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Statistical assessment of rainfall variability and trends in northeastern Algeria

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Abstract

In the present study, time series for annual, monthly rainfall and number of rainy days per year were analysed to quantify spatial variability and temporal trends for 22 rainfall stations distributed in northeastern Algeria for the period 1978–2010. The Mann–Kendall test and the Sen’s slope estimator were applied to assess the significance and magnitude of the trend. The results showed that precipitation decreases spatially from North to South and from East to West. The application of the Mann–Kendall test (for 0.05% threshold) to the time series data showed that for annual precipitation, no station showed statistically significant trends, unlike the number of rainy days, where there was a significant negative trend in four stations (Jijel, Constantine, Oum El Bouaghi and Tébessa). For the monthly time series, significant positive trends were observed during the months of September in the coastal stations and July for the plateaus and southern Saharan Atlas stations, while significant negative trends were recorded during the months of February and March for the stations of the extreme East in the study area. These results revealed that for the period analysed, there was no significant climate change in northeastern Algeria but there is a seasonal delay having important agroecological implications.

Key words: *climate change, Mann-Kendall test, northeastern Algeria, precipitation, rainfall trend*

INTRODUCTION

The scientific community has been very interested in the study of climate variability and climate change during this century. Many researchers have tried to study, identify and determine climate systems and their variability for different regions.

Rainfall variability is one of the most important elements for climate and hydrometeorology studies. Thus, the spatial and temporal trends of precipitation are important for climate analyst and water resources planner [SAYE-MUZZAMAN, JHA 2014]. However, rainfall is an essential climatic factor because it is the most important factor in the regionalization of climatic and environmental condi-

tions and affects the temporal and spatial patterns of climatic variability [JAVARI 2016].

In the current context of climate change, various studies have shown that in the Mediterranean basin, trends in rainfall variability at different time scales are decreasing significantly [IPCC 2001; PHILANDRAS *et al.* 2011; PIERVITALI *et al.* 1997; TRAMBLAY *et al.* 2013; TURKEŞ *et al.* 2008].

In Algeria, the study of spatial evolution and temporal trends of precipitation have been carried out in all or part of the country, such as ANRH [1993]; MEDDI and MEDDI [2007], TAIBI *et al.* [2015], BESSAKLIA *et al.* [2018], NOUACEUR and MURĂRESCU [2016]. However, few studies have addressed the variability and trends in Eastern Alge-

ria. These studies were much more interested in hydrographic basins. In addition, they were conducted on rainfall data from the National Agency of Water Resources, which use stations different from those used by the National Meteorological Office (ONM), for example: MRAD *et al.* [2018], BALAH and AMARCHI [2016].

In the studies of trend detection of annual and monthly precipitation, and number of rainy days per year, several statistical methods have been developed and used over the years. [CALOIERO *et al.* 2011; DUHAN, PANDEY 2013; LOPEZ-MORENO *et al.* 2010; MODARRES, SARHADI 2009; NASRI, MODARRES 2009; NEL 2009]. The most commonly used method is the Mann–Kendall non-parametric statistical test [KENDALL 1975; MANN 1945] to quantify the significance of trends in precipitation time series [BATISANI, YARNAL 2010; MODARRES, DA SILVA 2007; TABARI *et al.* 2011; ZHAO *et al.* 2015]. This test does not provide the magnitude of the trend. For this, another method called the Sen’s slope estimator is widely used to quantify the trend’s slope [DA SILVA *et al.* 2015; DUHAN, PANDEY 2013; PARTA KAHYA 2006; TABARI, TALAEI 2011].

The scope of this study lies in the fact that the precipitation series used in the analysis come from the National Climatology Centre (Centre Climatologique National) and the National Meteorological Office (Office National de Météorologie) of Algeria. The objectives of this study are (1) to reveal the statistical characteristics of precipitation in 22 meteorological stations, (2) to detect trends in annual, monthly and rainy days per year using the Mann–Kendall test, and (3) the estimation of the magnitude of trends by the Sen’s slope estimator for the 33-year period (1978–2010) in the northeastern Algeria.

These results will provide more information to understand the precipitation behaviour at the regional level in recent years for the study area. This analysis will also help for the design of efficient management of water resources and improve the efficiency of vegetation restoration and regeneration.

MATERIALS AND METHODS

STUDY AREA

The study area is northeastern Algeria with a superficie of 83 372 km². This area is located between 36°54’ and 34°48’ N latitude and 8°27’ and 5°4’ E longitude. It is bounded on the East by the Tunisian border, on the West by the Soummam Valley and the Babors Mountains, on the South by the piedmont of Saharan Atlas, and on the North by the southern littoral of the Mediterranean Sea (Fig. 1).

Our study area, by its position between the Mediterranean Sea and the African continent, is considered as an area of climatic transition between the temperate domain of the north Mediterranean and the subtropical African climate [GIORGI, LIONELLO 2008; LIONELLO *et al.* 2006; MERZOUGUI, SLIMANI 2012]. This fringe position also explains a gradual theoretical decline in latitude from the Sahara to the littoral. However, the interposition of the two vast mountainous ridges – the East-West oriented Tellian Atlas chain and the South-West oriented Saharan Atlas chain – changes the general climatic pattern. In general, the North-East of Algeria is subjected to the combined influence of the sea, the relief, and the latitude. It offers a great variety of climates that become warmer and drier as one

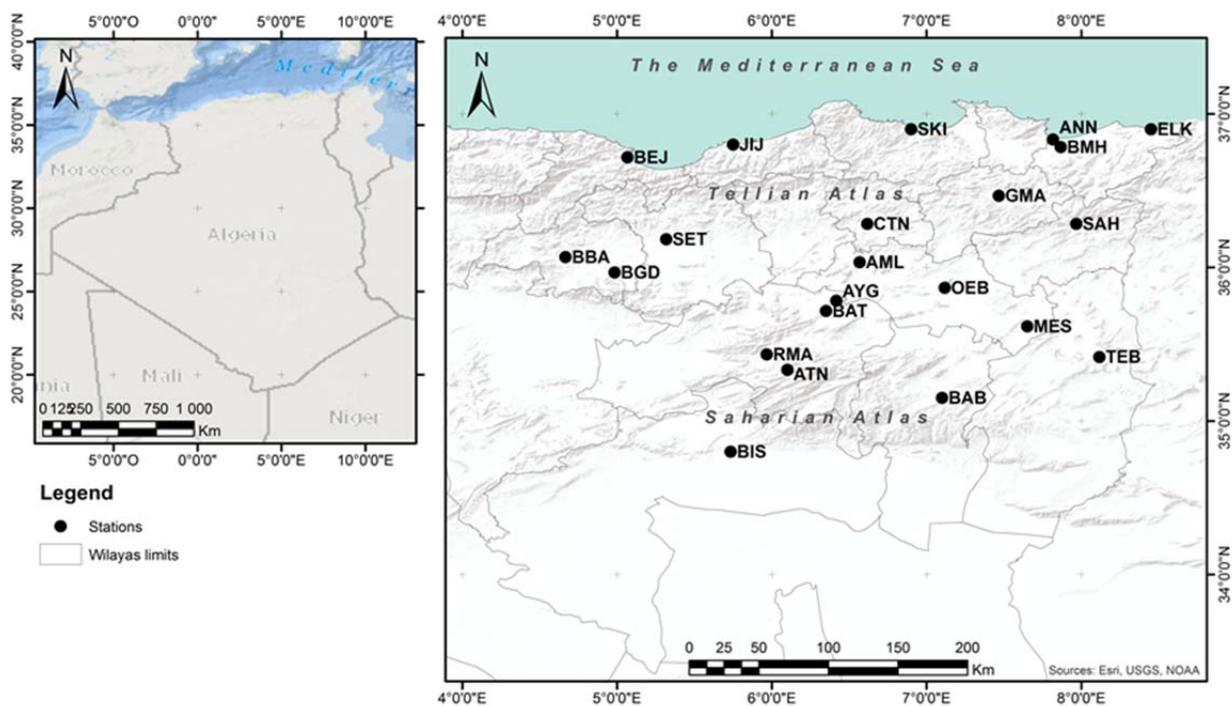


Fig. 1. Spatial distribution of selected meteorological stations in the northeastern Algeria; ELK = Elkalla, ANN = Annaba, SKI = Skikda, JIJ = Jijel, BEJ = Bejaia, BMH = Ben Mhidi, GMA = Guelma, SAH = Souk Ahras, BBA = Bordj Bou Ariridj, SET = Sétif, CTN = Constantine, OEB = Oum.ElBouaghi, AML = Ain mlila, AYG = Ain yagout, BGD = Borj el ghedir, BAT = Batna, TEB = Tébessa, ATN = Ain tinn, RMA = Ras el ma, BAB = Babar, BIS = Biskra, MES = Meskiana; source: own elaboration

moves far from the sea. However, the climate of northeastern Algeria (Fig. 1) presents three climatic regions. From North to South: (a) the littoral and the North versant of the Tellian Atlas with a humid climate to subhumid, (b) the southern versant of the Tellian Atlas, the high plateaus, and the North side of the Saharan Atlas are characterized by a semiarid climate, and (c) the southern versant of the Saharan Atlas and its piedmont with an arid Saharan climate.

DATA

The data used in this study consist of cumulative monthly precipitation and annual surveys from stations located in northeastern Algeria. This monthly rainfall data was collected from the National Climatology Centre (Centre Climatologique National) and the National Meteorological Office (Office National de Météorologie). In order to guarantee the minimum uncertainties when interpreting the series, it is therefore necessary to work on official time series recorded on stable sites from the point of view of measurement protocols and observation conditions as: approved material, no displacement of posts, presentation of site conditions [CANTAT 2004].

The choice of rainfall series was based on the number of years of rainfall observations (over 30 years) and the rate of deficiency on the one hand, and stations from professional networks on the other. Based on these criteria, 22 rainfall stations were selected with altitudes ranging from 1.3 to 1 640 m. The location and characteristics of all rain stations are presented in Table 1.

Table 1. Geographic coordinates for 22 meteorological stations in northeastern Algeria

Station	Code	Latitude N	Longitude E	Altitude (m a.s.l.)
Elkalla	ELK	36°54'	08°27'	15.0
Annaba	ANN	36°50'	07°49'	3.0
Skikda	SKI	36°54'	06°54'	1.3
Jijel	JIJ	36°48'	05°45'	2.0
Bejaia	BEJ	36°43'	05°04'	1.7
Ben Mhidi	BMH	36°47'	07°52'	10.0
Guelma	GMA	36°28'	07°28'	227.0
Souk Ahras	SAH	36°17'	07°58'	680.0
Bordj Bou Ariridj	BBA	36°04'	04°40'	928.0
Sétif	SET	36°11'	05°19'	1 009.0
Constantine	CTN	36°17'	06°37'	660.0
Oum El Bouaghi	OEB	35°52'	07°07'	888.7
Ain Mlila	AML	36°02'	06°34'	771.0
Ain Yagout	AYG	35°47'	06°25'	912.0
Borj El Ghedir	BGD	35°58'	04°59'	954.0
Batna	BAT	35°43'	06°21'	827.0
Tebessa	TEB	35°25'	08°07'	820.4
Ain Tinn	ATN	35°20'	06°06'	1 640.0
Ras El Ma	RMA	35°26'	05°58'	912.0
Babar	BAB	35°09'	07°06'	1 450.0
Biskra	BIS	34°48'	05°44'	86.0
Meskiana	MES	35°37'	07°39'	845.0

Source: own elaboration.

On the one hand, the search for homogeneity in rainfall data led us to retain the period 1978–2010 and on the other hand to take into consideration a maximum number of stations to cover the widest geographical space possible. The data set included monthly mean precipitation, annual precipitation, and the number of rainy days. For the latter, the availability of data forced us to use the main stations which are 14 in number.

TEST OF RANDOMNESS (AUTOCORRELOGRAM)

The application of the autocorrelogram test makes it possible to detect the presence or absence of an order in the time series of climatic data [KENDALL, STEWART 1943; WMO 1966]. The randomness of a time series is given by the autocorrelation coefficient value of 1. If the time series is random, the autocorrelation coefficients are not statistically different from zero. The randomness of the time series of annual rainfall and rainy days was tested by the autocorrelation function for a confidence interval (CI) defined by:

$$CI = \frac{z_{\alpha-\alpha/2}}{\sqrt{n}} \tag{1}$$

Where: z = the percent point function of the normal distribution, n = the sample size, α = the significance level.

MANN-KENDALL TEST

We used the Mann–Kendall test [KENDAL 1975; MANN 1945;] to estimate the trend in mean monthly precipitation, annual totals, and the number of rainy days. This test, which is usually used to evaluate the trend of a time series [DA SILVA *et al.* 2015; LONGOBARDI, VILLANI 2010; SAYEMUZZAMAN, JHA 2014] is calculated as follows:

$$S = \sum_{j=1}^{N-1} \sum_{i=1}^j \text{sign}(X_i - X_j) \tag{2}$$

Where: $\text{sign}(X)$ equal to 1 if $X > 0$; 0 if $X = 0$; and -1 if $X < 0$, and N for the number of data points.

When S is high and positive it implies that the trend is increasing, and a very low negative value indicates a decreasing trend. The variance of S is given by:

$$V(X) = \frac{N(N-1)(2N+5) - \sum_{i=1}^m t_i(t_i-1)(2t_i+5)}{18} \tag{3}$$

Where: m = the number of tied groups in the data set, t_i = the number of data points in the i^{th} tied group.

For n larger than 10, Z_{MK} approximates the standard normal distribution [YENIGUN *et al.* 2008; MRAD *et al.* 2018].

$$Z_{MK} = \begin{cases} (S - 1)/\sqrt{V(S)} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ (S + 1)/\sqrt{V(S)} & \text{if } S < 0 \end{cases} \tag{4}$$

The presence of a statistically significant trend is evaluated using the Z_{MK} value; the positive value of Z_{MK} indicates an upward trend and its negative value a downward trend.

SEN'S ESTIMATOR OF SLOPE

Sen's method proceeds by calculating the slope as a change in measurement per change in time, as shown here in equation below:

$$Q_i = \frac{(x_j - x_k)}{j - k} \text{ for } i = 1, 2, \dots, n \quad (5)$$

Where: x_j and x_k = data values at times j and k ($j > k$) respectively [DA SILVA *et al.* 2015; PARTAL, KAHYA 2006].

RESULTS

ANNUAL PRECIPITATION

The descriptive statistics concerning the annual rainfall for the studied stations are shown in Tables 2 and 3. However, the annual precipitation ranges between 126.71 mm in the Biskra station (South) and 911.42 mm in Jijel (North). The annual average for the study area is 473.92 mm. In the study area, the standard deviation values reveal a large absolute dispersion of annual precipitation. They vary between 54.21 mm and 189.87 mm for the southern region (Biskra) and the littoral (Bejaia), respectively. There is a high significant difference in central tendency parameters (mean and median). The difference between the minimum and the maximum values is very significant. The asymmetry coefficient characterizes the degree of symmetry of a distribution in relation to its mean, where it varies between -0.15 and 1.34. It is mainly positive with an average of 0.57 indicating that the annual precipitation is asymmetrical and that they have a unilateral distribution shifted to the right, with the exception of the Jijel and Bejaia stations (to the left), which means a low concentration around the average. The coefficient of kurtosis varies from -0.95 to 4.84. The average value of the kurtosis coefficient is 0.72 for northeastern Algeria. Coefficients with a positive value of kurtosis have a sharp-topped distribution, i.e., leptokurtic, while those with a negative value have a flat-topped distribution around the mean (i.e., platikurtic). These stations show that they have a distribution significantly different from that the normal distribution.

The average value of the coefficient of variation for the study area is 27%. For all the stations studied, it seems that the inter-annual variability is obvious; no station has a coefficient of variation of less than 20%. The Biskra station reached 42.7%. Spatially, the space wedged between the Mediterranean Sea to the North and the southern limit of the Tellian Atlas is characterized by stations with coefficients of variation of less than 27% for the case of Jijel (20.7%), Ben Mhidi (22.7%), Guelma (25.3%) and Constantine (25.4%). On the plateaus and in the northern part of the Saharan Atlas, the coefficient of variation varies between 27 and 35%. The South is characterized by values higher than 35% for the case of the Biskra station.

It can be concluded that relatively high rainfall amounts correspond to relatively low coefficients of variation; conversely, relatively low rainfall amounts correspond to relatively high coefficients of variation. In general, the values of annual variability increase from North to South in a very distinctive manner, and this shows that the

Table 2. Descriptive statistics for annual rainfall across stations (1978–2000)

Station	Mean	Median	SD	Mini- mum	Maxi- mum
	mm				
Elkalla	356.76	342.90	94.95	159.10	594.90
Annaba	522.80	506.50	133.16	252.70	876.10
Skikda	911.42	849.36	188.64	486.30	1 213.60
Jijel	762.37	767.30	189.87	319.20	1 100.90
Bejaia	769.95	754.00	164.02	491.70	1 157.40
Ben Mhidi	682.46	634.60	170.09	427.70	1 243.20
Guelma	323.35	308.50	100.34	159.20	601.90
Souk Ahras	361.96	359.60	109.60	156.60	665.00
Bordj Bou Ariridj	676.48	676.97	168.72	397.50	1 049.00
Sétif	126.71	126.30	54.21	47.00	295.00
Constantine	372.69	364.70	103.96	199.00	643.30
Oum El Bouaghi	459.05	434.40	133.72	221.00	779.30
Ain Mlila	392.96	401.20	83.60	200.80	605.30
Ain Yagout	686.38	674.30	180.12	367.90	1 017.00
Borj El Ghedir	598.58	579.20	151.86	362.70	938.50
Batna	345.25	331.47	105.92	180.50	727.28
Tebessa	308.29	284.50	102.12	90.40	520.90
Ain Tinn	244.94	250.90	84.20	131.20	531.30
Ras El Ma	359.15	364.00	107.15	191.00	608.20
Babar	296.20	298.95	102.53	134.90	680.60
Biskra	531.98	524.40	120.75	341.04	826.00
Meskiana	336.50	329.83	68.29	226.41	520.07

Explanations: SD = standard deviation. Source: own study.

Table 3. Spatial trends in the rainy days in meteorological stations (1978–2000)

Station	Mean of rainy days per year	Trend in rainy days per year	Sen's slope (mm·year ⁻¹)	p-value	R ²
Elkalla	98.33	-0.202	-0.741	0.103	0.13
Annaba	106.93	-0.435	-1.125	0.0004	0.56
Skikda	109.81	-0.264	-0.811	0.032	0.51
Jijel	100.33	-0.198	-0.477	0.110	0.74
Bejaia	99.66	-0.036	-0.105	0.780	0.52
Ben Mhidi	113.51	-0.217	-0.694	0.079	0.55
Guelma	78.66	0.131	0.392	0.291	0.73
Souk Ahras	83.09	-0.289	-0.980	0.019	0.41
Bordj Bou Ariridj	95.81	0.101	0.224	0.42	0.52
Sétif	36.27	0.155	0.235	0.214	0.68
Constantine	85.66	-0.307	-0.800	0.013	0.41
Oum El Bouaghi	103.45	-0.210	-0.604	0.090	0.56
Ain Mlila	96.84	0.075	0.254	0.545	0.22
Ain Yagout	97.66	0.161	0.400	0.192	0.60

Explanations: bold: trends statistically significant at $p < 0.05$; R² = the correlation coefficient between rainy day and annual rainfall. Source: own study.

rainfall irregularity become more important as the climate become more arid.

Before applying the MK test, all annual precipitation series are tested for the randomness in the time series of climate data. However, the application of the autocorrelogram of order 1 at the 0.05 threshold has shown that the series retained from the annual rainfall in the northeastern Algeria are random. Figure 2 presents the verification of the randomness of the rainfall series of the Souk Ahras and Skikda stations. The MK test is directly applied to the series to detect the trend at a level of significance of 5%.

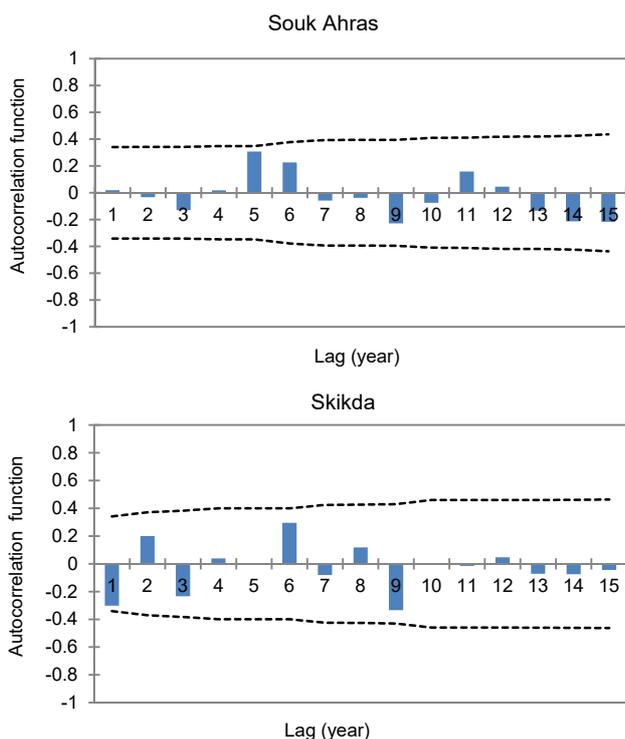


Fig. 2. Autocorrelation plots of annual precipitation for Souk Ahras and Skikda stations; upper and lower lines are 95% confidence bands; source: own study

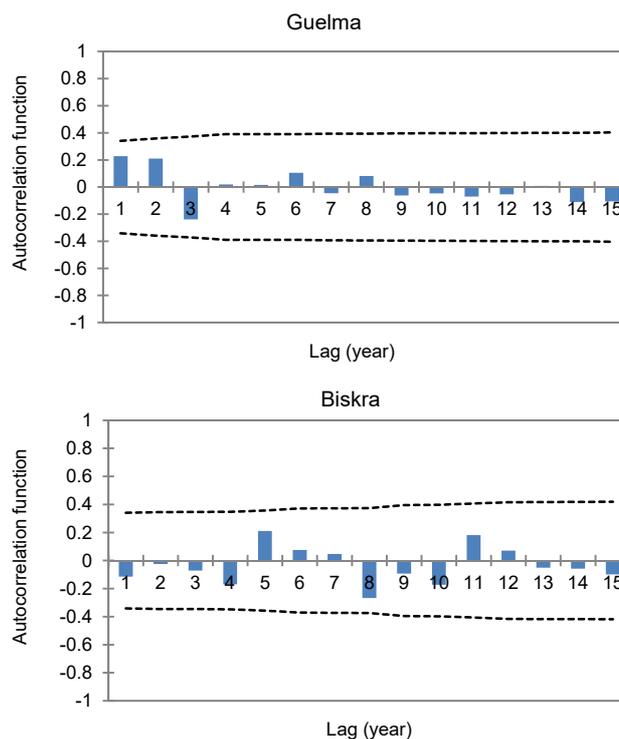


Fig. 3. Autocorrelation plots of rainy days number for Guelma and Biskra stations; upper and lower lines are 95% confidence bands; source: own study

THE NUMBER OF RAINY DAYS

The number of rainy days per year was calculated from the daily rainfall series. A rainy day is considered as having recorded a rainfall of ≥ 1 mm. However, the number of rainy days varies between 113.51 in the North (Annaba) and 36.27 in the extreme South of the study area (Biskra). The average number of rainy days is 93.28 for northeastern Algeria.

Figure 3 shows the autocorrelogram of rainy days number for Guelma and Biskra stations. The correlation coefficient decreases rapidly to zero, so there is no serial correlation. The results can be generalized to all the studied stations (not displayed). Significant negative trends of rainy days at the threshold of 0.5 are observed only at the stations of Constantine (-1.125 days per year), Jijel (-0.811 days per year), Oum El Bouaghi (-0.98 days per year) and Tebessa (-0.8 days per year) – Figure 4. For the threshold of 0.01 the significance of the trends is observed only in Constantine station. Figure 5 shows magnitudes of the significant negative trends of rainy days in four stations for study period. These results explained therefore a specific regional behaviour. Stations with significant trends have their topographic specificities. The station of Jijel is located on the littoral; the station of Constantine is located in the Tellian Atlas, whereas the two others are on the plateaus.

The decreasing and increasing trends in the other stations are not statistically significant at 95%. The variations explained between the annual rainfall and the number of rainy days are moderately high for the Bejaia and Batna stations, with a significant correlation coefficient of 0.74

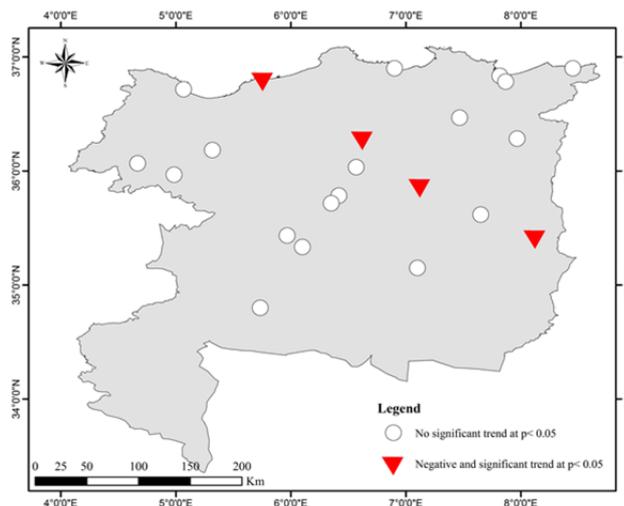


Fig. 4. Spatial trend distribution of rainy days; stations codes as in Fig. 1; source: own elaboration

and 0.73 respectively, moderate for the Constantine, Skikda, El Kalla, and Setif (on average 0.5) and relatively low for Oum El Bouaghi and Tebessa stations, with 0.41 for each. At the Bordj Bou Ariridj and Souk Ahras stations, the number of rainy days is not significantly correlated with annual precipitation at the 95% threshold (Tab. 3). As a result, apart from these two last stations, an approximate value of the annual precipitation can be obtained from the number of rainy days in the other stations. The results show that the decrease in the number of rainy days is more significant than the annual precipitation in the studied stations.

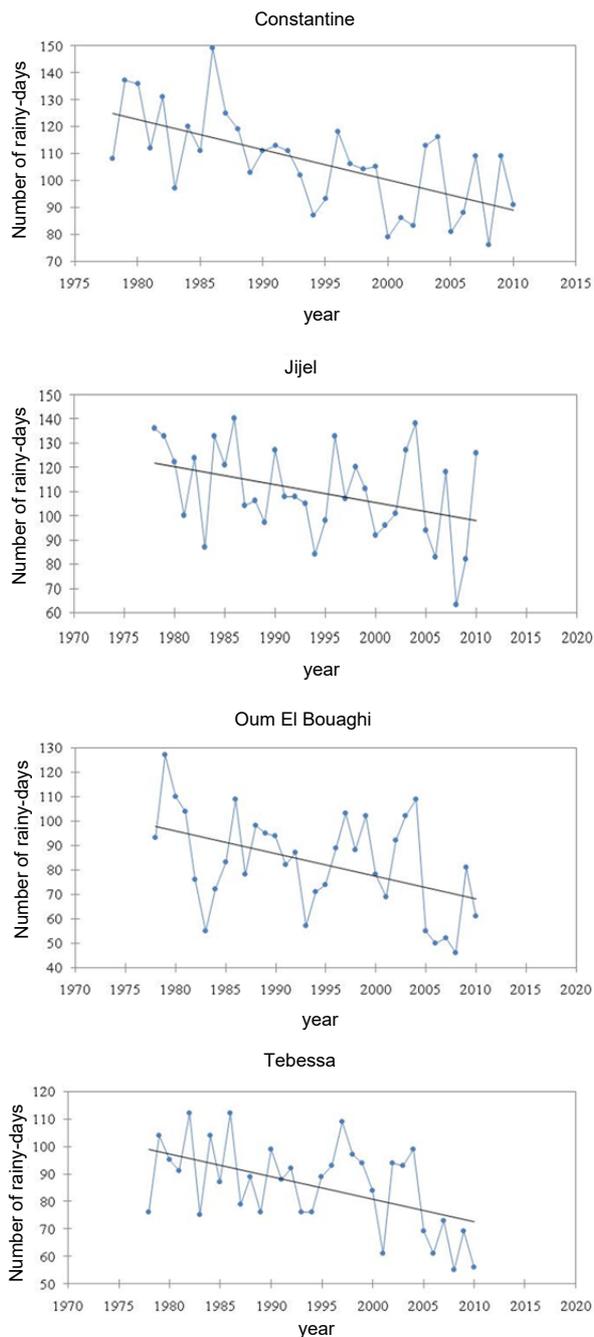


Fig. 5. Annual course of the number of rainy days for stations with significant trends; source: own study

MONTHLY PRECIPITATION

The average monthly precipitation trends for the 22 stations studied were analysed using the MK method. According to the latter, some months show positive trends, while others show negative trends. From among 22 stations analysed, there are only 12 stations with significant trends at 95%. This significance level is observed for one or two months only during the year. The greatest number of significant positive trends is clearly observed in September for littoral stations with a Sen's slope of: Jijel (0.014 mm·year⁻¹), Bejaia (0.027 mm·year⁻¹), Skikda (0.046 mm·year⁻¹), Annaba (0.039 mm·year⁻¹), and Guelma

(0.025 mm·year⁻¹) and July for the stations located in the plateaus and in the Saharan Atlas: Batna (0.023 mm·year⁻¹), Tebessa (0.016 mm·year⁻¹), Bordj El Ghedir (0.004 mm·year⁻¹), Ras El Ma (0.027 mm·year⁻¹).

Significant negative trends are observed during the month of February for Tebessa (0.019 mm·year⁻¹), Babar (0.042 mm·year⁻¹), Meskiana (0.0004 mm·year⁻¹) and March for El Kalla (0.022 mm·year⁻¹), and Meskiana (0.029 mm·year⁻¹). These significant negative trends are located mainly in the eastern part of Algeria in the Tellian Atlas.

DISCUSSION

This study examines the variability and trends in annual, monthly, and rainy days for 22 stations across the northeastern Algeria. Spatially, these results show that annual precipitation decreases rapidly as one moves south. In fact, littoral stations receive more than 700 mm·year⁻¹. The humid air masses crossing the mountain barrier (Tellian Atlas) lose a large part of their moisture, so they dry out; it is recorded 522.8 mm in Constantine, whereas to 100 km in the West, Setif located at more than 1 000 m of altitude, and already in the semiarid field (392.96 mm). The screen effect (Moroccan Atlas and Spanish Sierra Nevada) is particularly accentuated in the West of the study area despite the altitude. This variability can be explained by the presence of a longitudinal gradient where rainfall decreases from East to West [DJELLOULI 1990]. From the South, the role of continentality is more obvious where the rainfall does not exceed 150 mm at the Biskra station, the interannual rainfall variability is greater than 40% in the latter station, between 30 and 40% in the plateaus and the southern side of the Tellian Atlas (represented by Batna, Oum El Bouaghi and Babar), and less than 30% in the littoral and North of the Tellian Atlas. These results are consistent with those found by several studies [MEBARKI 2003; MRAD *et al.* 2018; TALIA *et al.* 2011; TOUAZI *et al.* 2004].

The annual overalls of precipitation are further explained by the number of rainy days in Bejaia and Batna, but more by isolated rainfall and intense events at Bordj Bou Ariridj and Souk Ahras. In the rest of the stations, the annual rainfall is explained by a balance between the number of rainy days and the intense rains. For BENHAM-ROUCHE *et al.* [2015] and GHENIM and MEGNOUNIF [2016], in northern Algeria, the proximity of the Mediterranean and the variety of surrounding reliefs make it difficult to define homogeneous areas. In addition, the increased baroclinic instability of saturated air and closely related to the latent heat release and thus to the development of convective phenomena. During the rainy season, northern Algeria is affected by the polar front, especially the eastern part of the country. For the South, plateaus are generally affected by western disturbances following orographic forcing that causes thunderstorms with intense rainfall. These results are consistent with studies conducted in other Mediterranean regions [MEDDI, MEDDI 2009; MOURATO *et al.* 2010; RUIZ SINOGA *et al.* 2011; SLIMANI *et al.* 2007].

Temporally, the trends for 33 years of the study period are obvious. In fact, for annual rainfall, no station has a statistically significant trend. For TRABOULSI [2010], it is always difficult to identify trends in the evolution of annual rainfall. These can only be perceived on the relative short term. Our results are consistent with those found by TAIBI *et al.* [2015], FRATIANNI and ACQUAOTTA [2010] and PHILANDRAS *et al.* [2011] in their studies on the Mediterranean regions. These results may therefore be based on the assumption that the entire study area experiences the same trend in annual precipitation trends. Consequently, the apparent shortage of water, observed after field surveys in different regions of eastern Algeria, is believed to have been caused by the large increases in withdrawals since the introduction of the water pump, carried out in the surface groundwater.

The number of days without rain is important and similar to Tunisia. For HENIA and BENZARTI [2006], the dry sequences are quite long and can extend over more than twenty or even more than thirty successive days even outside of summer. Examination of rainy day trends using the Mann–Kendall test shows that, contrary to annual rainfall, there are significant clear decreasing trends in the Constantine, Jijel, Oum El Bouaghi and Tebessa. This suggests that the insignificant trends in annual precipitation for the same stations are not associated with the number of rainy days, but rather with the intensity of rainfall. BRUNETTI *et al.* [2000] found that the decrease in the number of rainy days is more significant than that of annual rainfall in Italy. The number of rainy days can be considered as a factor that can determine the quality of a given year. The rainfall deficit in the dry years depends on the decrease in the number of rainy days rather than the decrease in the volumes precipitated by rainy days [DJOUFACK 2011].

The analysis of the monthly evolution shows that the significant positive trends are observed during the months of September for the littoral stations and July for the stations of the plateaus and the Saharan Atlas. MOSMANN *et al.* [2004] found that there was a significant increase in precipitation in July and September in different interior regions of Spain, and this increase in rainfall was related to the increase in the resulting convective processes because of global warming. For CHAOUCHE *et al.* [2010], it is in autumn, and in particular in November, that monthly precipitation records a significant increase and a decrease in June for the French Mediterranean regions. Significant negative trends can be found mainly in the extreme East of the Tellian Atlas (Tebessa – Babar – Meskiana – El Kalla) during the months of February and March. Here, they are attributed possibly to a decrease in the average monthly daily rainfall except for the Tebessa station where they are attributed to a reduction in the number of rainy days. This downward trend in rainfall is perhaps linked to a decrease in the frequency of disturbances from the North. According to TAIBI *et al.* [2015], monthly rainfall in the eastern mountain regions does not appear to have significant correlation with the atmospheric circulation indices. For GIORGI and LIONELLO [2008], the decreases in precipitation are

pronounced in winter on the Alps. These results are similar to those found around the Iberian Peninsula by GONZALEZ-HIDALGO *et al.* [2009]. In the southern France, the significant decrease is recorded during different months; October, November and March [NORRANT, DOUGUEDROIT 2004].

This leads us to believe that the distribution of annual rainfall can be explained by the variations between the number of rainy days per year and the intensity of the rains. Some stations receive more precipitation due to low frequency and high intensity events, while other stations receive their rainfall by more frequent and less intense events. This is why there is no significant trend in annual rainfall.

These results also indicate that climate change does not affect the annual cumulations, but rather there is a seasonal lag that affects the North-East of Algeria. NACEF and BACHARI [2012] have shown that the seasonal variation of air-sea temperature flows in the western Mediterranean is a source of seasonal rainfall variability in the eastern Algerian littoral with a delay for four seasons.

Therefore, the above results will be useful for public administrators, planners, farmers, and hydrologists in developing irrigation and water management plans, as well as for flood risk prevention and drought prediction in the North eastern Algeria.

CONCLUSIONS

The present research has studied the spatial and temporal variability of precipitation in northeastern Algeria, by analysing annual precipitation data, monthly data and the number of rainy days per year collected in 22 stations. The results showed that precipitation decreases from North to South and from East to West. Autocorrelation showed the absence of time cycles in the time series of annual rainfall and the number of rainy days.

The application of the Mann–Kendall test to time series data showed that, for annual precipitation, all stations do not show statistically significant trends, conversely to the number of rainy days, where it was found that there is a significant negative trend in four stations located in different geographic regions, namely Jijel, Constantine, Oum El Bouaghi, and Tebessa, showing a consistent spatial pattern for stations considered. Monthly trend analysis revealed that the significant positive trend is observed during the months of September in the littoral stations and July for the stations of the plateaus and the South of the Saharan Atlas, while the significant negative trends are observed during the months of February and March in stations in the extreme East of the study area.

These results indicate that, for the analysed period, there is no significant climatic change in the northeastern Algeria, but rather there is a seasonal delay, which could have an injurious impact on cereal crops and steppe rangelands in the plateaus, and also on the vegetation layering in both Atlas.

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Statystyczna ocena zmienności i trendów opadu w północnowschodniej Algierii

STRESZCZENIE

W przedstawionych badaniach analizowano serie rocznych i miesięcznych opadów oraz liczbę dni z deszczem w ciągu roku celem ustalenia przestrzennej zmienności i czasowych trendów w latach 1978–2010 dla 22 stacji pomiarowych rozmieszczonych w północnowschodniej Algierii. Wykorzystano test Manna–Kendalla i estymator Sena do oceny istotności i rozmiaru trendu. Wyniki dowodzą, że opady malały z północy na południe i ze wschodu na zachód. Zastosowanie testu Manna–Kendalla ($p < 0,05$) do serii danych pomiarowych nie wykazały w żadnej stacji statystycznie istotnych trendów dla rocznych opadów w przeciwieństwie do liczby dni z opadem, które cechował istotny negatywny trend w czterech stacjach pomiarowych (Jijel, Constantine, Oum El Bouaghi i Tébessa). Analiza serii miesięcznych opadów dowiodła występowania dodatniego trendu w odniesieniu do sierpnia w stacjach na wybrzeżu i w odniesieniu do lipca w stacjach na płaskowyżach i w południowym Atlasie Saharyjskim. Istotny trend ujemny uzyskano w przypadku lutego i marca w stacjach na wschodzie badanego obszaru. Wyniki dowodzą, że w analizowanym okresie nie stwierdzono istotnych zmian klimatu w północnowschodniej Algierii, z wyjątkiem sezonowych opóźnień, które wywołują ważne skutki agro-ekologiczne.

Słowa kluczowe: *opad, północnowschodnia Algieria, test Manna–Kendalla, trend, zmiana klimatu*