medjerda sub-basin represents a downward but significant trend (P value < 0.1) with a slope of −0.3604 and a rupture detected by the Pettitt test around 1984 (table 4). The reduction in flow is about 61% on average for the Chelif basin and 43% on average for the Medjerda basin.

The runoff over the years of study in the Chelif basin has experienced excess periods, especially from 1968 to 1980 and during the years 1986, 1991 and 1995 with a maximum standardized index (> 3). More marked deficits have been recorded for the other years with a maximum standardized index (> −1). Although the runoff of some rivers was above average during the period 2008–2013, the hydrological regime of this watercourse is very heterogeneous from one hydrometric station to another because of the location of many structures built on its main course or tributaries.

Runoff rates in the Medjerda basin have shown a remarkable decrease since the 1970s. Runoff has had different periods of surplus from one basin to another.

For those with deficits, the Chelif basin is the most affected with wet years with a standardized
Figure 2. Standardized mean annual rainfall anomalies in the Cheliff and Medjerda basins.

Table 4. Results of the statistical tests on the runoff analysed in the Cheliff and Medjerda basins. We provide the $p$-value of the Mann–Kendall and tau test and the Sen’s slope of the trend (+ if rising, – if falling). The last column contains the probable date of rupture of the Pettitt test.

<table>
<thead>
<tr>
<th>Sub-basin</th>
<th>$P$ value</th>
<th>tau</th>
<th>Sen’s slope</th>
<th>Pettitt test (date of rupture)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cheliff Basin</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ouerk</td>
<td>$&lt; 0.0001^*$</td>
<td>$-0.4396$</td>
<td>$-2.2213$</td>
<td>1985</td>
</tr>
<tr>
<td>Ch-b</td>
<td>$&lt; 0.0001^*$</td>
<td>$-0.4219$</td>
<td>$-1.152$</td>
<td>1986</td>
</tr>
<tr>
<td>Ch-e</td>
<td>$&lt; 0.0001^*$</td>
<td>$-0.4751$</td>
<td>$-3.5588$</td>
<td>1986</td>
</tr>
<tr>
<td>Ch-f</td>
<td>$&lt; 0.0001^*$</td>
<td>$-0.4972$</td>
<td>$-7.2138$</td>
<td>1986</td>
</tr>
<tr>
<td>Ch-g</td>
<td>$&lt; 0.0001^*$</td>
<td>$-0.4928$</td>
<td>$-8.9478$</td>
<td>1986</td>
</tr>
<tr>
<td>Mina</td>
<td>$0.06678^{**}$</td>
<td>$-0.0465$</td>
<td>$-0.0867$</td>
<td>1986</td>
</tr>
<tr>
<td><strong>Medjerda Basin</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medjerda</td>
<td>$0.0900^{**}$</td>
<td>$-0.1724$</td>
<td>$-0.3604$</td>
<td>1984</td>
</tr>
<tr>
<td>Mellegue</td>
<td>$0.0002^*$</td>
<td>$-0.3830$</td>
<td>$-0.6438$</td>
<td>1976</td>
</tr>
<tr>
<td>Zergua</td>
<td>$0.01065^*$</td>
<td>$-0.1678$</td>
<td>$-0.0416$</td>
<td>1977</td>
</tr>
</tbody>
</table>

*Trend statistically significant at 5%; **Trend statistically significant at 10%.
maximum index (> 3), and a significant decrease (figure 3), with a standardised maximum index (> -1).

The most remarkable surplus years are the same for both basins. It concerns the years from 1968 to 1980, 1986 and 1995, with decrease in the flow rate with four years compared to two years for the medjerda in the 1980s, three years and one year for the medjerda in the 1990s and three years for the Chellif with two years for the medjerda in 2000 (figure 3).

Numerous studies have also highlighted a reduction in runoff in North Africa and the western Mediterranean (Bergaoui and Louati 2010; Laborde et al. 2010; Singla et al. 2010; Zamrane et al. 2016; Belarbi et al. 2017; Hallouz et al. 2018). These observations are consistent with those observed in Morocco by Singla et al. (2010); Zamrane et al. (2016) where monthly and annual runoff in Morocco have revealed a decrease since the late 1970s and early 1980s. Bergaoui and Louati (2010) have shown in Tunisia that the rainfall deficit affects river runoff and consequently influxes of reservoirs. It is likely that this downward trend is partly due to climate change. Additionally, Laborde et al. (2010) have found a moderate relative decrease in precipitation in northern Algeria that had a major effect on surface runoff, 15% decrease in precipitation resulted in 40% reduction in runoff.

4.2 Hydrological variability based on wavelet analysis

4.2.1 Rainfall

For all studied periods, multiple energy bands have been observed on the runoff of wavelet spectra in...
Table 5. The time variation of the rainfall variability modes, extracted from the continuous wavelet analysis, at Chelif and Medjerda sub-basin.

<table>
<thead>
<tr>
<th>Sub-basins</th>
<th>1 yr</th>
<th>2 yrs</th>
<th>2–4 yrs</th>
<th>4–8 yrs</th>
<th>8–16 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chelif basin</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Medjerda basin</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1995–2000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

the Chelif and Medjerda basins: 1, 2, 2–4, 4–8, and 8–16 yrs (table 5 and figure 4).

4.2.1.1 Basin of Chelif: Two periods have been observed: the first period, from 1968 to 1980, is characterized by energy bands of strong signal of one year and 8–16 yrs, whereas the band of 2 yrs was observed at the level of some basins located at south and west of Chelif basin (figure 4). For the second period, from 1980 to 2013, an alternation of wet and dry periods (the 1 yr band) was observed with the appearance of the 2–4 yr mode and the absence of the 2 yr variability mode and 8–16 yrs (figure 4).

For the energy band of one year, the high and low energies successively define the wet and dry periods in the study basins. The one-year signal appears in all sub-basins with very significant periods of alternation and a decrease in energy. It appears almost seven times between 1968 and 2013. The distribution of energy bands illustrates a clear point of change in stationarity during the 1970s. The Mina basin found at the extreme west of the Chelif basin was the most affected by a strong signal (figure 4). The total absence of this signal from the 90’s confirms the reduction of the rainfall observed in north-west Algeria by Meddi et al. (2002), Taibi et al. (2017) and in eastern Morocco by Zamrane et al. (2016). The two-year energy band is only found with a strong signal in the south and west of the basin (sub-basin Ouerk and Mina). The energy band of 2–4 yrs is observed in most sub-basins with low intensities and a discontinuity after the year 2000. The band of variability 8–16 yrs of strong signal is visible on all the sub-basins for the first period going from 1968 to 1980. This signal disappeared after this date except for the arid part of the basin represented by the basin of Ouerk.

During the study period, three major discontinuities have been observed from the wavelet spectrum in the rainfall series of the Chelif basin.

The first discontinuity is visible during the decade of 1970 marked by the appearance of the bands of 1, 2 and 8–16 yrs which is in concordance with Hasanean (2004) who has shown that subtropical anticyclonic cells have been characterized by an increase in pressure since the 1970s, coinciding with the decrease of precipitation in the western Mediterranean.

The second discontinuity is visible during the 1980s, the appearance of a new mode namely 2 yrs and the interruption of the mode of 8–16 yrs which is consistent with the results found by Dieulin et al. (2019) who showed a rupture in the rainfall regime around 1979/1980, on the scale of the whole African continent.
The third discontinuity is visible during the decade 1990 which has been marked by the appearance of the mode 2–4 yrs. This discontinuity can be related to a very strong negative NAO index in winter (Ward et al. 1999).

4.2.1.2 Basin of Medjerda: Two periods have been observed: the first period, from 1968 to 1980, is characterized by strong signal energy bands of 1, 2–4, and 8–16 yrs (figure 4). For the second period from 1980 to 2013, alternating wet and dry
periods (the 1 yr band) have been observed with the appearance of a new mode 4–8 yrs and the absence of the mode of variability of 8–16 yrs (figure 4).

The 2–4 yr energy band is observed in most sub-basins with low intensities and a discontinuity after 2000, except for the Zerga basin located in the southern basin. The band of variability 8–16 yrs of strong signal is visible on all the sub-basins for the first period going from 1968 to 1980. This signal disappeared after this date (figure 4).

During the study period, three major discontinuities have been observed from the wavelet spectrum in the rainfall series of the Medjerda basin. The first discontinuity is visible during the 1970s marked by the appearance of 1 yr bands, 8–16 yrs, and sometimes 2–4 yrs. The second discontinuity is visible only during the 1980s with the appearance of the 1 yr mode with a strong signal and the interruption of the mode of 8–16 yrs in some sub-basins. The third discontinuity is visible during the decade 1990–2000. It was also marked by the appearance of a new mode namely 4–8 yrs.

The results obtained show fairly large and very heterogeneous rainfall variability in the two basins of Cheliff and Medjerda. Different signals have been observed: 1, 2, 2–4, 4–8 and 8–16 yrs. These results corroborate those found in Morocco by Zamrane et al. (2016), in Tunisia (Jemai et al. 2017) and in the central part of Algeria (Turki et al. 2016).

### 4.2.2 Runoff rate

#### 4.2.2.1 Cheliff basin: The same energy bands as the rainfall series are apparent in the sub-basins of Cheliff (those of 1, 2, 2–4, 4–8, and 8–16 yrs). These are found in their majority and do not always appear during the same period.

Two periods have also been observed as for rainfall:

The first period, between 1968 and mid-1980, is characterized by strong signal energy bands of 1 yr and 2–4 yrs in most sub-basins as well as 8–16 yrs for the whole basins (table 6 and figure 5).

The second period begins in mid-1980 to 2013. It presents an appearance of the mode 2–4 yrs in the sub-basins of Ouerk and the appearance of the mode 1, 2–4, 4–8 and 8–16 yrs in the Mina. The absence of the 1 yr variability pattern, of 2–4 yrs and 8–16 yrs in the rest of the Cheliff basin is observed (figure 5). This decrease in runoff is in relation with the decrease of precipitation, and the construction of dams in the second period of mid-1980–2013 is also at the origin of this decrease as specified by Chaponniere and Smakhtin (2006). However, it should be noted that the northeastern part shows a significant hydrometric decrease compared to the western part which is characterized by low precipitation.

Numerous dams were constructed in the Cheliff basin during this period, which represents 65% of the total of the current dams (Deurdeur 1984, Barrage Herraza 1984, Sidi Yacoub 1986, Gargar 1988, Barrage Merdja Sidi Abed 1984, Ouled

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### Table 6. The time variation of the runoff variability, extracted from the continuous wavelet analysis, at Cheliff and Medjerda sub-basin.

<table>
<thead>
<tr>
<th>Sub-basins</th>
<th>1 yr</th>
<th>2 yrs</th>
<th>2–4 yrs</th>
<th>4–8 yrs</th>
<th>8–16 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cheliff basin</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Medjerda basin</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The one-year strong signal band appears in all sub-basins with significant loss from the 1970s, proving direct link between rainfall and hydro-metric data. With regard to the two-year band that appears in a single sub-basin of Chelif-g. The
Table 7. Comparison between rainfall and runoff at Cheliff and Medjerda sub-basin.

<table>
<thead>
<tr>
<th>Sub-basin</th>
<th>Rainfall</th>
<th>Runoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheliff basin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ouerk</td>
<td>1968-1972; succession of wet and dry years</td>
<td>-</td>
</tr>
<tr>
<td>Chellif-b</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chellif-e</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chellif-f</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chellif-g</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Minia</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Medjerda basin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mellegue</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Zerga</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Green: presence of the signal in both (rain and runoff); red: absence of the signal in both; yellow: presence of the signal in one of the two; blue: presence of signal but with different period.
2–4 yr band is present in most sub-basins except those in the north. A 4–8 yr band appears only in the Mina sub-basin located to the west. The 8–16 yr strong signal band is observed in the Chelif basin as a whole.

During the study period two major discontinuities have been observed from the wavelet spectrum in the runoff series. The first discontinuity is visible during the 1970s marked by the appearance of energy modes of 1, 2–4 and 8–16 yrs. The second discontinuity is visible during the year 1986 marked by the interruption of variability mode 8–16 yrs and the appearance of the 1 yr mode.

4.2.2.2 Medjerda basin: The band of one year of strong signal appears in all the sub-basins with a significant loss from the 1970s, it appeared 6 times to the maximum. Concerning the 2–4 yr and 4–8 yr bands, they appear at the level of all sub-basins maximum 2 times. The 8–16 yr strong signal band is observed in the entire Medjerda basin.

During the study period, three major discontinuities have been observed from the wavelet spectrum in the runoff series of the Medjerda basin. The first discontinuity is visible during the 1970s marked by the appearance of energy modes of 1, 2–4 and 8–16 yrs. The second discontinuity is visible during the year 1986 marked by the appearance of new mode of variability 4–8 yrs. The third discontinuity is visible during the 2000s marked by the appearance of the modes of variability 1, 2–4 and 4–8 yrs and the absence of the signal 8–16 yrs.

4.3 Comparison between rainfall and runoff

The results obtained from the wavelet analysis show three discontinuities in the 1970s, 1980s and 1990s. The wavelet analysis shows common energy bands in the first period between rainfall and runoff, at annual and inter-annual scales of 8–16 yrs have been identified between rainfall and runoff for all sub-basins of the Medjerda and Chelif especially from 1968 to 1980 (table 7), after a discontinuity which appears from this signal in the majority of sub-basins. The mode of 4–8 yr is observed only in the whole sub-basins of the Medjerda, the signal is observed in the basin of the Medjerda for the runoff during the second and third periods and for the precipitation during the third period. For the Chelif basin only the runoff of the Mina basin shows an appearance of this signal in the second and third periods.

The 2–4 yr mode is observed in all sub-basins of the Medjerda for the runoff and for the rainfall in the first and the third periods. However, this mode does not appear for both climatic and hydrometric variables at the same time for the Chelif basin. This mode appears during the first and third periods for runoff and only during the second period for precipitation.

The 2-yr mode characterizes the Ourek sub-basin, located in the south of the Chelif basin, and it is observed during the first period for runoff and rainfall.

There is a good correlation between the 1 and 8–16 yr bands for runoff rates and rainfall in the majority of sub-basins from 1968 to 1980. For the period from 1985 to 2013, the 8–16 yr band disappears from the two basins with the exception of the western part of the Chelif basin (under the Mina basin) and the northern part of the Medjerda basin (figures 4 and 5). This change may be due to anthropogenic influence (Bakhadda dam for Mina) and (Ain Dallia dam for Medjerda).

The results obtained show a fairly high and very heterogeneous variability of flows in the two basins of the Chelif and Medjerda. Different signals have been observed: 1, 2, 2–4, 4–8 and 8–16 yrs. With three major discontinuities in 1970, 1986 and 2000, these results corroborate those found in Morocco by Laignel et al. (2010), Turki et al. (2016), and Zamrane et al. (2016). Massei et al. (2011) also
revealed discontinuities during 1970 and 1990 of Seine River flow (France). On the other hand, in Algeria, hydrometric variability has not been previously studied by the wavelet method. Turki et al. (2016) have studied only the variability of precipitation in the central part of Algeria.

5. Origin of hydrological and rainfall variability

To explain the possible links that could exist between the variability of precipitation and the climatic fluctuation, the wavelet approach has been used.

The North Atlantic Oscillation (NAO) influences the Mediterranean climate of North Africa (Hurrell et al. 2001; Cullen et al. 2002; Di Mauro et al. 2008; Zamrane et al. 2016; Turki et al. 2016; Jemai et al. 2017). In what follows the influence of this index on the rainfall and hydrometric regime in the Cheliff and of the Medjerda basins will be studied.

5.1 Discussion: Influence of the climatic fluctuations of the North Atlantic Oscillation (NAO) on the hydrological variability of the Cheliff

5.1.1 Determination of the variability modes of the climate index (NAO) by the continuous wavelet method

Previous studies have shown that the NAO index has a strong influence on the Mediterranean climate and Western Europe (Hurrell 1995; Di Mauro et al. 2008; Fritier et al. 2012; Oubeidillah et al. 2012; Turki et al. 2016; Vergni et al. 2016).

When the highly positive NAO index is linked to a westward movement, which is more pronounced between the two entities because the pressure difference causing the winds is greater. In addition, the larger anticyclone on the Azores is driving northward. The winters are then mild but rainy in northern Europe however drier around the Mediterranean (Knippertz et al. 2003).

On the other hand, when the index is negative, the westward circulation is weaker or more to the south giving cold winters and the depressions then

<table>
<thead>
<tr>
<th>Modes (yr)</th>
<th>Period</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>4–8</td>
<td>1968–1972</td>
<td>01</td>
</tr>
<tr>
<td>8–16</td>
<td>1990–2013</td>
<td>01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Basin</th>
<th>Region</th>
<th>Years</th>
<th>1 (yr)</th>
<th>2 (yrs)</th>
<th>2–4 (yrs)</th>
<th>4–8 (yrs)</th>
<th>8–16 (yrs)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chellif basin</td>
<td>South</td>
<td>65</td>
<td>60</td>
<td>64</td>
<td>69</td>
<td>70</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td></td>
<td>East</td>
<td>70</td>
<td>60</td>
<td>68</td>
<td>70</td>
<td>72</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td></td>
<td>North</td>
<td>70</td>
<td>59</td>
<td>67</td>
<td>79</td>
<td>73</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chellif-e</td>
<td>71</td>
<td>56</td>
<td>65</td>
<td>82</td>
<td>75</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chellif-f</td>
<td>71</td>
<td>54</td>
<td>64</td>
<td>80</td>
<td>75</td>
<td>69</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chellif-g</td>
<td>71</td>
<td>72</td>
<td>60</td>
<td>76</td>
<td>78</td>
<td>71</td>
<td></td>
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<td></td>
<td>West</td>
<td>71</td>
<td>72</td>
<td>60</td>
<td>76</td>
<td>78</td>
<td>71</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mina</td>
<td>70</td>
<td>60</td>
<td>65</td>
<td>76</td>
<td>74</td>
<td>69</td>
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<tr>
<td></td>
<td>Total</td>
<td>68</td>
<td>70</td>
<td>80</td>
<td>67</td>
<td>84</td>
<td>71</td>
<td></td>
</tr>
</tbody>
</table>

| Medjerda basin | North   | 68    | 70     | 67      | 68        | 74        | 69        |       |
|               | Center  | 68    | 70     | 71      | 67        | 89        | 73        |       |
|               | South   | 67    | 69     | 73      | 65        | 90        | 71        |       |
|               | Total   | 68    | 70     | 80      | 67        | 84        | 71        |       |
go towards the Mediterranean basin (Hurrell 1995).

If the index is very negative, winters are particularly cold in Northern Europe and rainfall is shifted to the Mediterranean Sea and North Africa (Cassou 2004).

The use of information provided by large-scale climate indices, such as the North Atlantic Oscillation (NAO), as support for drought prediction, the NAO reflects the main fluctuations in climatic conditions. The North Atlantic Oscillation is also considered to be the dominant mode of winter
atmospheric variability in the northern hemisphere (Di Mauro et al. 2008).

The NAO is affected by several temporal discontinuities in its spectral composition for the years from 1968 to 2013. The NAO (figure 6) is slightly dominated by the low-frequency fluctuation of the multi-decadal scale (8–16 yrs). Interannual scale fluctuations (2–4 and 4–8 yrs) are organized differently over time with the appearance of four times for the band 2–4 yrs and once for the band 4–8 yrs. The annual fluctuation of one year is the most dominant fluctuation; it appears five times (table 8 and figure 6). The results found corroborate with those found by Zamrane et al. (2016) in Morocco.

The NAO displays several non-stationary features (Appenzeller et al. 1998; Higuchi et al. 1999) that can be easily detected using continuous wavelet analyzes, specifically designed for the study of non-stationary signals (Massei et al. 2007).

During the study period 1968–2013, three major discontinuities have been observed from the wavelet spectrum in the NAO. The first discontinuity is visible in the decade 1970. It was marked by the appearance of the bands of 1, 2–4 and 4–8 yrs. A major change, therefore, was reported in the 1970s. According to Massei et al. (2011), this discontinuity concerns all climate indices. It is considered as a major period of climate observed in several areas (Alexander et al. 2008; Alheit and Niquen 2004; Zamrane et al. 2016; Turki et al. 2016). The NAO index was negative, so this probably showed itself in a very rainy year in the Mediterranean basin. The second discontinuity is visible during the decade 1980 marked by the interruption of mode of variability 1 year and the appearance of 2–4 yrs. Since 1980, the NAO has tended to stay in an extreme phase. The third discontinuity is visible during the 1990s marked by the appearance of a new mode of variability of 8–16 yrs, and the presence of variability modes 1 and 2–4 yrs. Hurrell and Van Loon (1997) and Hurrell et al. (2001) have found, during the last decades, that the NAO index has steadily strengthened with an increase in its low index, with a historical maximum that was recorded during the 1990s. As a result, the NAO has been introduced into the debate on global warming with the search for mechanisms that could solve to what extent this trend is a combination of anthropogenic factors perturbation and natural variability (Hoerling et al. 2001).

The three discontinuities found were also observed by Rossi et al. (2009) on the Mississippi (USA) and showed the presence of discontinuities around the 1970s and 1980s. However, Massei et al. (2009) identified other discontinuities during the period from 1970 to 1990 in Colorado. Three discontinuities were observed in 1980, 1990 and 2000 in Morocco by Zamrane et al. (2016).

6. Continuous wavelet coherence for the characterization of potential links between climatic indices, rainfall and runoff

6.1 Application of relationship between climatic indices (NAO) and precipitation

It seems, therefore, useful to compare the evolution of NAO and precipitation changes by wavelet coherence analysis in order to better identify their

<table>
<thead>
<tr>
<th>Basin</th>
<th>Region</th>
<th>Years</th>
<th>1 (yr)</th>
<th>2 (yrs)</th>
<th>2–4 (yrs)</th>
<th>4–8 (yrs)</th>
<th>8–16 (yrs)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chellif basin</td>
<td>South Ouerk</td>
<td>70</td>
<td>71</td>
<td>71</td>
<td>62</td>
<td>68</td>
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<tr>
<td></td>
<td>Chellif-b</td>
<td>71</td>
<td>70</td>
<td>73</td>
<td>60</td>
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<td></td>
<td>Chellif-e</td>
<td>71</td>
<td>66</td>
<td>67</td>
<td>66</td>
<td>78</td>
<td>70</td>
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</tr>
<tr>
<td></td>
<td>Chellif-f</td>
<td>71</td>
<td>66</td>
<td>69</td>
<td>70</td>
<td>70</td>
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</tr>
<tr>
<td></td>
<td>Chellif-g</td>
<td>71</td>
<td>64</td>
<td>77</td>
<td>77</td>
<td>75</td>
<td>73</td>
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<tr>
<td></td>
<td>West Mina</td>
<td>70</td>
<td>67</td>
<td>73</td>
<td>71</td>
<td>85</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>71</strong></td>
<td><strong>67</strong></td>
<td><strong>72</strong></td>
<td><strong>68</strong></td>
<td><strong>74</strong></td>
<td><strong>70</strong></td>
<td></td>
</tr>
<tr>
<td>Medjerda basin</td>
<td>North Medjerda</td>
<td>75</td>
<td>69</td>
<td>80</td>
<td>75</td>
<td>74</td>
<td>75</td>
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<td>Center Mellegue</td>
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<tr>
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<td>South Zerga</td>
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<td>72</td>
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<td><strong>Total</strong></td>
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</tbody>
</table>
degree of correlation and improve our understanding of the relationship between precipitation and the climate index NAO. The contribution between NAO and precipitation by the analysis of wavelet coherence (table 9 and figure 7) highlights the appearance of annual, interannual and
multi-annual energy bands. These periods can be distinguished by the presence or absence of significant correlations on the variability scale during measurement decades. The different scales of precipitation variability appear to be clearly related to NAO with different degrees of correlation.

For the energy band of one year, it is found in all sub-basins with variations ranging from 65 to 71% for the Chelif basin and 67 to 68% for the Medjerda. For the 2 yr band, the variations range from 54 to 72% for the Chelif and 69 to 70% for the Medjerda. The 2–4 yr band is poorly correlated in the Chelif basin with variations ranging from 60 to 68% and a good correlation ranging from 67 to 73% for the Medjerda. It should be noted that there is a statistically significant correlation between NAO and precipitation for the variability scale of 4–8 yrs with a variation rate ranging from 69 to 82% for Chelif and from 65 to 68% for Medjerda. It should also be marked that there is a significant correlation between NAO and precipitation for the 8–16 yr band for all stations with correlations ranging from 70 to 90% for both basins. The bands of 1, 4–8 and 8–16 yrs have the most correlated signals with the NAO/precipitation for the Chelif basin and bands 2–4 and 8–16 yrs for the Medjerda basin. These results are very consistent with the results obtained in Morocco by Zamrane et al. (2016) where the average contribution varies from 63% to 78% and in Tunisia by Jemai et al. (2017) where the average contribution varies from 66% to 72%.

6.2 Relationship between the North Atlantic Oscillation index (NAO) and runoff

The contribution of the relationship between the NAO teleconnection and the runoff varies according to the modes of variability. In the case of wavelet coherence analysis, the NAO/runoff correlation is acceptable. It varies from 60 to 85% for all the sub-basins of Chelif and Medjerda (table 10 and figure 8).

For the one-year band, the NAO has been found to be well correlated with runoff over the entire Chelif basin. It varies from 70 to 71% and for the Medjerda varies from 67–75%. For the 2-yr band, the correlation is low and it varies from 64 to 71% for all basins. The 2–4 yr band has a correlation ranging from 67 to 77% for Chelif and 62–80% for Medjerda. For the 4–8 yr band, the runoff is poorly correlated with the climatic index, where the band oscillates between 60 and 77% for all the basins. The 8–16 yrs band is strongly correlated (66–85%) (table 10). These results are in clear concordance with those found in Morocco by Zamrane et al. (2016).

7. Conclusion

The study covered monthly rainfall and flow series in the Chelif and Medjerda basins to identify wet and dry periods in western and eastern Algeria and to check their trends. Data from these two basins were used to determine interannual variability and the relationship with climate fluctuations due to the natural non-stationarity of the hydrological series. Continuous wavelet analyses have improved our understanding of precipitation variability. The correlation between rainfall variability and NAO on the one hand, and flow with the NAO index on the other hand, ranges from 60 to 82% and 67 to 74%, respectively. The results obtained reveal that the basins represent a marked spatial and temporal variability with a downward trend as early as the 1970s, with an increase in the frequency of dry years. Severe droughts have been recorded after 1980 in both basins with a maximum standardized index exceeding −1 and a total reduction ranging from 30 to 36%. Flows in the Chelif and Medjerda basin have shown a remarkable decrease since the late 1970s with a maximum standardized index (> −1) and a total reduction ranging from 61% for the Chelif to 43% for the Medjerda. The continuous wavelet method has shown a distribution of high and low frequency energy bands divided into five variability modes: 1, 2, 2–4, 4–8 and 8–16 yrs. During the period from 1968 to 2013, three major discontinuities have been observed from the wavelet spectrum during the 1970s, 1980s and 1990s. These findings are consistent with those recorded in Morocco and Tunisia as well as in central Algeria.

It should be noted that the extracted components are significantly consistent with the NAO climate index, which remains a good reference for studying the relationship between climate fluctuations, rainfall, and flow variability. These results could be further developed with a comparative study of rainfall variability over the whole of Tunisia, Algeria and Morocco in order to highlight the specificities of semi-arid regions.
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