Rainfall regime evolution and drought forecasting in eastern Algeria

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Abstract During the last century, Algeria has been subject to frequent periods of drought, especially since 1975. In this work, we studied drought persistence at annual and seasonal scales in Eastern Algeria on the basis of an analysis of rainfall data observed in 17 rainfall stations (from 1950 to 2005). The stations located west of longitude 5°50′E have a stationarity break in 1975. However, in the eastern areas of Algeria, and more specifically the area east of longitude 5°50′E, no significant break is detected. Drought forecasting has revealed two distinct areas; the first one concerning the region located before longitude 5°50′E. For the first region the probability to have a dry year after a dry or non dry departure year is low and barely exceeds 40%. In the southern high plains of south Constantine the probability is over 50%.

Key words drought; Markov Chain; SPI; eastern Algeria

INTRODUCTION

Algeria is one of the southern Mediterranean countries that suffer from water shortage from one season to another and from one year to another. Drought forecasting is often difficult because, to be useful, it must be done several weeks or months in advance. The spatial distribution of drought is highly complex. It is very common to find an area subject to dry conditions, while the neighbouring areas are under wet conditions. This trend has been recorded in many countries such as Nigeria (Oladipo, 1995), England (Fowler & Kilsby, 2002) and Turkey (Komuscu, 1999). This variation is often attributed to complex patterns of atmospheric circulation, complicated by the fact that drought can not be associated with only one type of weather conditions (Vicente-Serano, 2006), which makes it difficult to determine the areas on which the evolution of drought is homogeneous (Vicente-Serano, 2006). In Algeria, drought is characterized by an increase in the minimum and maximum temperatures and a decrease in rainfall (Meddi & Hubert, 2003). In Morocco for example, the characterization of drought during the period 1961–2004 showed a significant increase in the frequency of droughts, their severity and spatial field (Stour & Agoumi, 2008). This study is based on the study of drought persistence at annual and seasonal scale in eastern Algeria on the basis of an analysis of rainfall data observed in 17 rainfall stations, covering the largest area of eastern Algeria, from 1950 to 2005.

MATERIAL AND METHODS

Presentation of the study area

The study area is bounded in the west by a vertical line crossing Bejaia, the mountains and Chott Hodna to the Zab Mountains, in the east by the Algero-Tunisian border, in the north by the Mediterranean Sea and in the south by Chott Melrhir (Fig. 1). It is a quadrilateral delimited by the meridians 4°40′E and 8°30′E and the parallels 37°10′N and 34°20′N. Rainfall decreases from coastal areas to inland regions, following a strong latitudinal gradient, altered by the orographic effect of the Saharan Atlas, before decreasing again in the Saharan piedmont where rain is scarce. According to Côte (1996), the transition from wet in the north to arid in the south is not regular.

Data

The data used in the study come from the two organizations responsible for rainfall networks: the National Agency of Water Resources and the National Meteorological Office. The rainfall data collected for the study consists of 17 stations for the period from 1950 to 2005 (54 years) (Fig. 1).

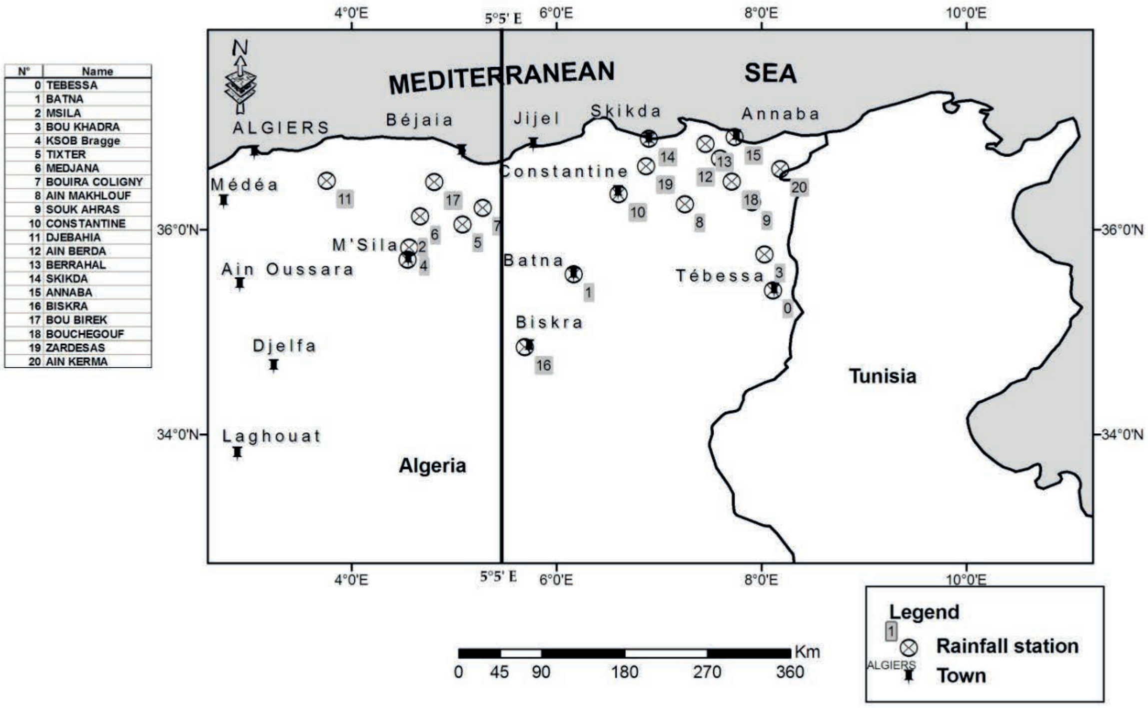

Fig. 1 Location of the study area and rainfall stations.

METHODS

Determination of drought thresholds

Some authors, who have studied drought from climatic data, suggest arbitrary thresholds of rainfall: 10% of the average (Le Goff, 1985), or the last decile (Meko, 1985). To estimate the intensity of rainfall deficit, many indices have already been mentioned. To overcome the lack of official indicators of drought, there are many indices and techniques to define dry years (Beran & Rodier, 1985). To assess the thresholds of dry and wet years, the quintile method (frequency) has been selected. These thresholds are needed for seasonal and annual forecasting using Markov chains (Benzerti & Habaieb, 2001).

Quintile method

The calculation can be based on the appropriate probability distribution of an observation series. The use of the probability distribution allows us to estimate more accurately the different quantiles and calculate their return periods. The threshold of dry years is observed, on average, every 2.5 years and that of the very dry years every 5 years. After several tests we found that normal root distribution gives the best fit for annual rainfall (Chaumont & Paquin, 1971; Laborde, 1988; Meddi, 2001). The calculated thresholds take into account the following criteria (Benzerti & Habaieb, 2001):

– The years of frequency below 0.15 are considered as very dry years
– The years of frequency ranging from 0.15 to 0.35 are considered as dry years
– The years of frequency ranging from 0.35 to 0.65 are considered as normal years
– The years of frequency ranging from 0.65 to 0.85 are considered as wet years
– The years of frequency higher than 0.85 are considered as very wet years

The SPI: drought quantification

Currently, the permanent monitoring mechanism of drought is based on various indices: the Standardized Precipitation Index (SPI) and the percent of normal precipitation (PNP). The SPI is used to quantify the precipitation deficits on multiple time scales. The SPI (Standardized Precipitation Index) was developed in order to characterize the deficits of precipitation for a given period (McKee *et al.*, 1993). It takes into account the importance of time in the analysis of water resource availability. In fact, the period of time over which the deficit of precipitation is accumulated becomes extremely important in separating the different types of droughts (McKee *et al.*, 1993). It can be calculated at different time scales (1, 3, 6, 12, 24 and 48 months) in order to reflect the impact of drought on different water resources (McKee *et al.*, 1993). The SPI is calculated by fitting the rainfall series collected over long periods to a probability distribution. The different values of this index (SPI) show the number of years during which the standard deviation of rainfall observations deviated from the mean established over a long period. As a general rule, a continuous series of more than 30 years of observations is required to calculate this index (Anctil *et al.*, 2002). Dracupin 2002 (in Vicente-Serrano, 2006) tested the robustness of 18 drought indices by means of statistical methods and concluded that the SPI was the best climatic index to characterize drought and quantify the intensity, duration and spatial extent of drought. The positive values of the SPI reflect wet conditions and the negative values indicate a meteorological drought (McKee *et al.*, 1993).

The SPI is expressed as follows: $SPI = \dfrac{P_i - P_m}{\sigma}$

where: P_i, precipitation of the year i; P_m, mean precipitation; σ, standard deviation.

The study of drought persistence was conducted using Markov chains. The methodology of Markov chains allowed determining or forecasting the probability of having a dry year after a dry or a non dry year (Thirriot, 1986). The model of Markov chains is an iterative, stochastic model. Thus, the state of the year k depends only on the state of the year k–1 for the Markov process of order 1. It depends on the states k–1 and k–2 for the Markov process of order 2. A year can be characterized in terms of rainfall by two states: State 0: presence of drought (dry or very dry); State 1: absence of drought (normal, wet and very wet).

A Markov chain of order r therefore models the realization of a given state among the existing possibilities. However, the analysis and practical implementation of the Markov modelling show that the estimation problems increased with the order (Thirriot, 1983; Afouda, 1985; Afouda *et al.*, 1997). We therefore limited the Markov chains to an order one.

RESULTS AND DISCUSSION

Stationarity or non-stationarity of rainfall data is of interest to many users in different applications (hydrology, agronomy, and water management to name a few). The detection of one or more breaks gives information on rainfall evolution. In Algeria, the climate changes in the recent decades have had a negative influence on the water resource (groundwater recharge, filling of reservoir dams and agricultural yields). We aim to show this evolution by determining the year or years of break in the stationarity of rainfall data of several stations in eastern Algeria.

The methods used to highlight these breaks are: U Buishand statistics, the test of Pettitt and Kendall test, whose power and robustness have been reviewed by Lubes-Niel *et al.* (1998) and applied in Algeria (Meddi & Hubert, 2003).

The stations of east central and eastern Algeria located east of longitude 5°50′ have a break in the stationarity such as those of west central and western Algeria. However, in the eastern areas of Algeria, and more specifically the area between the longitude 5°50′ and 8°E, no significant break could be detected, for the period between 1950 and 2005, despite the decrease in annual totals over the last decades (Fig. 2). Furthermore, no break in the rainfall series was highlighted by a similar study in central Tunisia with the same statistical tools (Kingumbi *et al.*, 2001) and southern Tunisia (Ellouze & Abida, 2008). The reduction varies from 15 to 20%. This order is similar to the values found in central and western Algeria (Meddi & Hubert, 2003). The thresholds for annual and seasonal scales are estimated using the method of quintiles in order to start the calculation of the probability of the occurrence of a dry year by Markov chains (Table 1). Drought forecasting has revealed two distinct areas: the first one concerns the region located east of longitude 5°50' and the region covering a group of sub-littoral and coastal mountains (the Tel) and plains. The second area consists of the eastern steppe in eastern Hodna which is formed by the high plains of southern Constantine. For the region's stations that have experienced a significant reduction in rainfall and the stations of the coastline and mountains close to them (located west of longitude 5°50′), the probability to have a dry year after a dry or non dry departure year is low and barely exceeds 40%. However, in the area lying between the first region and the steppe, this probability varies between 40 and 50%. In the southern high plains of south Constantine, the probability is well over 50%. The reverse occurs when the departure year is dry or not dry, the probability of having a non dry year the following year in comparison with the proportions mentioned above. These results are consistent with those found in the north and centre of Tunisia (Benzerti & Habaieb, 2001).

Seasonally, we find that for the three seasons (autumn, winter and spring) and whatever the nature of the season of the starting year (dry or not dry), the probability of having a dry season the following year is lower than that of having a non dry season at southern stations (M'sila and Biskra). However, the reverse is true for having a non dry season the following year whatever the nature of the starting season (dry or not dry).

For highlighting rainfall deficit, we calculated the values of the Standardized Precipitation Index (SPI) for the time interval of 3, 6 and 12 months. The dry periods (events) were analysed on the basis of several drought parameters: the duration, maximum intensity, magnitude and the beginning and end of drought. The selected time intervals express the duration of the accumulation of rainfall deficit. Thus, the SPI values for the time interval of 3 months represent meteorological drought of short duration, and those of 6 and 12 months, meteorological drought of medium duration. The SPI calculation was performed for the period 1950–2005 by applying this analysis on the Skikda stations representing the coastal region (wet), Meskiana the region of high plateaus (semi-arid) and the station of M'sila for the arid region. The severity of drought is characterized by three attributes: extremely dry (ED), severely dry (SD) and moderately dry (MD). The largest dry periods were recorded in the south of the study area, there are 77 cases (M'sila station) and the minimum number of dry sequences (49 cases) was recorded at the Skikda station representative of the coastal region in its central part, the number of dry sequences is 62 cases at the station of the El Hamiz dam, which indicates that the drought was more severe in this region than the east of the country. The longest average duration was recorded at the M'Sila station (4.9 months) and the lowest at the Skikda station (3.7 months). Compared to these average values, the maximum duration varies from 7 months (Skikda) to 10 months (M'Sila). At the level of this last station representative of the southern region of the study area, the longest dry period lasted from February 1992 to November 1992 (10 months). It was moderately dry, with a magnitude of 10.2 and a maximum intensity of –1.5. The maximum intensity of dry periods is highest in the north (the Skikda station with a value of –2.34) recorded during May 1960 with a combined magnitude of 6.5. The greatest intensities were recorded for the years 1960, 1965, 1973, 1974, 1996 and 2000. The greatest magnitudes, i.e. the most severe droughts, were recorded at Meskiana and Skikda stations with 11.1 and 10.5, respectively.

Table 1 Probability from Markov chains of order 1

	Stations	Djebahia	Bouira	Bou Birek	ZarDezasBge	Skikda	Constantine	Bouchegouf	Ain Berda	Annaba
Annual	D-D	37.05	36.4	38.1	33.3	33.3	35.0	28.6	39.1	38.5
	D-ND	62.05	59.1	61.9	61.9	66.7	65.0	71.4	60.9	57.7
	ND-D	48.391	42.4	38.2	41.2	41.2	34.3	41.2	40.6	55.2
	ND-ND	48.391	57.6	58.8	58.8	55.9	62.9	55.9	56.3	44.8
	Stations	Batna	La Meskiana	Ain Makhlouf	Souk Ahras	Bou Khadra	Tebessa	KsobBge	M'sila	
Annual	D-D	46.155	43.5	47.8	56.0	54.5	51.9	54.2	57.1	
	D-ND	53.855	52.2	52.2	44.0	45.5	44.4	41.7	38.1	
	ND-D	48.286	37.5	34.4	33.3	27.3	42.9	35.5	26.5	
	ND-ND	48286	62.5	62.5	63.3	69.7	57.1	64.5	73.5	

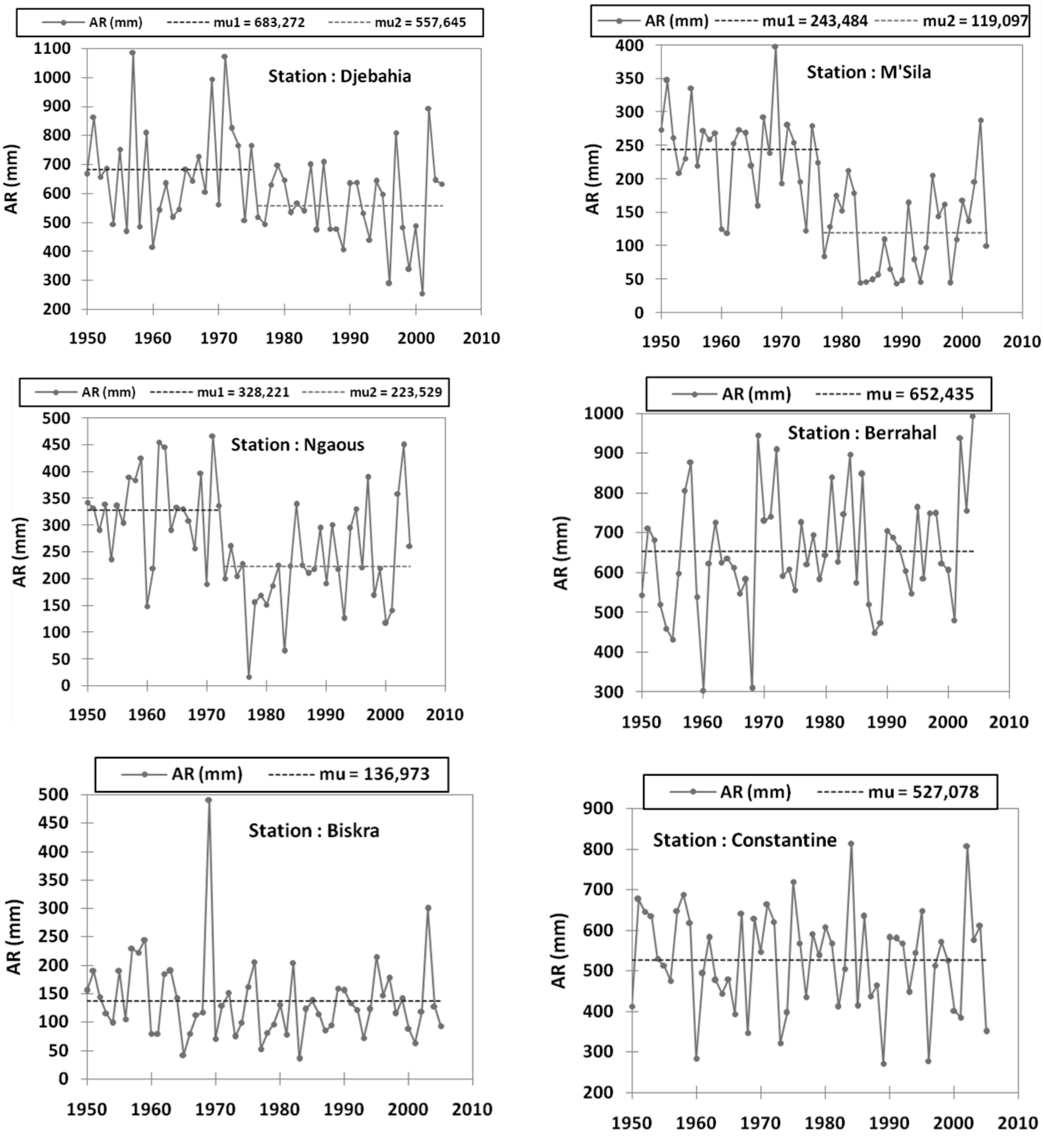

Fig. 2 Temporal evolution of annual rainfall (AR).

In general, at Skikda and Meskiana stations, the lowest number of droughts with shorter periods were observed compared to the south, but with higher intensities and magnitudes than those of the south represented by the M'Sila station.

CONCLUSION

During the last decades, Algeria was subject to drought. Significant decreases of rainfall amounts were recorded in most regions with large variability in their spatio-temporal distribution. The study of the stationarity showed that the stations located east of longitude 5°50′E have a break in the stationarity in 1975. But, specifically the area west of longitude 5°50′E, no significant break is detected. The study of drought persistence by using Markov chains showed that for the area located east of longitude 5°50′, the probability to have a dry year after a dry or non dry departure year is low and barely exceeds 40%. In the southern high plains of south Constantine, the probability is well over 50%.

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