Fayrouz Bahloul
Imp spatiotemporal analysis of precipitation and their relationship with climate indices (Soummam Basin, Algeria)
International Journal Water Sciences and Environment Technologies
Vol. (vii), Issue 1, March 2022, pp. 18-35
ISSN Online: 1737-9350; ISSN Print: 1737-6688, Open Access
www.jiste.org
Scientific Press International Limited
Received: 30 January 2022 / Revised: 28 February 2022 / Accepted: March 2022 / Published: March 2022

Imp spatiotemporal analysis of precipitation and their relationship with climate indices (Soummam Basin, Algeria)

Fayrouz Bahloul[1]
[1] Laboratoire de recherche en biochimie, biophysique, biomathématiques et scientométrie "L3BS", Université Abderrahmane Mira Bejaia, Algérie,

Abstract

Drought is a natural and repetitive phenomenon, characterized by a prolonged and abnormal lack of humidity that leads to negative impacts on water resource management and planning. This work provides an analysis of drought in terms of frequency, persistence and severity. To this end, the analysis is based on monthly precipitation data collected during the period 1967 to 2011 in Soummam basin located in the north eastern Algeria. Based on SPI values at different time scales (3-, 6-, 12- and 24-months) and statistical methods (Pettitt and Mann-Kendall), the results show alternating dry and wet periods and an uneven in the spatial and temporal distribution of rainfall. The region marked by a long period of deficit since the 1970s and two break points was detected, one in 1972 indicates the decline in the precipitations, unlike the 2001 break point that show an increase in rainfall. To explain this variation, a correlation analysis with four climate indices was performed using the Spearman correlation. It appears that the MO and NAO are the dominant modes on annual and monthly scales, but it is above all the Mediterranean Oscillation (MO) that affects the rainfall regime, thus explaining one of the causes of this variability, namely the decrease in rainfall from the 1970s and its increase from the 2000s onwards

Key Words*:* Teleconnection pattern; Circulation Index; Soummam basin; spatiotemporal variability; Standardized Precipitation Index; statistical tests

Analyse spatio-temporelle des précipitations et leur relation avec les indices climatiques (bassin de la Soummam, Algérie)

Résumé

La sécheresse est un phénomène naturel et répétitif, caractérisé par un manque d'humidité prolongé et anormal qui entraîne des impacts négatifs sur la gestion et la planification des ressources en eau. Ce travail fournit une analyse de la sécheresse en termes de fréquence, persistance et sévérité. A cette fin, l'analyse est basée sur les données de précipitations mensuelles collectées pendant la période 1967 à 2011 dans le bassin de la Soummam situé dans le nord-est de l'Algérie. Sur la base des valeurs SPI à différentes échelles de temps (3, 6, 12 et 24 mois) et des méthodes statistiques (Pettitt et Mann-Kendall), les résultats montrent une alternance de périodes sèches et humides et une inégalité dans la distribution spatiale et temporelle des précipitations. La région est marquée par une longue période de déficit depuis les années 1970 et deux points de rupture ont été détectés, celui de 1972 indique le déclin des précipitations, contrairement au point de rupture de 2001 qui montre une augmentation des précipitations. Pour expliquer cette variation, une analyse de corrélation avec quatre indices climatiques a été réalisée en utilisant la corrélation de Spearman. Il apparaît que la MO et la NAO sont les modes dominants aux échelles annuelle et mensuelle, mais c'est surtout l'oscillation méditerranéenne (MO) qui affecte le régime pluviométrique, expliquant ainsi une des causes de cette variabilité, à savoir la diminution des précipitations à partir des années 1970 et leur augmentation à partir des années 2000.

Mots Clés : schéma de téléconnexion ; Indice de circulation ; bassin de la Soummam ; variabilité spatio-temporelle ; Indice de précipitation standardisé ; tests statistiques

[1] Corresponding author: bahloulfayrouz@hotmail.com

INTRODUCTION

Climate has always fluctuated over time under the direct or indirect influence of natural forcing. Unfortunately, anthropogenic activities have compromised this fragile balance and disrupted the climate due to the amplification of greenhouse gases in the atmosphere, thus increasing the frequency and severity of risks and natural disasters. In all its reports, the IPCC [1,2] describes these changes as very serious and sounds the alarm about the extent of these disturbances with the alarming occurrence of extreme events that could lead to future global instability with the gradual lack of basic resources such as water and food.

In Africa in particular, the notion of climate change is primarily attributed to a decrease in precipitation, which has been established as the key climatic factor in many studies [3–5]. In recent decades, precipitation has varied considerably, contributing to droughts and occasionally floods. The occurrence of these extreme events involves a potential change in the climate regime. This decrease in precipitation has several consequences, most of which are drastic. Several studies have been carried out in this context, analyses of precipitation over long series have become essential to explain the decrease in precipitation, the persistence and impacts of droughts on water resources and agriculture [6],[7] as well as the factors related to these disturbances such as the relationship with the general atmospheric circulation [8]. The analysis of precipitation variability has been the subject of several studies around the Mediterranean basin at different spatiotemporal scales. The region is classified as a climate change sensitive area and identified as a hot spot [9], showing a significant decrease in precipitation since the 1970s [10]. In the IPCC (2007) report, the southern Mediterranean basin will increasingly experience a pronounced aridity. Moreover, the temperatures and rainfall projected by general circulation models [11] have shown that water will become increasingly scarce while temperatures will continue to rise. According to the 2007 IPCC report a number of countries, especially arid and semi-arid, will face a real problem of water resources and water stress between 2020 and 2075.

In Algeria, a Mediterranean country where aridity is dominant, the studies already carried out on the spatio-temporal evolution of rainfall show a decreasing trend in rainfall since the 1970s [12–14]. The most persistent were during the 1980s to 1990s and the year 1988/1989 was listed as the driest one for the country [15–18]. Some authors showed a return to wet episodes from the early 2000s [19,20]. All these studies use different time-series and methodological methods to assess trends and ruptures, making comparisons between studies exceedingly difficult [6,21]. Thus, the country is already experiencing an increasingly alarming water deficit and is facing this almost endemic shortage [22]. A decrease of 10% in rainfall with a surface water deficit of 15% is observed [23]. The lack of this vital resource is directly linked to the high spatial and temporal variability of precipitation, which results in violent floods and water-free cycles that can last for months or even several consecutive years. Four main categories of drought were identified [24]: meteorological drought related to the number of rain-free days for different well-defined thresholds for each country, agricultural drought related to the demand for water for crop growth, hydrological drought related to the recharge of surface or underground reservoirs, socio-economic drought related to supply and demand and lately the ecological drought [25]. The drought is a prolonged period of water shortage, ranging from the absence of precipitation to a reduction in the supply of surface or underground reservoirs. Each drought must be considered as a particular case and can be defined as a phenomenon that sets in and lasts for months or even years, causing a water deficit. This deficit can be aggravated by the excessive increase of water consumption by individuals and industry. To define a drought, several characteristics must be determined, namely its onset, decrease, intensity, duration, frequency and magnitude [26]. All this variation in the precipitation regime in the Mediterranean basin has been explained by the significant influence of the general atmospheric circulation by several authors, such as the North Atlantic Oscillation (NAO) [27], El Niño-Southern Oscillation (ENSO) [28], Mediterranean Oscillation (MO) [29] and the Western Mediterranean Oscillation (WeMO) [30]. In Algeria, there are few studies demonstrating the relationship between variations in the precipitation regime and general trends of atmospheric circulation. The study by Meddi et al. (2010) [28], shows that the temporal variability of annual precipitation in the west of the country is influenced by the ENSO. The study carried out by Taibi et al. (2014) [6], shows that the seasonality of rainfall is influenced by the MO, whose influence is mainly felt in winter, as well as a significant relationship between this mode and the monthly rainfall in the north-west of the country. However, this relationship is not observed in the Eastern and Eastern Highlands regions. Taibi et al., 2015[31]; show in their work, the influence of the MO mode on daily precipitations in the Cheliff basin (north western algeria). A significant negative correlation observed since the mid-1970s due to the positive phase of this mode.

The main objective of the present study is to detect where precipitation showed the greatest variation between 1967 and 2011 for 23 stations in the studied basin and to look for a relationship between the different atmospheric circulation patterns that gave rise to these precipitation trends. The content is organized as follows. In Section 2 is presented the study area and the precipitation database, as well as the methods used. In Section 3 the results are described. And in Section 4 the discussion and the conclusions are presented.

MATERIALS AND METHODS

Study Area Presentation and Data Set

The Soummam basin covers an area of 9125 km² and is located in the northeast of Algeria between 3°38' and 5°38' east and 35°45' and 36°45' north. It joins the Mediterranean through the Gulf of Bejaia while most of its territory is remote on the continent. It consists of three major regions, the Bouïra Plateau, the Setif Plateau and the Soummam Valley. This basin is bounded to the north and west by the mountain ranges of Djurdjura which stretch to the Mediterranean Sea, to the east by the Little Kabylia Mountains (Babor Mountain), to the south and to the southeast by the Hodna Mountains. The average length of the hydrographic network is 726 km. The climate is generally Mediterranean, where most of the rainfall occurs in winter ranging from 350 mm in the southeast in Setif and reach 1000 mm in the north on the coast. The Soummam Valley is subject to a humid climate with seasonal temperature variations (the average annual temperature varies from 13° to 19°). In contrast, in Setif and Bouïra, the climate is continental and dry, with cold winters and hot summers. The southern part of the Setif Plateau is sub-humid to semi-arid. The data used are the monthly precipitation time series of 23 stations distributed on the study area during the period 1967 to 2011 (Figure 1).
The percentage of monthly missing data in the database is 1.29 to 9.63%. Before data processing, the implementation of the missing data was ensured with Amelia multiple imputations method [33] and was subjected to homogeneity tests for a reliable database [34].

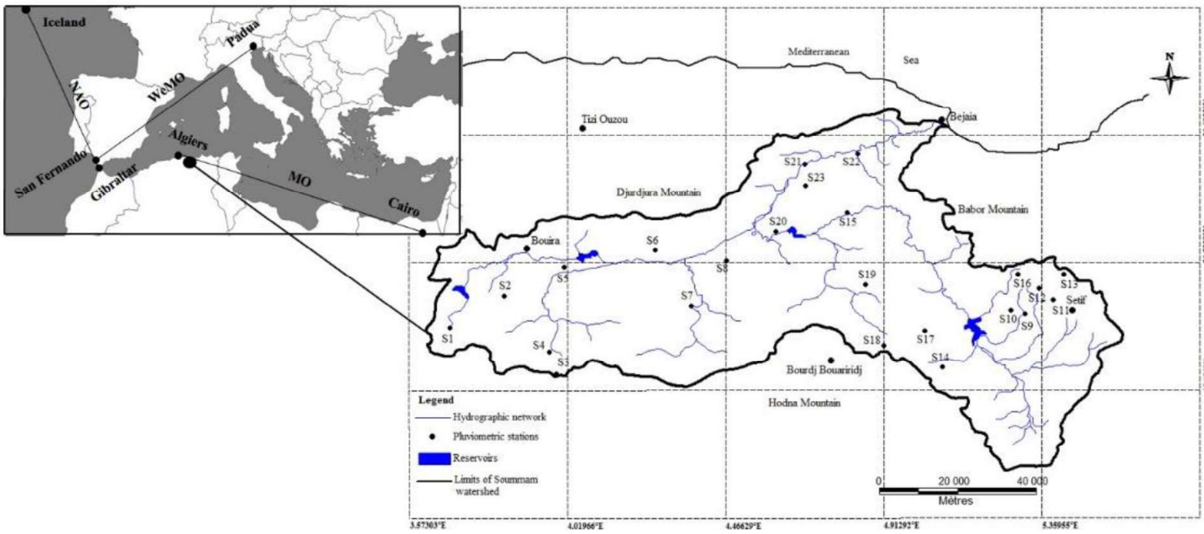

Figure 1. Location of the Soummam watershed, its hydrographic network, position of the selected rainfall stations and measurement points of the different circulation modes considered represented in medallion.

For climate indices, the NAO and MO data used were provided by the Climatic Research Unit (available on http://www.cru.uea.ac.uk/cru/data/pci.htm). The NAO values considered in this study are those between Gibraltar and Iceland [33]. The MO values are defined by the dipole Algiers and Cairo [35]. The WeMO Index was acquired from the Group of Climatology at the University of Barcelona developed by Martin-Vide and Lopez-Bustins (2006) using the dipole Padua in northern Italy and San Fernando in southwest Spain.

METHODS

To conduct the study, these approaches are applied: (i) method based on the analysis of the evolution of precipitation indices (SPI) to characterize droughts and humidity in terms of intensity, frequency, duration, amplitude and determine wet and dry periods; (ii) a method based on the use of statistical tests to detect ruptures and trends, and (iii) correlations with atmospheric circulation models such as the NAO, the MO and the WeMO.

Standard Precipitation Index (SPI)

This index, developed by McKee, Doesken and Kleist (1993) [36], quantifies the precipitation deficit for multiple time scales such as for periods of 3, 6, 9 and 12 months, compared to these same months historically [37]. For a given region, the index is based on a long-term rainfall record, usually at least 30 years, and on the cumulative probability of rainfall for different time scales, then adjusted to a gamma distribution that is transformed to a standard normal (mean = 0 and SD = 1). This is achieved through a process of maximum likelihood estimation of the gamma distribution parameters, β and γ (eq. 1)

$$P(x) = \frac{x^{\gamma-1}\exp(-x/\beta)}{\beta^{\gamma}\Gamma(\gamma)} \qquad \gamma > 0 \qquad (1)$$

Where:
P(x) is the probability density frequency (p.d.f.) equation and x is the variable.
α> 0: is a shape parameter.
β>0: is a scale parameter and x> 0 is the amount of precipitation.
Γ (γ): is the gamma function, defined by:

$$\Gamma(\gamma) = \int_0^{\gamma} y^{\gamma-1}\, e^{-y}\, dy \qquad (2)$$

Fitting the distribution to the data requires the estimation of γ and β. Using Thom's (1958) approximation, these parameters can be estimated as follows:

$$\gamma = \frac{1}{4A}\left(1 + \sqrt{\frac{4A}{3}}\right) \qquad \beta = \frac{\bar{x}}{\gamma} \qquad (3)$$

with:

$$A = Ln\,(\bar{x}) - \frac{\sum Ln(x)}{n}$$

$\bar{x}$: Average value of the amount of precipitation.
n: measurement number of precipitations.
x: amount of precipitation in a sequence of data.

Integrating the probability density function with respect to x gives the expression G (x) for the cumulative probability given below:

$$G(x) = \int_0^x g(x)\, dx = \frac{1}{\beta^{\gamma}\,\Gamma(\gamma)} \int_0^x x^{\alpha-1}\, e^{-\frac{x}{\beta}}\, dx \qquad (4)$$

By replacing t = x/β, the equation (4) is reduced to:

$$G(x) = \frac{1}{\Gamma(\gamma)} \int_0^x t^{\alpha-1}\, e^{-t}\, dt \qquad (5)$$

It is possible to have several zero values in a sample. In order to take into account, the probability of zero values, since the Gamma distribution is not defined for x=0, the cumulative probability function for Gamma distribution is modified as follows:

$$H(x) = q + (1-q)G_x \qquad (6)$$

q: is the probability of zero precipitation, calculated using the following equation:

$$q = \frac{m}{n} \qquad (7)$$

m: number indicating, how many times the precipitation was zero in data series.
n: number of observations of precipitation in data series.

Finally, the cumulative probability distribution is transformed into normal distribution to give the SPI. After the approximate conversion provided by Abramowitz and Stegun (1965), it results in that:

For 0 < H(x) <0.5

$$z = SPI = -(t - \frac{C_0 + C_1\,t + C_2\,t^2}{1 + d_1\,t + d_2\,t^2 + d_3\,t^3}) \qquad (8)$$

$$t = \sqrt{ln\,(\frac{1}{(H(x))^2})}$$

For 0.5 < H(x) <1

$$z = SPI = +(- \frac{C_0 + C_1\,t + C_2\,t^2}{1 + d_1\,t + d_2\,t^2 + d_3\,t^3}) \qquad (9)$$

$$t = \sqrt{ln\,(\frac{1}{(1-H(x))^2})}$$

As for the Gamma distribution, the Log-normal distribution is asymmetrically positive and not negative, it is only a transformation of the data, i.e. y=ln (x), supposing that the resulting transformed data are described by Gaussian distribution. By fitting the Log-normal distribution to the sample mean and the variance of the logarithmically transformed data μ(y) and σy^2, the SPI becomes:

$$SPI = z = \frac{\ln(x) - \mu_y}{\sigma_y} \qquad (10)$$

x: total precipitation of a period (mm).
μ: Historical average precipitation of the period (mm).
σ: Historical standard deviation of precipitation for the period (mm).

The Gamma distribution tends toward normal as the shape parameter α tends toward infinity. It is possible to use the normal probability distribution instead of Gamma, which is easier to compute and perhaps more accurate due to a better fit to the data. In this case, the SPI simply becomes:

$$SPI = z = \frac{x - \mu}{\sigma} \qquad (11)$$

The SPI parameter measures the qualitative condition of a drought or humidity allows to assess a precipitation deficit or excess based on the long-term precipitation history corresponding to the time period studied [38]. The SPI is calculated by dividing the difference between the normalized precipitation and its average over a specific period by the standard deviation of the same period (eq.12).

$$SPI = \frac{X_{ij} - X_{im}}{\sigma} \qquad (12)$$

X_{ij}: precipitation considered (annual, seasonal, and monthly) at the ith raingauge station and jth observation.
X_{im}: average precipitation for the period considered.
σ: standard deviation of the period under consideration.
The results give seven classes of the SPI, as shown in Table 1.

Table 1. SPI classification [36]

Wet classes	SPI values	Drought classes	SPI values
Extremely wet	2.0 and more	Near normal	−0.1 to −0.99
Severely wet	1.5 to 1.99	Moderately dry	−1.0 to −1.49
Moderately wet	1.0 to 1.49	Severely dry	−1.5 to −1.99
Near normal	0.1 to 0.99	Extremely dry	−2.0 and less

The advantage of the SPI is that it can be measured on different time scales. In this work, the SPI values were calculated for 3, 6, 12- and 24-months' time scales. For each of these scales, the magnitude of drought or humidity was calculated as follows (eq.13):

$$M = \pm \left(\sum_{j=1}^{j=x} SPI_{ij} \right) \quad (12)$$

Where i represents the time scale, j begins with the first month of a dry or wet event and continues to increase until the end of the event (month x). McKee (1993) [36], defines an episode of drought for a time scale i, as a period during which SPI is continuously negative and the SPI reaches the value −1.0 or less and ends when this value becomes positive (likewise for humidity). The magnitude calculation provides an estimate of the weight of dryness or moisture and is expressed in units of months.

Pettitt Test

The Pettitt test [39] is used to detect a rupture in the rainfall series at an unknown time. This test is sensitive to changes in the mean and it is based on two hypotheses: H0 no change and H1 when a point of change exists. If the null hypothesis of homogeneity of the series is rejected, it proposes an estimate of a single break date.
The test is based on the signs of the differences between the values that make up the sample. A resulting time series is constructed. The p-value of the statistic indicates whether this rupture is statistically significant at the threshold.
In our work, it was used to detect the suspected single rupture in the rainfall time series for the twenty-three rainfall stations in the Soummam basin over the period 1967–2011.

Mann Kendall Test

Parametric and non-parametric tests are used to evaluate whether a change in a data set is significant or not. Thus, the parametric test assumes normality and homogeneity of variance along the series over a sufficiently long period (> 100 years) and with no gaps. The absence of some of these criteria has led us to opt for the Mann Kendall's Non-Parametric Test. Mann [40] and Kendall [41], widely used in climate series trend analyses [42]. This test is used in two cases. The first, when the series has an observation number less than or equal to 9, the test is based on the S statistic, or its absolute value is compared to Mann-Kendall's probability of a non-parametric trend test [43], to define the existence or not of a monotonous trend at the significant α level. If the series has a number equal to or greater than 10, the test is based on the Z statistic or its absolute value is compared to the normal cumulative distribution to see if there is a significant trend or not at the α level. In both cases, the negative or positive value of S or Z indicates a decreasing or increasing trend, respectively. This test is completed by the Sen's estimate which gives the true slope of the linear trend [44].

Spearman Correlation

In order to show the influence of the general atmospheric circulation on the evolution of the rainfall regime in the study area, a correlation analysis between the standardized precipitation indices at different time steps with the climatic indices was tested. The modes considered are: the MO, the NAO and the WeMO because of their influence on rainfall patterns in several regions of the Mediterranean basin. The correlation is made using Spearman's Rank correlation [45]. It is a non-parametric measure of the statistical dependence between the rankings of two variables, useful when the series, such a precipitation series, are not Gaussian and then the Pearson's coefficient of correlation should not be used.

RESULTS AND DISCUSSIONS

Standardized Precipitation Index Approach

Description of Drought and Wet Months in the Soummam Basin

At the global scale of the basin, meteorological drought was assessed by reconstructing its history during the study period. Several time steps were considered using the Standardized Precipitation Index (SPI) approach calculated for 23 stations during the 1967–2011 common registration period (September 1966 to August 2011) by varying the time scales of the index 3, 6, 12 and 24 months. The rainfall taken is the average of the 23 stations taken in this study. Figure 2 (a to d) shows the SPI values obtained for the different scales respectively.

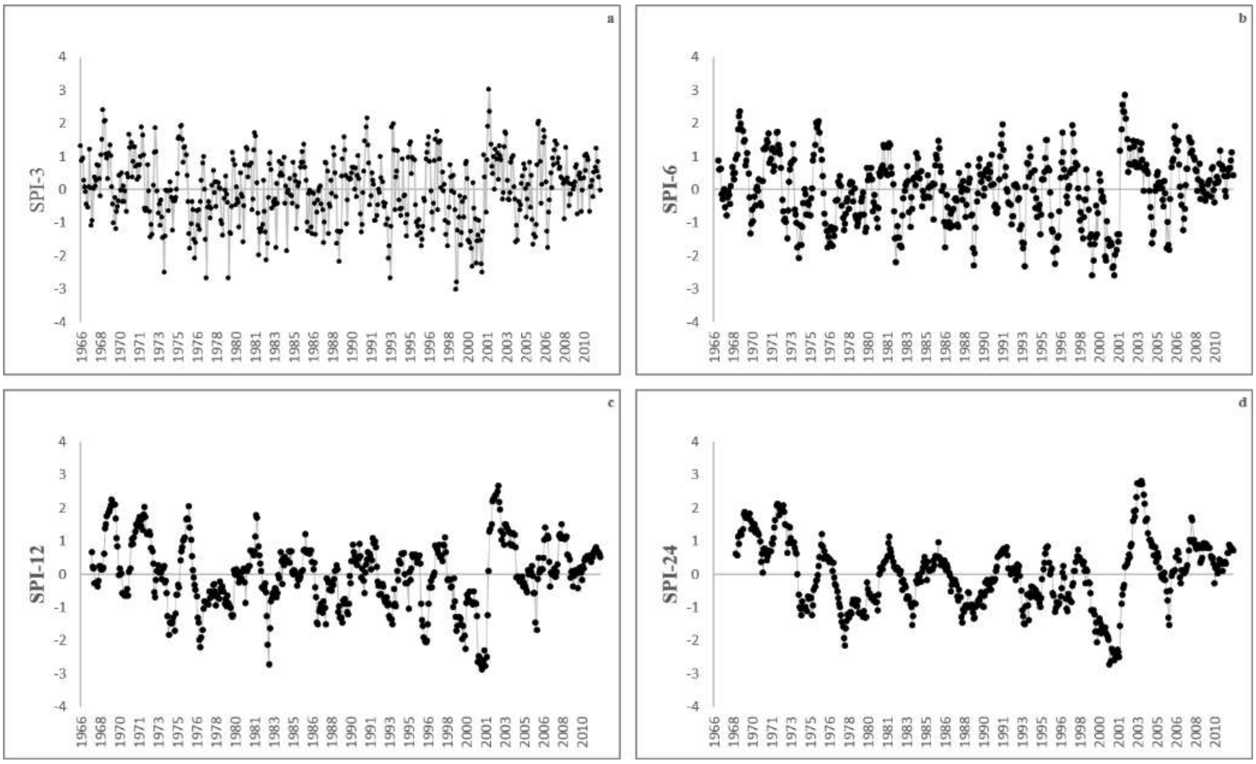

Figure 2. (a–d): Chronological changes in the SPI based on total monthly precipitation in the Soummam basin at scales 3, 6, 12 and 24 months (September 1966 to August 2011).

Fluctuations in the drought and wet conditions are similar in all time scales during the study period, but the frequency of the SPI series was larger in short time scales (3-, 6-months) than in long time scales (12-, 24-months). In general, the evolution of the SPI series showed alternating between dry and wet episodes indicate different categories of drought (wet). The SPI showed larger severity in drought episodes in all the period and for all time scales.

Identification of Drought and Wet Events in the Soummam Basin

Major drought and wet events were identified according to the magnitude reached for each event and the duration in month (Table 2) at the basin scale for the period 1967–2011 for the long-time scales.

At 24-month time scale, 9 drought episodes were recorded, the major drought occurred in Soummam basin between February 1999 and March 2002. This exceptional drought lasted for 38 consecutive months, reaching the maximum severity between September 1999 and November 2001, where extremely dry conditions dominated during 27 consecutive months. Moreover, the SPI identify two wettest events. The first, between August 1968 and November 1973, which lasted for 64 consecutive months reaching the extremely wet conditions during 13 consecutive months. The second event, between April 2002 and April 2005 lasted for 37 consecutive months and reaching the extremely wet conditions during 16 consecutive months December 2002 to March 2004. Other two drought events identified, from February 1977 to December 1980 for 47 consecutive months and reaching the severe drought conditions for 12 consecutive months; and the other event from February 1987 to January 1991 lasted for 48 consecutive months reaching the severe drought condition for 6 consecutive months.

Table 2. Drought and wet events identified in Soummam basin using the 24-month SPI.

	Episodes	Duration (months)	Magnitude
Drought events	Dec 1973/Sep 1975	22	−16.19
	Feb 1977/Dec 1980	47	−45.84
	Dec 1982/Aug 1984	21	−11.58
	Feb 1987/Jan 1991	48	−31.57
	Mar 1993/Feb 1995	24	−18.01
	Jan 1996/Oct 1996	10	−8.01
	Jan 1997/Oct 1997	10	−6.57
	Feb 1999/Mar 2002	38	−61.78
	Oct 2005/Apr 2006	7	−4.85
Wet events	Aug 1968/Nov 1973	64	78.86
	Oct 1975/Jan 1977	12	8.51
	Jan A981/Nov 1982	23	8.22
	Apr 2002/Apr 2005	37	49.13
	Mar 2007/Dec 2009	34	22.88

Drought Events versus Wet Events :The SPI index has been used to identify dry and wet periods. Its calculation at the basin scale and at different time scales showed the chronological distribution of dry, normal and wet months, which in fact determines the rainfall regime. As a function of duration, magnitude and intensity, the graphs obtained (Figure 3) display the distribution of droughts and humidity identified at the basin scale, show that the longest duration is not necessarily the most intense.

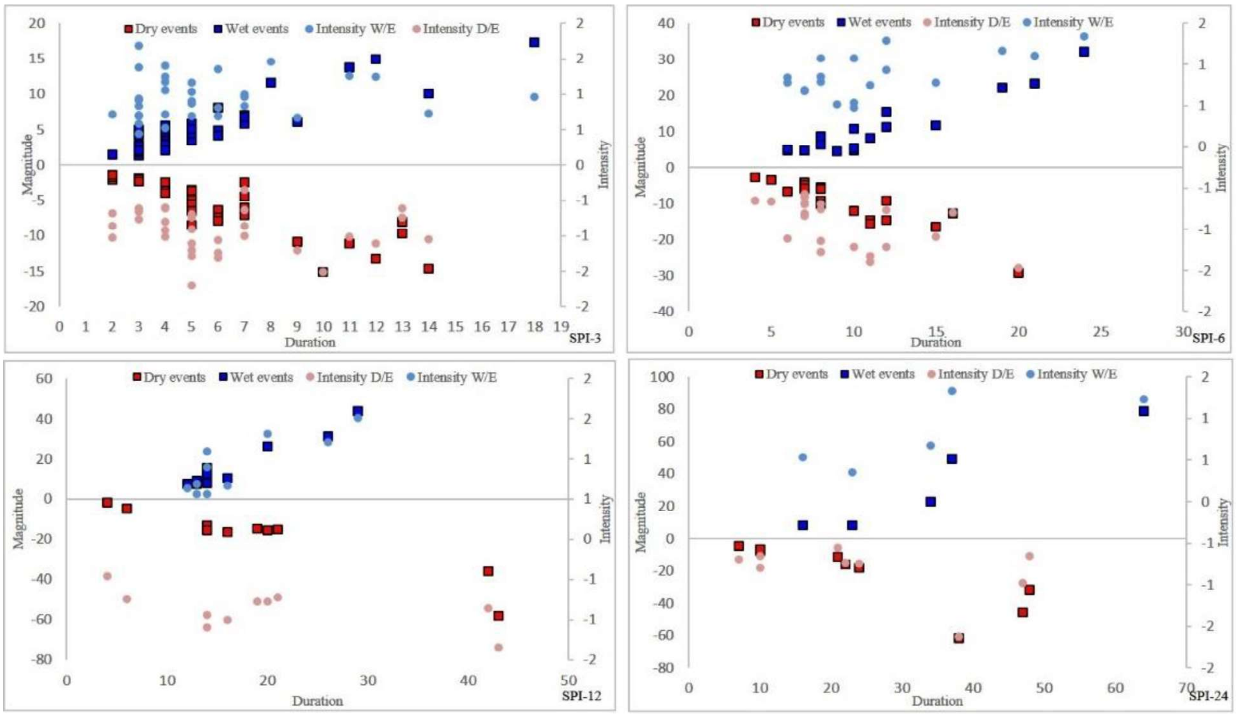

Figure 3. Identification of dry and wet events at the basin scale (1967–2011) according to the magnitude and intensity reached for each episode related to the duration in months for the different time scales (SPI-3, -6, -12 and -24 respectively).

Drought Events versus Wet Events: Drought and wet events were identified for each station taken in this study for the period 1967–2011 for 24-month time scale. It appears that several droughts were recorded. Exceptional drought lasted for 165 consecutive months, from December 1977 to August 1991 at the station S12 (Table 3). The drought of the late 1990s and early 2000s affected almost all stations. Some began in 1997, others in 1998 and 1999, and ended in 2002.

Table 3. Drought characteristics at the SPI-24 months' time scale of the considered stations (Mo: months; D: duration in months; M: magnitude; I: mean intensity).

	Maximum index during 1967/2011			Longest duration				Most intense duration				Number of episodes	Number of dry months	Relative frequency %
	SPI	Year	Mo	D	Years	M	I	D	Year	M	I			
S1	−2,08	1983	11	58	73–78	−39,89	−0,69	50	81–86	−47,34	−0,95	8	244	45,19
S2	−2,17	1978	1	60	86–91	−35,83	−0,60	40	99–02	−53,37	−1,33	7	193	35,74
S3	−2,48	2010	12	49	99–03	−39,98	−0,82	45	08–11	−83,04	−1,85	5	183	33,89
S4	−2,40	1995	10	134	91–02	−131,39	−0,98	35	73–75	−45,91	−1,31	2	169	31,30
S5	−2,17	1999	8	97	87–95	−65,29	−0,67	67	97–02	−64,8	−0,97	6	271	50,19
S6	−1,62	1991	4	35	89–92	−32,21	−0,92	35	89–92	−32,21	−0,92	1	35	6,48
S7	−1,86	1988	3	60	86–91	−63,9	−1,07	23	83–85	−25,49	−1,11	5	186	34,44
S8	−3,05	1997	4	92	94–02	−128,52	−1,40	92	94–02	−128,52	−1,40	2	127	23,52
S9	−1,72	1994	2	58	93–97	−48,84	−0,84	47	77–81	−78,61	−1,67	4	167	30,93
S10	−1,45	2010	1	77	05–11	−55,38	−0,72	46	99–02	−62,51	−1,36	4	193	35,74
S11	−1,95	1974	6	42	05–09	−33,84	−0,81	34	72–75	−38,94	−1,15	8	210	38,89
S12	−1,81	1975	3	165	77–91	−150,52	−0,91	27	73–75	−35,28	−1,31	2	192	35,56
S13	−1,86	2001	1	53	85–90	−56,43	−1,06	53	85–90	−56,43	−1,06	7	227	42,04
S14	−2,02	2001	6	132	95–06	−139,16	−1,05	132	95–06	−139,16	−1,05	2	204	37,78
S15	−2,34	1989	3	80	86–92	−76,28	−0,95	36	99–02	−40,84	−1,13	6	201	37,22
S16	−2,82	2001	12	39	99–02	−61,2	−1,57	39	99–02	−61,2	−1,57	7	165	30,56
S17	−2,38	1988	3	63	97–02	−68,68	−1,09	45	87–90	−58,72	−1,30	4	189	35,00
S18	−2,21	2011	6	50	98–02	−61,86	−1,24	50	98–02	−61,86	−1,24	8	218	40,37
S19	−2,28	2001	10	41	98–02	−56,2	−1,37	41	98–02	−56,2	−1,37	6	179	33,15
S20	−1,88	1973	11	20	73–75	−26,4	−1,32	20	73–75	−2,4	−1,32	26	222	41,1
S21	−1,67	1982	10	21	76–78	−19,0	−0,91	9	82–83	−10,0	−1,11	28	237	43,9
S22	−1,86	2004	8	31	75–78	−27,8	−0,90	8	04–05	−9,1	−1,14	29	248	45,9
S23	−1,77	1979	10	20	76–77	−18,1	−0,91	7	99–00	−9,1	−1,30	30	234	43,3

Table 4. Wet characteristics at the SPI−24 months' time scale of the considered stations (Mo: months; D: duration in months; M: magnitude; I: mean intensity).

	Maximum index during 1967/2011			The longest duration				The most intense duration				Number of episodes	Number of wet months	Relative frequency %
	SPI	Year	Mo	D	Years	M	I	D	Year	M	I			
S1	3,64	2003	6	66	06–11	91,61	1,39	66	06–11	91,61	1,39	3	126	23,33
S2	3,55	1972	2	35	71–73	67,76	1,94	35	71–74	67,76	1,94	5	134	24,81
S3	2,55	1972	2	62	72–75	84,32	1,36	62	68–73	84,32	1,36	5	181	33,52
S4	2,04	2003	10	69	77–83	64,14	0,93	26	69–72	38,3	1,47	5	198	36,67
S5	2,9	1969	10	65	06–11	42,37	0,65	61	68–72	92,86	1,52	3	159	29,44
S6	4,47	1972	12	235	68–88	374,12	1,59	118	01–11	200,25	1,70	4	414	76,67
S7	2,49	1995	6	52	93–98	61,04	1,17	52	93–98	61,04	1,17	6	189	35,00
S8	2,57	1969	5	65	68–73	97,09	1,49	65	68–73	97,07	1,49	5	165	30,56
S9	2,13	2003	6	66	06–11	47,74	0,72	44	01–05	37,84	0,86	8	265	49,07
S10	2,4	1992	2	117	84–93	133,03	1,14	117	84–93	133,03	1,14	5	215	39,81
S11	3,63	2003	10	41	01–05	68,38	1,67	41	01–05	68,38	1,67	5	149	27,59
S12	2,59	2003	6	66	06–11	49,13	0,74	60	68–73	81,81	1,36	5	221	40,93
S13	2,48	2009	8	54	07–11	88,34	1,64	54	06–11	88,34	1,64	6	162	30,00
S14	2,46	2008	8	50	89–93	50,68	1,01	30	07–11	50,16	1,67	5	166	30,74
S15	2,64	2008	2	58	69–74	74,39	1,28	58	69–74	74,39	1,28	3	133	24,63
S16	2,29	1976	1	55	82–87	52,06	0,95	27	74–77	36,33	1,35	8	211	39,07
S17	2,94	2003	9	66	06–11	51,15	0,78	45	01–06	67,33	1,50	5	188	34,81
S18	3,13	2003	10	33	08–11	31,62	0,96	30	01–05	49,15	1,64	7	178	32,96
S19	3,41	1973	4	43	01–05	32,48	0,76	39	71–75	68,81	1,76	6	164	30,37
S20	2,57	2003	10	63	68–73	83,87	1,33	63	68–73	83,87	1,33	4	165	30,56
S21	3,19	2003	7	53	68–72	52,5	0,99	38	01–05	71,09	1,87	5	205	37,96
S22	2,28	2008	2	45	06–10	43,64	0,97	28	71–73	47,4	1,69	6	158	29,26
S23	2,61	2003	7	42	06–10	38,82	0,92	36	71–73	43,66	1,21	7	198	36,67

As the SPI indicates degrees and types of droughts, it can also determine wet events (Table 01). Calculation of this index shows that all stations experienced extreme humidity in different time scale At SPI 24 months, the station S6 shows an exceptional case, with 235 consecutive wet months (August 1968 to February 1988) with a magnitude of 374.1. (Table 4). Another case is recorded in station S10, between 1983 and 1993, lasted for 117 consecutive wet months reaching the extremely wet condition during 20 consecutive months (Jan 1991-Aug 1992). It appears that the frequency of drought or wet events substantially varies from one station to another. Considering all stations, along with their magnitude, intensity and duration corresponding to four-time scales, at least 40 graphs can be developed. Figure 4 show the distribution of drought and wet events at stations S6 and S12 at 24- months' time scale.

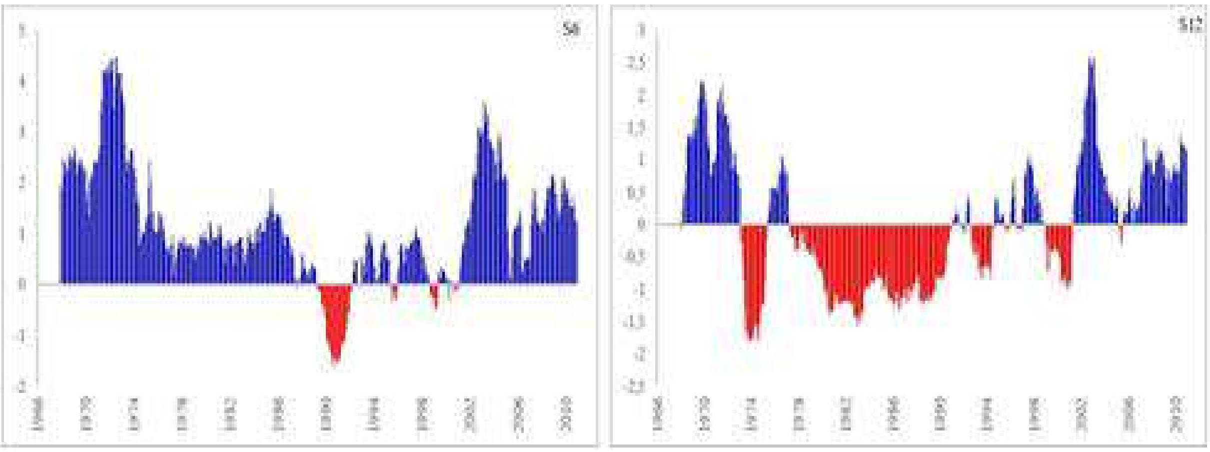

Figure 4. Time series of the SPI calculated for stations S6 and S12 for 24- months' time scale.

SPI values in all stations across the Soummam basin clearly showed the occurrence of severe drought in 2001. The 24-month SPI through the end of October 2001 indicate that most of the region marked by severe drought conditions. The basin influenced by each category (near normal 22%, moderate dryness 17%, severe dryness 35% and extreme dryness 26%). For the wet event, the 24-month SPI through the end of May 2002 show that the basin experienced wet conditions, influenced by 4% near normal, 8% moderate wet, 27% severely wet and 61% extremely wet (Table 5).

Table 5. The 24-month SPI through the end of October 2001 and May 2002.

Stations	SPI Values (Drought) through the End of October 2001	SPI Values (Wet) through the End of May 2002
S1	−1,30	3,63
S2	−1,73	2,27
S3	−1,66	0,81
S4	−0,50	1,74
S5	−1,49	2,61
S6	−0,10	3,09
S7	−2,03	2,26
S8	−0,97	1,71
S9	−1,85	2,08
S10	−2,33	1,03
S11	−1,75	3,15
S12	−0,98	2,47
S13	−1,48	1,83
S14	−2,04	1,02
S15	−1,74	2,43
S16	−2,45	1,98
S17	−1,63	2,73
S18	−2,21	2,68
S19	−2,28	1,98
S20	−1,71	2,28
S21	−0,34	3,07
S22	−1,44	1,89
S23	−1,55	2,53

Rupture Analysis

At the basin scale and at the annual time step, the results obtained by applying the Pettitt rupture test showed a rupture in 2001 in the direction of increased precipitation with a 17.1% increase rate at a significance level of 99%.

Figure 5 reveals that 52% of the stations taken in this study showed an increasing trend with a rate of increase ranging from +15.8% recorded at station S7 to 44.7% at station S1 and all these stations indicate this rupture in 2001 at a significance level of 99%. However, 9% of the stations experienced a rupture in 1995 in the direction of decreasing precipitation with a rate of decrease ranging from −10.3% for station S16 to −20.2% for station S10 and 39% of the stations show no rupture.

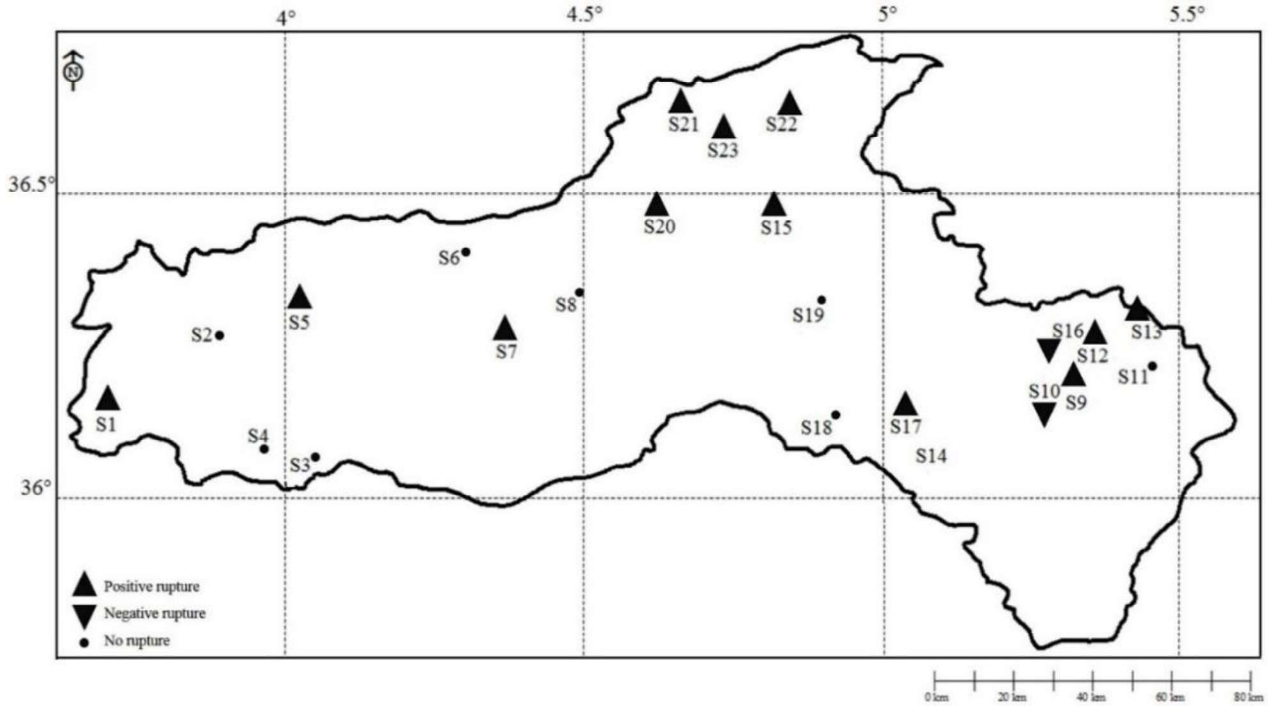

Figure 5. Results of the Pettitt test on an annual scale with stations recording positive and negative ruptures at the 99% significance level during the 1967–2011 period.

At the monthly time step, only 4 months show ruptures (October in 2006; November in 1996; February in 2008 and July in 2000) all in the direction of an increase in precipitation, with a rate that varies from 23.3% in November to 88.5% in February and all at the significance level of 99%.

The application of this test for all stations and at monthly time steps, has a total of 123 ruptures detected over the 1967–2011 period. These ruptures are unevenly distributed by month, ranging from 4 in September to 15 in August (Figure 6-a).

The histogram (6-b) clearly shows that these ruptures are organized around the years 2000, more precisely in 2001.

It can be seen that from the early 1990s onwards, there has been an increase in the number of ruptures. Some series experienced increases (66.7%) and others decreases (33.3%) at different levels of significance. The year 2001 is the most significant with 53.7% of ruptures, all in the direction of an increase in precipitation at the 99% significance level.

The graph (6-c) shows that out of 123 ruptures, 70.7% occurred at the 99% significance level (positive rupture 53.7% and negative rupture 17.1%). The month of March recorded 100% negative ruptures at different significance levels (35.7% at 90%; 42.9% at 95% and 21.4% at 99%). Figure 6-d shows the spatial distribution of these ruptures.

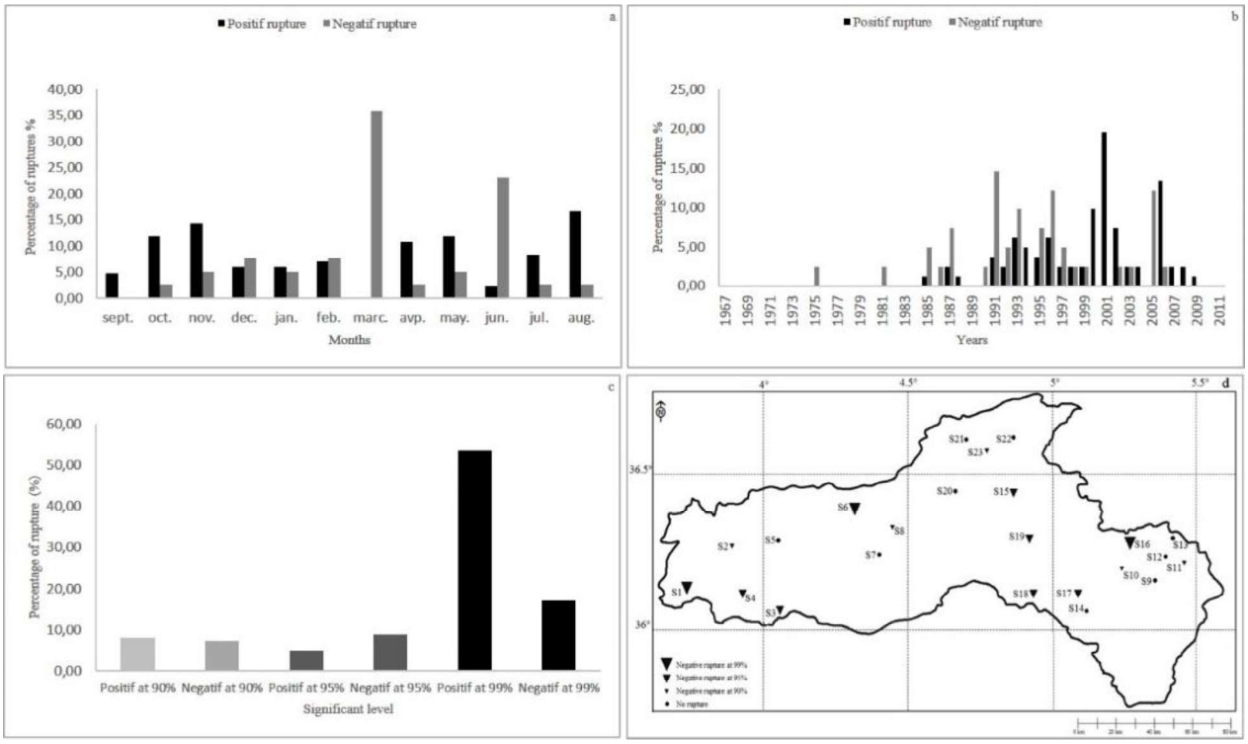

Figure 6. (**a**) Distribution of ruptures results by month (**b**) by year (**c**) Percentage of ruptures at different significant level (**d**) The spatial distribution of rupture results recorded in March, over the period 1967–2011.

Trend Analysis

On an annual scale and considering the whole basin, the first striking fact concerning the evolution of rainfall is the absence of significant trends. The Mann-Kendall test and the Sen Slope estimates show no trend during the 1967–2011 period (Figure 7a), although the Pettitt test shows a significant rupture (at significance level 99.99%) in 2001. The division of the series into sub-series shows a negative trend over the period 1967–2001 ($Z = -2.41$ and $Q = -0.0304$) at the 95% threshold and no trend is recorded over the period 2002–2011. On the other hand, the division of this period into four decades (1970–1979; 1980–1989; 1990–1999 and 2000–2009) shows significant trends (Figure 7b, 7c, 7d and 7e).

The analysis of the first three decades shows a downward trend ($Z = -5.19$ and $Q = -0.0998$; $Z = -3.70$ and $Q = -0.0547$; $Z = -3.22$ and $Q = -0.0562$) with a statistical significance of 99.9% (excellent) for the two first decades and 99% (very good) for the third decade, unlike the last decade (2000–2009) which shows a significant positive trend ($Z = 1.93$ and $Q = 0.0444$) with a significance level of 90%.

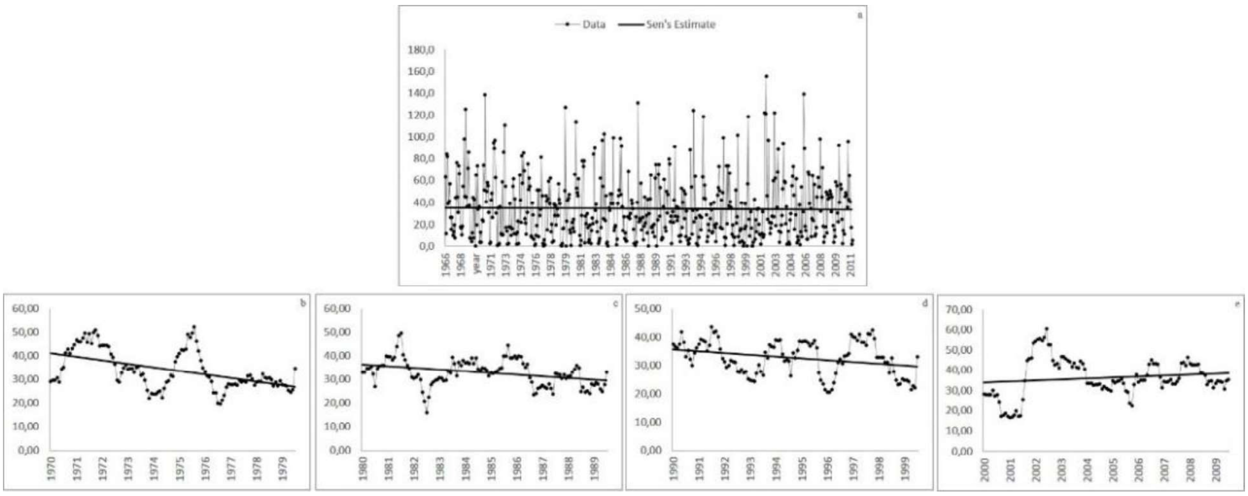

Figure 7. Evolution and trend of annual (a:1967–2011) and decadal (b:1970/1979- c:1980/1989- d:1990/1999- e:2000/2009) precipitation.

The same test applied to basin at the monthly time step indicates that all months show no significant trend except March (Z = −0.667, Q = −10.39, SL = 99.99%), April (Z = −0.389, Q = −3.515, SL = 90%) and August (Z = +0.333, Q = +1.93, SL = 90%), although the Pettitt test shows no ruptures in these months. Also, the results of the Pettitt test show ruptures in the months of October, November, February and July. The application of the trend test on the sub-series showed no trend.

On the other hand, the application of the Mann Kendall trend test and the Sen slope for individual stations at an annual resolution, shows significant trends at only four stations. Three stations show negative trends with a statistical significance of 95% and 90% (S3, Z = −0.250, Q = −4.892 and S14, Z = −0.204, Q = −3.003 at the 95% threshold and S4, Z = −0.202, Q = −2.465 at the 90% threshold) and one station shows a positive trend with a statistical significance of 95% (S1, Z = 0.216, Q = 3.337).

Applying the trend test for each station to the monthly time step revealed significant trends for some months. Positive significant trends appear in September with 53.9% stations and in August with 30.8% stations.

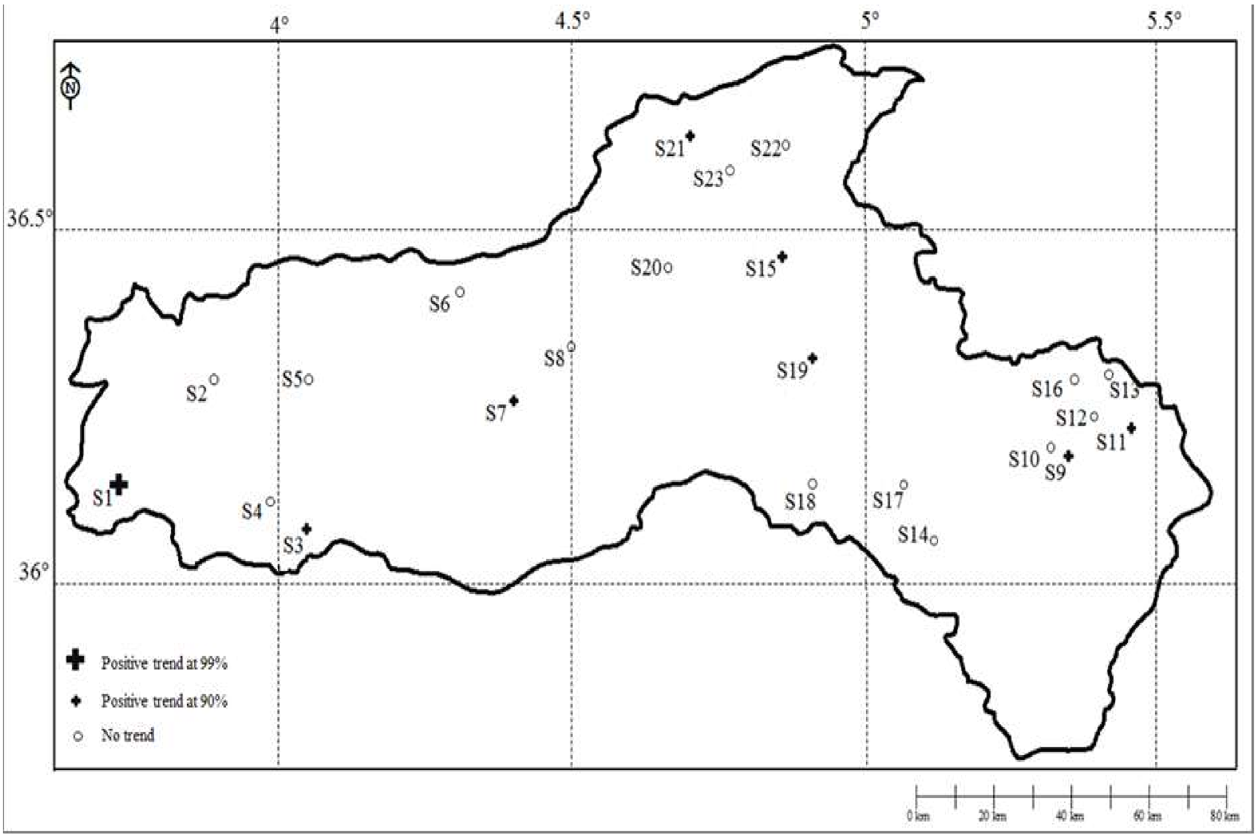

Figure 8. The spatial distribution of trends results recorded in September over the period 1967–2011.

The other months show significant negative trends, particularly in March when 50% of the stations (Figure 9) show a decrease in precipitation. Some months and stations show no significant trends (months: October, January, May and July/stations: S12, S16, S20 and S22).

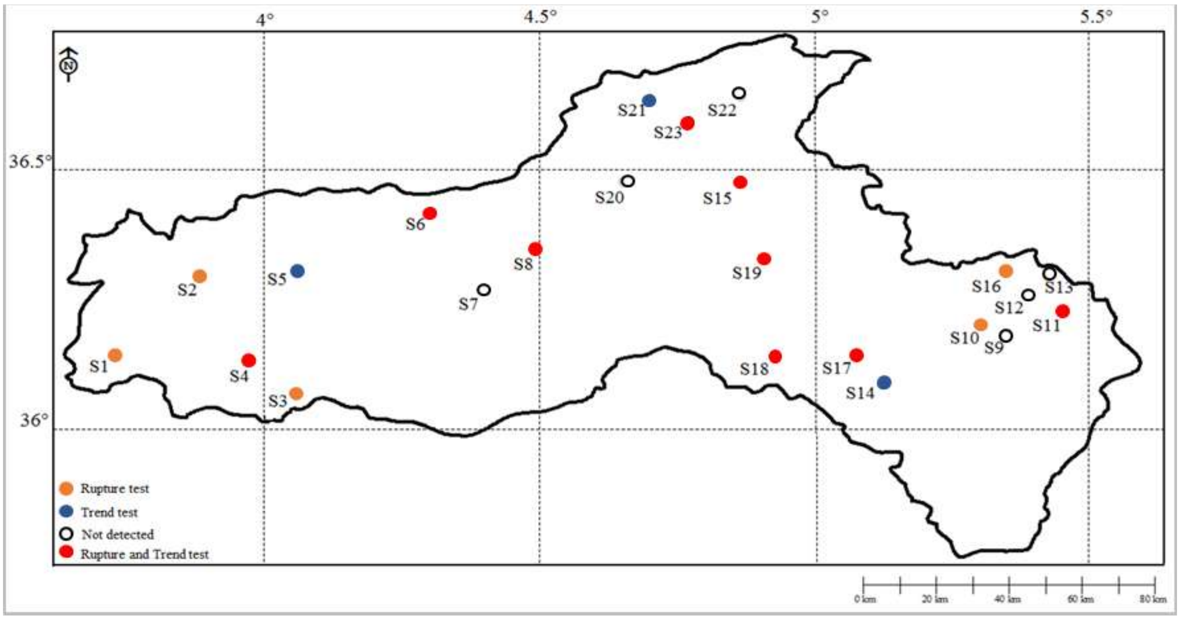

Figure 9. The spatial distribution of ruptures and trends results recorded in March at different significant level.

Correlation Analysis

Correlation analysis of annual rainfall and climate indices will help to explain the variability of the rainfall regime in the Soummam basin and mainly the drought that has affected the region since the 1970s and the return to a wet episode in the early 2000s. It should be recalled that not all stations have experienced a rupture in the rainfall regime. The correlation coefficients calculated between the annual rainfall at each station and the three climate indices show significant negative correlations with the MOi (Figure 10), however, the other indices NAOi and WeMOi show no significant correlation.

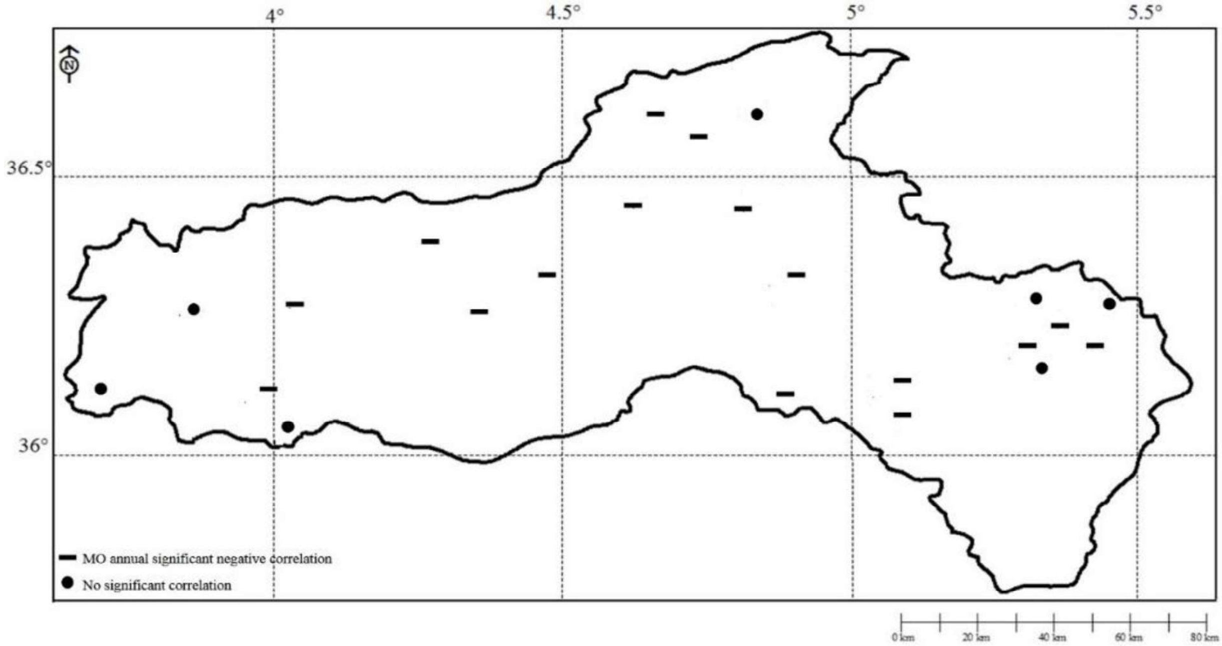

Figure 10. Correlations between annual precipitation and MOi.

The analysis of the relationships between climate indices and monthly precipitation shows significant correlations at the 5% significance level. Significant negative correlations are observed in the month of September (Figure 11), which is influenced by the NAO and MO mode (47.8% and 73.9% of stations respectively) showing an increase in precipitation. The month of December is influenced by the WeMO mode which shows significant positive correlations on 39.1% of the stations with a decrease in precipitation. November is influenced by the

MO mode which shows significant negative correlations on 34.8% of the stations with an increase in precipitation. Some stations and some months do not show significant correlations.

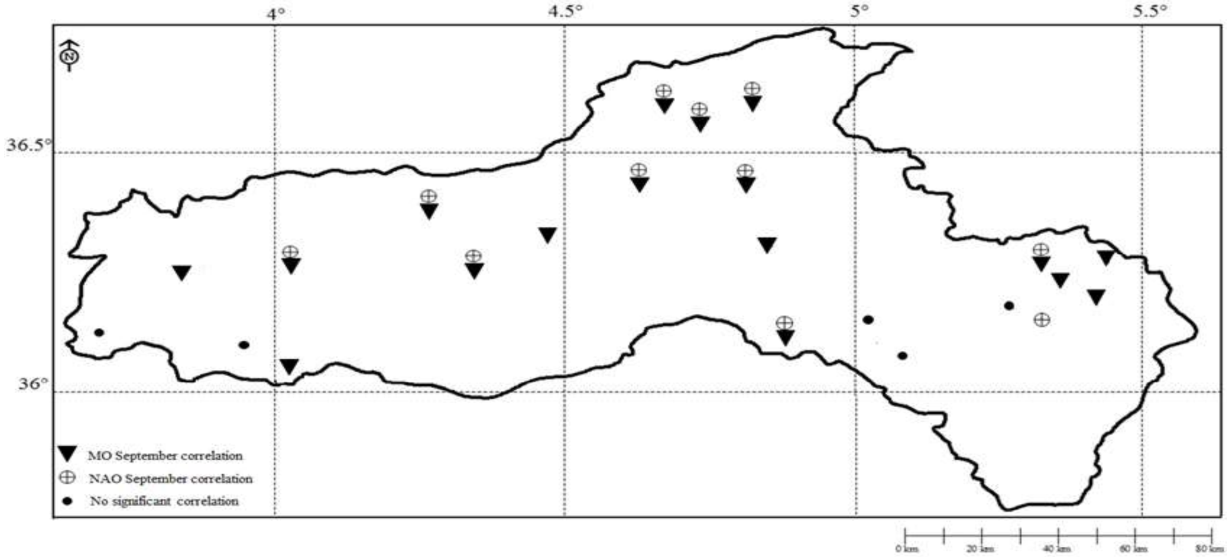

Figure 11. Correlation between September precipitation and MOi and NAOi.

The positive or negative phase triggered by the atmospheric circulation influences the variability of precipitation, as this influence may take time to appear and the consequences of this change may not be observed over the whole study period and may be seen in specific years. Therefore, it is proposed to analyze the correlations between decadal precipitation and climate indices at annual and monthly scales.

Analysis of the relationships between the NAO and MO climate indices with decadal annual precipitation shows significant negative correlations during the decade 1970–1979. The results show that 11 stations are influenced by the NAO mode, 17 stations by the MO mode and 8 stations show a simultaneous influence of the two modes NAO and MO, corresponding to the positive phase of both modes, thus leading to a decrease in precipitation during this decade. The WeMO mode shows no significant correlation. For the decades 1980–1989 and 1990–1999, the results show no significant correlation. On the other hand, for the decade 2000–2009, the results show significant negative correlations in all stations (100% of the stations) with the MO mode which corresponds to an increase in precipitation, and only 2 stations show significant positive correlations with the NAO mode and no significant correlation with the WeMO mode (Figure 12).

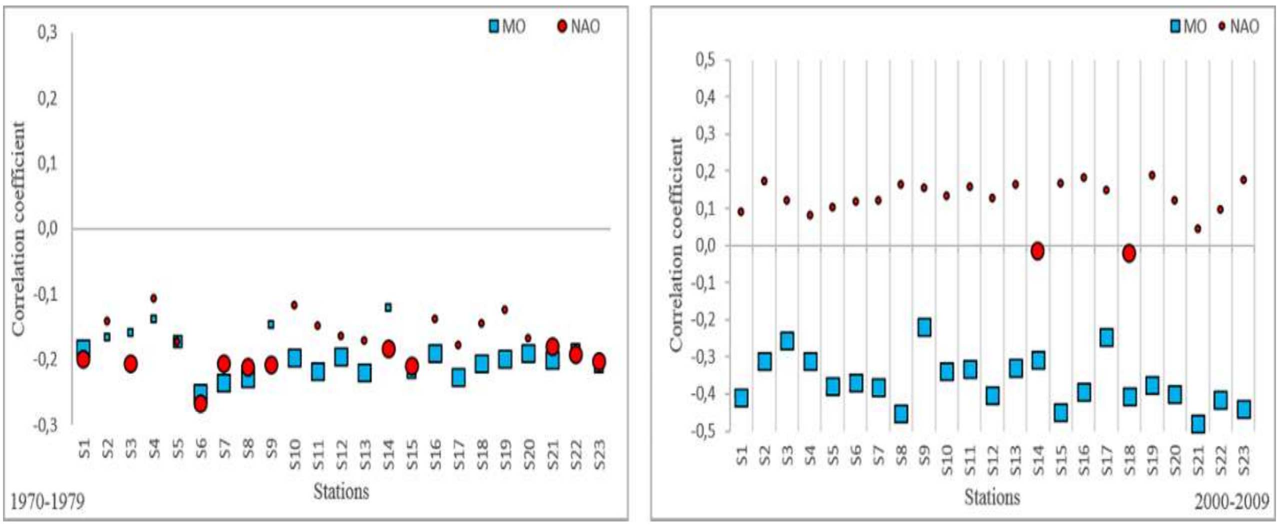

Figure 12. Correlation coefficients between annual decadal precipitation of the periods 1970–1979/2000–2009 with NAO and MO mode (significant correlation are in large characters).

Application of the same test for monthly precipitation shows several significant correlations. The results show significant correlation coefficients with the MO mode during the decade 1980–1989. Positive correlations in December with 16 stations and in January with 13 stations and coefficients ranging between 0.65 and 0.85, coinciding with positive phases of an increase in precipitation during these two months. Negative correlations were observed in March with 14 stations giving us a decrease in precipitation and in June with 9 stations with an increase in precipitation and coefficients ranging between −0.66 and −0.98 and between −0.65 and −0.79 respectively. Over the 1990–1999-decade, significant positive correlations appeared in April with a decrease in precipitation with 8 stations and coefficients ranging between 0.67 and −0.83. Over the decade 2000–2009, significant negative correlations appeared in October with 18 stations showing an increase in precipitation during that month and in June showing a decrease in precipitation at 8 stations with correlation coefficients varying between −0.68 and −0.83 and between −0.66 and −0.86 respectively. Significant positive correlations were observed in January with 16 stations coinciding with the positive phase of the mode showing an increase in precipitation with coefficients varying between 0.65 and 0.79.

The same is true for the NAO index, which shows its influence on monthly precipitation for the decade 1980–1989. Significant positive correlations are observed in December showing an increase in precipitation with 13 stations (between 0.66 and 0.84) and negative correlations in February with 13 stations (between −0.66 and −0.84) and in March with 8 stations (between −0.70and −0.81) showing a decrease in precipitation. Over the 2000–2009-decade, significant positive correlations appeared in January with 7 stations (between 0.66 and 0.83) showing an increase in rainfall and in May with 7 stations (between 0.66 and 0.79) showing a decrease in precipitation. On the other hand, the WeMO mode appears with significant positive correlation coefficients during the decade 1980–1989 in December with 9 stations (between 0.66 and 0.92) with an increase in precipitation.

Thus, the results show the impact of the NAO and MO mode on precipitation variability. However, it is mainly the MO mode that affects this variability with higher correlation coefficients than the other indices.

DISCUSSION AND CONCLUSION

The greatest advantage of the Standardized Precipitation Index (SPI), is that it is based exclusively on precipitation data, which makes it very easy to calculate and use. It is applicable to all weather patterns to either detect or monitor droughts at different time scales.

The analysis of rainfall using the SPI allowed the characterization of dry years, wet years and their degrees of severity, thus, it highlights the temporal and spatial distribution of these years. The values, either for the basin or individually for each station, clearly indicate that a drought has occurred in the basin and a humidity period too. The SPI values for the main station through the end of October 2001 clearly show that a significant drought occurred the basin. The area assigned to moderate, severe and extreme drought classes based on the 24-month SPI, highlight the fact that very little precipitation fell over the majority of the basin during 2000–2001 and showed a 29-year drought starting from 1973 until 2001. In 2001, the average rainfall over the basin was only 241mm, which is reduction of about 28% from the previous year's average and 40.5% from the average of the previous 34 years. The relative frequencies (Table 3), help to know how many droughts have occurred in the Soummam basin. The results show that the mean relative frequencies of 6.48% and 50.19% for drought occurring at the basin at 24-month time scale. A drought with the longest duration is not necessarily the most intense, so it may not result a huge impacts or damage. The longest 24-month SPI drought at station S21, which lasted for 165 months with a magnitude of −150.52 and mean intensity of −0.98, had less impact than the 27-month drought with a magnitude of −35.28 and mean intensity of −1.31. The same for the wet conditions. The SPI values through the end of May 2002, show that the basin experienced a wet condition based on the 24-month SPI from moderate, severe to extreme wet classes. In 2002, the average rainfall over the basin was 657 mm, which represents 63.3% increase compared to the previous year and 39.1% compared to the 35 previous years. The relative frequencies in Table 4, show that the mean relative frequencies of 23.33% and 76.67% for wet occurring at the basin at 24-month time scale. The test of Pettitt shows a break in the direction of an increase of the rains in 2002 what qualifies it as an excess over the whole period. The longest 24-month SPI wet at station S6, which lasted for 235 months with a magnitude of 374.12 and mean intensity of 1.59 had less impact than the 118 months drought with a magnitude of 200.25 and mean intensity of 1.70. Summing up there was an overall decreasing trend during the decades 70/79, 80/89 and 90/99. The recovery of rainfall from 2002, which represents a very wet year, agrees with the results obtained by other researchers on the increase in average rainfall in the Mediterranean basin during the last decade, as concluded Ramos and Martinez-casanovas 2006 [46], Nouacer et al.,2014 [47] and Khoualdia et al.,2014 [20]. This makes the decade 00/09 wetter than previous decades. The drought that has hit the region was dominated by mild droughts and not extreme droughts a result consistent with the work of Faye et al.,2015 [48]. Monthly, the evolution of the SPI index shows significant trends in the direction of a decrease in the month of March, result consistent with the works of Khoualdia et al., 2014 [20] for Algeria and Gonzales-Hidalgo et al.,2009 [49] for Spain. On the other hand, rainfall increasing trends appear in September and August, in contrast with in the declining rainfall in March. The large variation in precipitation patterns in the study area may be related to the influence of general atmospheric circulation. The correlation analysis between the teleconnection pattern indices and the average precipitation in the region showed that the MO and NAO modes are predominant. Nevertheless, the results obtained, show that the low frequency variability patterns explain only a part of the variability of precipitation in the Soummam basin. So the return to a wet phase since 2002 makes us wonder if this is the end of the drought. Would it be the beginning of a wet phase after a long period of drought from 1973 to 2001?

The climate has experienced remarkable variability in recent decades and the impacts of these changes have been observed in several regions of the world. In the future, the expected effects will be significant and the environmental and socio-economic impacts are likely to be very severe. However, the local effects remain poorly described in some regions of the Mediterranean basin. This work has shown that rainfall is remarkably variable in space and time in Soummam basin, with a long deficit period starting in the 1970s and a return to an upward trend from 2001 onwards. It appears that the NAO and MO partly influence this variability. All these results will be used in other future work. They can contribute to the evaluation of the performance or capacity of regional climate models (RCMs) to reproduce the variability of past precipitation and assess the impact of climate change at the local scale. Also, the development of a water resources planning and management tool to address the impact of future climate change and take adaptation measures to maintain the sustainability of water resources in the region. This model will allow to reproduce the evolution of precipitation in the past and the future to anticipate the impact of climate change on hydro-climatic variability at the local scale, particularly the prediction of extreme events. Finally, our results show that the frequency of drought and wetness episodes varies considerably in space and time despite the fact that we are talking about a single basin, the behavior of each sub-basin is different. A random phenomenon that must be taken seriously, especially drought, because future drought projections indicate drier conditions in the Mediterranean basin during the 21st century [50].

References

[1] G.d.e.i.s.l.é.d.c.W.G. I, R. Alley, Climate Change 2007: The physical science basis: Summary for policymakers, IPCC, 2007.

[2] M. Collins, R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, Long-term climate change: projections, commitments and irreversibility, in: Climate Change 2013-The Physical Science Basis: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, 2013, pp. 1029–1136.

[3] J. Bricquet, F. Bamba, G. Mahe, M. Toure, J. Olivry, Evolution récente des ressources en eau de l'Afrique atlantique, Publisher, City, 1997.

[4] P. Hubert, J.P. Carbonnel, A. Chaouche, Segmentation des séries hydrométéorologiques—application à des séries de précipitations et de débits de l'Afrique de l'ouest, Publisher, City, 1989.

[5] E. Servat, J. Paturel, H. Lubes-Niel, B. Kouamé, J. Masson, M. Travaglio, B. Marieu, De différents aspects de la variabilité de la pluviométrie en Afrique de l'Ouest et Centrale non sahélienne, Publisher, City, 1999.

[6] Bhaga, T. ; Shekede, M. ; Shoko, C. (2020) : Impacts of Climate Variability and Drought on Surface Water Resources in Sub-Saharan Africa Using Remote Sensing: A Review. Remote Sensing. 12. 4184. 10.3390/rs12244184.

[7] Verner, D. ; Treguer, D. ; Redwood, J.; Christensen, J. ; McDonnell, R. ; Elbert, C. ; Konishi, Y. ; Belghazi, S.(2018) : Climate Variability, Drought, and Drought Management in Morocco's Agricultural Sector. 10.1596/30603.

[8] S. Taibi, M. Meddi, G. Mahé, A. Assani, VariabiltyOf Annual And Extreme Rainfall Over Northern Algeria And RelashioshipWhithTeleconnections Patterns, Publisher, City, 2014.

[9] F. Giorgi, Climate change hot-spots, Publisher, City, 2006.

[10] M. New, M. Todd, M. Hulme, P. Jones, Precipitation measurements and trends in the twentieth century, Publisher, City, 2001.

[11] C. Goodess, J. Palutikof, M. Agnew, Climate change scenarios for the mediterranean: A basis for regional impact assessment, in, Nota di Lavoro, Fondazione Eni Enrico Mattei, 2000.

[12] H. Meddi, M. Meddi, Variabilité spatiale et temporelle des précipitations du Nord-Ouest de l'Algérie, Publisher, City, 2007.

[13] Achour, K., Meddi, M., Zeroual, A., Bouabdelli, S., Maccioni, P. and Moramarco, T. (2020) Spatio-temporal analysis and forecasting of drought in the plains of northwestern Algeria using the standardized precipitation index. Journal of Earth System Science 129(1), 1-22.

[14] Habib,B., Meddi, M., Toris, P.J., Remaoun, M. and Van Lanen, H.A. (2018) Characterisation and prediction of meteorogical drought using stochastic models in the semi-arid Cheliff-Zahrez basin (Algeria). Journal of Hydrology: Regional Studies 16, 15-31

[15] Y. Djellouli, P. Daget, Conséquences de la sécheresse des deux dernières décennies sur les écosystèmes naturels algériens, Publisher, City, 1993.
[16] A. Talia, M. Meddi, La pluvio-variabilité dans le Nord de l'Algérie, in: Actes du colloque" Terre et Eau, 2004, pp. 477-480.
[17] A. Medjerab, L. Henia, Régionalisation des pluies annuelles dans l'Algérie nord-occidentale, Publisher, City, 2005.
[18] A. Hirche, A. Boughani, M. Salamani, Annual rainfall evolution in some arid Algerian stations, Publisher, City, 2007.
[19] Z. Nouaceur, B. Laignel, I. Turki, Changements climatiques au Maghreb: vers des conditions plus humides et plus chaudes sur le littoral algérien?, Publisher, City, 2013.
[20] W. Khoualdia, Y. Djebbar, Y. Hammar, Caractérisation de la variabilité climatique: cas du bassin versant de La Medjerda (Nord-Est algérien), Publisher, City, 2014.
[21] S. Taibi, M. Meddi, D. Souag, G. Mahé, Évolution et régionalisation des précipitations au nord de l'Algérie (1936–2009), Publisher, City, 2013.
[22] R. Hadef, A. Hadef, Le déficit d'eau en Algérie: une situation alarmante, Publisher, City, 2001.
[23] M. Amyay, Z. Nouaceur, A. Tribak, T.A. Okba Kh, Caractérisation des évènements pluviométriques extrêmes dans le Moyen Atlas marocain et ses marges, in: Actes du XXV ème colloque international de climatologie, 2012, pp. 75-80.
[24] D.A. Wilhite, M.H. Glantz, Understanding: the drought phenomenon: the role of definitions, Publisher, City, 1985.
[25] Shelley D. Crausbay, S.D. ; Ramirez, A.R.; Carter, S.L.; Cross, M.S.; Hall, K.R.; Bathke, D.J.; Betancourt, J.L.; Colt, S.; Cravens, A.E.; Dalton, M.S.; Dunham, J.B.; Hay, L.E.; Hayes, M.J.; McEvoy, J.; McNutt, C.A.; Moritz, M.A.; Nislow, K.H.; Raheem, N.; Sanford, T. (2018) : Defining Ecological Drought for the Twenty-First Century. Bulletin of the American Meteorological Society, 98, 12,
[26] M.M. Saravi, A. Safdari, A. Malekian, Intensity-Duration-Frequency and spatial analysis of droughts using the Standardized Precipitation Index, Publisher, City, 2009.
[27] E. Xoplaki, J. González-Rouco, J.u. Luterbacher, H. Wanner, Wet season Mediterranean precipitation variability: influence of large-scale dynamics and trends, Publisher, City, 2004.
[28] M.M. Meddi, A.A. Assani, H. Meddi, Temporal variability of annual rainfall in the Macta and Tafna catchments, Northwestern Algeria, Publisher, City, 2010.
[29] J.-A. Lopez-Bustins, J. Martin-Vide, A. Sanchez-Lorenzo, Iberia winter rainfall trends based upon changes in teleconnection and circulation patterns, Publisher, City, 2008.
[30] J. Martin-Vide, J.A. Lopez-Bustins, The western Mediterranean oscillation and rainfall in the Iberian Peninsula, Publisher, City, 2006.
[31] Taibi, S., Meddi, M. and Mahé, G. (2015). Evolution des pluies extreme dans le bassin du Cheliff (Algerie) au cours des 40 dernières années 1971-2010. Proceeding of the International Association of Hydrological Sciences 369, 175-180.
[32] J. Honaker, G. King, M. Blackwell, Amelia II: A program for missing data, Publisher, City, 2011.
[33] G. Hiez, L'homogénéité des données pluviométriques, Publisher, City, 1977.
[34] P. Jones, T. Jonsson, D. Wheeler, Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and south-west Iceland, Publisher, City, 1997.
[35] M. Conte, A. Giuffrida, S. Tedesco, Mediterranean Oscillation: Impact on Precipitation and Hydrology in Italy, in: Conference on Climate and Water., 1989.
[36] T.B. McKee, N.J. Doesken, J. Kleist, The relationship of drought frequency and duration to time scales, in: Proceedings of the 8th Conference on Applied Climatology, American Meteorological Society Boston, MA, 1993, pp. 179-183.
[37] A.C. Steinemann, M.J. Hayes, L. Cavalcanti, Drought indicators and triggers, Publisher, City, 2005.
[38] M. Svoboda, M. Hayes, D. Wood, Standardized precipitation index user guide, Publisher, City, 2012.
[39] A. Pettitt, A non-parametric approach to the change-point problem, Publisher, City, 1979.
[40] H.B. Mann, Nonparametric tests against trend, Publisher, City, 1945.
[41] M. Kendall, Rank Correlation Methods, Charles Griffin, London (1975), Publisher, City, 1975.
[42] A. Benhamrouche, J. Martin-Vide, Évolutions de la concentration des précipitations journalières sur les littoraux du bassin méditerranéen occidental (1951-2010), Publisher, City, 2017.
[43] R.O. Gilbert, Statistical methods for environmental pollution monitoring, John Wiley & Sons, 1987.
[44] P.K. Sen, Estimates of the regression coefficient based on Kendall's tau, Publisher, City, 1968.
[45] C. Spearman, " General Intelligence," objectively determined and measured, Publisher, City, 1904.
[46] M. Ramos, J. Martinez-Casasnovas, Nutrient losses by runoff in vineyards of the Mediterranean Alt Penedès region (NE Spain), Publisher, City, 2006.
[47] Z. Nouaceur, vers un retour des pluies sur la rive sud du bassin mediterraneen occidental: analyse et evaluation de la tendance pluviometrique sur plus d'un demi–siecle en algerie, Publisher, City, 2011.
[48] C. Faye, A.A. Sow, J.B. Ndong, Étude des sècheresses pluviométriques et hydrologiques en Afrique tropicale: caractérisation et cartographie de la sècheresse par indices dans le haut bassin du fleuve Sénégal, Publisher, City, 2015.
[49] J.C. Gonzalez-Hidalgo, J.A. Lopez-Bustins, P. Štepánek, J. Martin-Vide, M. de Luis, Monthly precipitation trends on the Mediterranean fringe of the Iberian Peninsula during the second-half of the twentieth century (1951–2000), Publisher, City, 2009.
[50] Kirtman, B, Power, S.B., Adedoyin, J.A, Boer, G.J., Bojariu, R., Camilloni, I., Doblas-Reyes, F.J., Fiore, A.M., Kimoto, M.,Meehl, G.A., Prather, M., Sarr., A., Schar, C., Sutton, R., van Oldenborgh, G.J., Vecchi, G., Wang, H.J. 2013. Near term climate change: Projections and Predictability. In: T.F. Stocker, D.Qin. G.K. Plattner, M. Tignor, S.K. Allen, J.Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.), Climate Change 2013: The Physical Science Basis. Contribution of working group 1 to fifth Assessment Report of Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York