Acta Sci. Pol.
Formatio Circumiectus 20 (1) 2021, 19–31
ENVIRONMENTAL PROCESSES

www.acta.urk.edu.pl/pl ISSN 1644-0765 DOI: http://dx.doi.org/10.15576/ASP.FC/2021.20.1.19

ORIGINAL PAPER Accepted: 2.09.2020

SPATIAL-TEMPORAL CHARACTERIZATION OF METEOROLOGICAL DROUGHT USING THE STANDARDIZED PRECIPITATION INDEX. CASE STUDY IN ALGERIA

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ABSTRACT

Aim of the study

In this study, the spatial and temporal characteristics of drought in the upper and middle Cheliff, a semi-arid region of northwestern Algeria, was examined using the standardized precipitation index [SPI] at an annual time scale, as a tool for measuring the severity of meteorological drought.

Material and methods

To assess the SPI, annual precipitation totals from 11 precipitation stations covering the period 1970–2009 were studied. In order to identify the possible changes in the precipitation trend of the studied series, appropriate statistical tests were selected. The extent, severity and duration of the drought in the studied area were obtained.

Results and conclusions

Statistical tests revealed that the occurrence of ruptures in the rainfall regime was detected at the end of the 1970s and at the beginning of 1980s with a negative trend. The results of the SPI showed a strong prevalence of dry years after 1979 and 1980. The years 1993, 1999 and 2001 presented an extremely severe drought (SPI < –2). The evolution of SPI showed a dominance of the frequency of normal years (67%) and alternation of dry years (17%) and wet years (16%) over a period of 40 years. The total surface of the studied area had been affected by drought during severe years (1993, 1999). The study area exhibits irregularity and heterogeneity of drought due to the great variability of precipitation, which can vary from one sub-basin to another, and from one year to another.

Keywords: severity of drought, precipitation variability, standardized precipitation index, Algeria

INTRODUCTION

Drought is a recurring phenomenon and a complex natural hazard that affects every region of the world, every year. It is mainly related to rainfall deficit leading to a decrease in water supplies affecting the flora and fauna of a given region (Dracup et al., 1980; Wilhite and Glantz, 1985). The impact of drought on society, the environment, and the economy depends on its duration and spatial extent.

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In Africa, drought is the most frequent climate catastrophe. Several studies have shown that drought depends on a significant reduction in annual rainfall (Paturel et al., 1997; Servat et al., 199), which has led to major humanitarian and economic crises in some countries such as Ethiopia (Edossa et al., 2010) and Somalia (Beltrando and Cambrelin, 1995).

Drought in Algeria is one of the most worrying manifestations of climate variability. Numerous droughts had already been observed at the beginning of the twentieth century, during the 1940s and since the 1970s (Seltzer, 1946; Demmak, 1982; Farmer and Wigley, 1985; Kadi, 1995).

North-west Algeria has also experienced many droughts of varying magnitude. The droughts of the 1940s in western Algeria were due to a decrease in precipitation in the spring season, and in the 1980s, to a decrease in precipitation in the winter season (Matari and Douguedroit, 1995). The most recent droughts were even more remarkable for their spatial extent and intensity (Achite and Touaibia, 2007; Meddi and Hubert, 2003; Meddi and Meddi, 2009). They were typified by rainfall deficits (Hamlaoui-Moulai et al., 2013; Taibi et al., 2017; Zeroual et al., 2017) causing a notable decrease in monthly mean flows (Zeroual et al., 2013).

In order to characterize, evaluate and monitor drought, many indices have been proposed. Munger (1916), Blumenstock (1942) and McQuigg (1954) were among the first to suggest drought indices. Among the most widely used indexes are the Palmer Drought Severity Index (PDSI) (Palmer 1965), the Crop Moisture Index (CMI), the Surface Water Supply Index (SWSI), the Rainfall Anomaly Index (RAI), the standardized Precipitation Index (SPI), and the Standardized Precipitation – Evapotranspiration Index (SPEI). In order to characterize meteorological drought, it has been recommended to use the standardized precipitation index (SPI) developed by McKee et al. (1993) as a universal meteorological drought index because of its many advantages (WMO, 2006; WMO, 2012; Hayes et al., 2011). It is a simple and powerful index, only based on rainfall data; it enables the extraction of both the dry periods and wet periods. The SPI compares precipitation over different time scales from 1 to 24 months and across different regions (Guttman, 1994; Edwards and McKee, 1997).

Several drought studies used the SPI (eg. Wu et al., 2001; Keyantash and Dracup, 2002; Morid et al., 2006; Paulo and Pereira, 2006; Wu et al., 2007; Yildiz, 2009; Du et al., 2012; Jayanthi et al., 2013; Deo and Shahin, 2015; Ionita et al., 2016; Rimkus et al., 2017; Habibi et al., 2018).

Our objective in this study was to perform an assessment of the meteorological drought phenomenon, in the specified study area, over an annual time scale over 40 years, using the standardized precipitation index. This study is organized as follows:

I) Identification of ruptures (years of change) in the rainfall regime using statistical tests; II) Calculation of the annual SPI to determine the frequency and severity of the drought; III) Mapping the spatial evolution of drought on the basis of SPI classifications.

MATERIAL AND METHODS

Study area and data

The Upper and Middle Cheliff region is part of Cheliff, the largest basin in the north of Algeria. The study area is located at the longitude between 0°54' and 3°5' east, and the latitude between 35°35' and 36°26' north. It is subdivided into eleven sub-basins with a total area of 10930 km² (see: Fig. 1). The study area is characterized by a semi-arid climate with relatively cold, rainy winters and hot, dry summers.

In this study 11 rainfall stations were selected according to the length of available rainfall records and their geographical positions in order to cover the whole region more efficiently. Each station represents a sub-basin. The annual rainfall was chosen, covering a period of 40 years (1970–2009). The statistical characteristics of rainfall stations are given in Table 1.

Average annual precipitation varies between 524 and 339 mm/year. In the Derrag, Zoubiria and Arib Ebda stations, the average precipitation is greater than 500 mm. The coefficient of variation fluctuates between 24% (Derrag) and 33% (Souk El Had). Annual rainfall is low in the plains (e.g. El Ababsa, El Touaibia, El Abadia, Chlef DDA) compared to mountainous areas as well as areas south of the mountains (e.g. Derrag, Zoubiria, Fodda BGE).

The terrain and the distance to the sea are two important factors affecting the variability of precipitation.

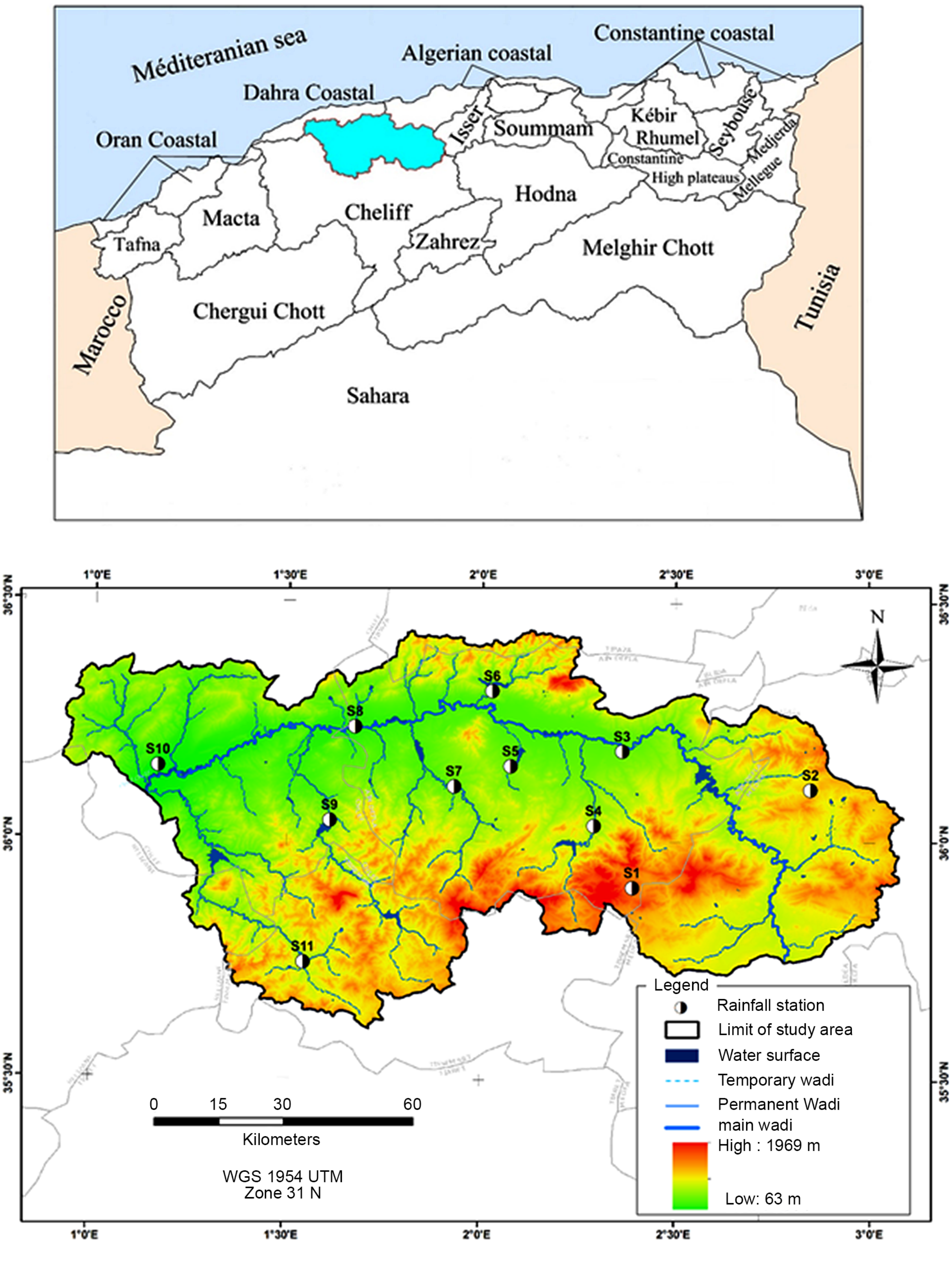

Fig. 1. Location of the study area and position of rainfall stations (Author: M. Achite)

Table 1. Descriptive statistics of rainfall stations in the study area

N° station	Name	X	Y	Elevations of station Z [m]	Average annual rainfall [mm]	Coefficient of variability CV [%]
S1	Derrag	02°23’23”	35°54’26”	1150	524	24
S2	Zoubiria	02°50’54”	36°06’45”	932	528	26
S3	Domaine ferroukhi	02°21’45”	36°11’34”	313	430	29
S4	Sidi Mokrefi	02°17’24”	36°02’12”	425	400	26
S5	El Ababsa	02°04’31”	36°09’37”	320	365	24
S6	AribEbda	02°01’34”	36°19’04”	280	501	25
S7	El Touaibia	01°55’48”	36°07’01”	350	306	30
S8	El Abadia	01°40’22”	36°14’27”	162	359	27
S9	Fodda BGE	01°36’37”	36°02’41”	432	416	30
S10	Chlef DDA	01°20’56”	36°10’35”	110	346	27
S11	Souk El Had	01°32’47”	35°44’50”	550	339	33

Statistical approaches for detecting discontinuities in precipitation series

In order to detect discontinuities in rainfall data during the period 1970–2009, four statistical tests were applied to identify the break point [year of change] in the rainfall regime. According to Lubès et al. (1994), a break can be defined by a change in the probability law of the random variables whose successive realizations define the time series studied; this change point modifies the rainfall and hydrological regimes.

The time series breaks were detected using the following tests: test of Buishand (Buishand, 1982; 1984), test of Pettitt (Pettitt, 1979), test of Lee and Heghinian (Lee and Heghinian, 1977), and Hubert Segmentation (Hubert et al., 1989). These tests are integrated in the Khronostat software set up by the Research Institute for Development (IRD) and the University of Montpellier (Boyer, 1998).

The standardized precipitation index SPI

As mentioned earlier, in this paper, the Standardized Precipitation Index (SPI) has been applied to assess drought, as it allows comparisons over time and space, and can detect drought at different time scales (Edwards and McKee, 1997; Lloyd-Hughes and Saunders, 2002; Bonaccorso et al., 2003; Sonmez et al., 2005, Vicente-Serrano, 2006; Wu et al, 2007).

The calculation of the SPI requires the adjustment of the collected rainfall series to a probability curve (McKee et al., 1993). Since the distribution of precipitation is generally positively asymmetric, a transformation is applied to the data in order to render their distribution normal or Gaussian (Sharma, 1997). Most often, the choice of the transformation concerns the Gamma’s law probability. Although adjustment to this law can be done by analytical methods, a statistical method based on shape and scale parameters according to Edwards and McKee (1997) is used. The gamma distribution is defined by its probability density represented by:

$$g(x) = \frac{1}{\beta^{\alpha}\,\Gamma(\alpha)} x^{\alpha-1}\, e^{\alpha/\beta} \quad \text{for } x > 0 \qquad (1)$$

Where α and β are the shape and scale parameters, respectively. Γ (α) represents the mathematical gamma function and x is the amount of precipitation.

Using the resulting parameters to find the accumulated probability of an observed precipitation episode, the cumulative probability (distribution function) becomes:

$$G(x)=\int_0^x g(x)\,dx=\frac{1}{\hat{\beta}\hat{\alpha}\Gamma(\hat{\alpha})}\int_0^x x^{\hat{\alpha}-1}\,e^{-x/\hat{\beta}}dx \quad (2)$$

Allowing that $t = x/\hat{\beta}$, this equation becomes the incomplete gamma function:

$$G(x)=\frac{1}{\Gamma(\hat{\alpha})}\int_0^x t^{\hat{\alpha}-1}\,e^{-1}\,dt \quad (3)$$

Since the gamma function is not defined for $x = 0$ and a precipitation distribution can contain zeros, the cumulative probability becomes:

$$H(x)=q+(1-q)\,G(x) \quad (4)$$

H [x] is the cumulative probability when $X = 0$ and q is the frequency of zero precipitation. In this last calculation, the cumulative probability is only the variable Z; a standard normal distribution characterized by a mean value of zero and a variance of one. After this transformation, the calculated values give the value of the SPI (Nuñez-Lopez, 2006). The wet and dry periods can be represented in the same way; thus, wet periods can also be displayed using the SPI.

The SPI in this study was calculated using annual precipitation data (hydrological year), which implies that we used a specific case of SPI-12. We have listed the SPI classes of the severity of drought in Table 2.

Table 2. Classification of drought on the basis of SPI values (McKee et al., 1993)

SPI Values	Drought Category
2.00 or more	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
–0.99 to 0.99	Near normal
–1.00 to –1.49	Moderately drought
–1.50 to –1.99	Severely drought
–2.0 or less	Extremely drought

RESULTS AND DISCUSSION

The chronological evolution of the rainfall regime and the trend observed between 1970 and 2009 are illustrated in Figure 2. The analysis of the annual precipitation trend was negative in all rainfall stations. The annual rainfall at Souk Elhad (S11) revealed a notable change in the year 1974. Precipitation decreased by more than 370 mm, down to 150 mm. El Touaibia (S7) had a deficit period from 1980 to 1993 (reaching 200 mm). A strong fluctuation of precipitation had been recorded in all stations, from one year to another. These conclusions were confirmed by the statistical tests of break in rainfall data.

The break years are identified by the four statistical tests, and the results are summarized in Table 3 showing that for almost all the stations, a rupture (changes in the annual rainfall) appeared between the end of the 1970s and the beginning of the 1980s, whereas the years 1979/80 and 1982 were the years of change and the beginning of a deficit of rainfall. Domaine Ferroukhi Station recorded a break outside these dates (1973).

Only Derrag station did not record any break. This absence of rupture does not mean the absence of a decrease in rainfall. There was a variation of the rainfall regime, but it remained insignificant (Lubès et al., 1994). The calculation of the reduction rate for the 11 time series shows that there is a downward trend in rainfall totals, and this reduction rate varies between 19.7% and 32.6% (negative values).

The SPI time series were calculated for all rainfall stations in the study area, at an annual time scale, for the period 1970–2009. Figure 3 shows that the 1970–1979 decade had no drought except in the two stations Arib Ebda (S6) in 1970 and the station Souk el Had (S11) in 1974. This wet decade (1970–79) was followed by alternating dry and wet years.

Drought is often repeated, and this is due to the deficiency of rainfall. In terms of frequency, the evolution of SPI revealed a dominance of normal years (67%) compared to dry years (17%) and wet years (16%). These two classes show a certain alternation in the studied area.

The drought persisted during the years 1992–1993, 1999, 2001 and 2004. These years marked critical drought with values lower than –2. There was also an

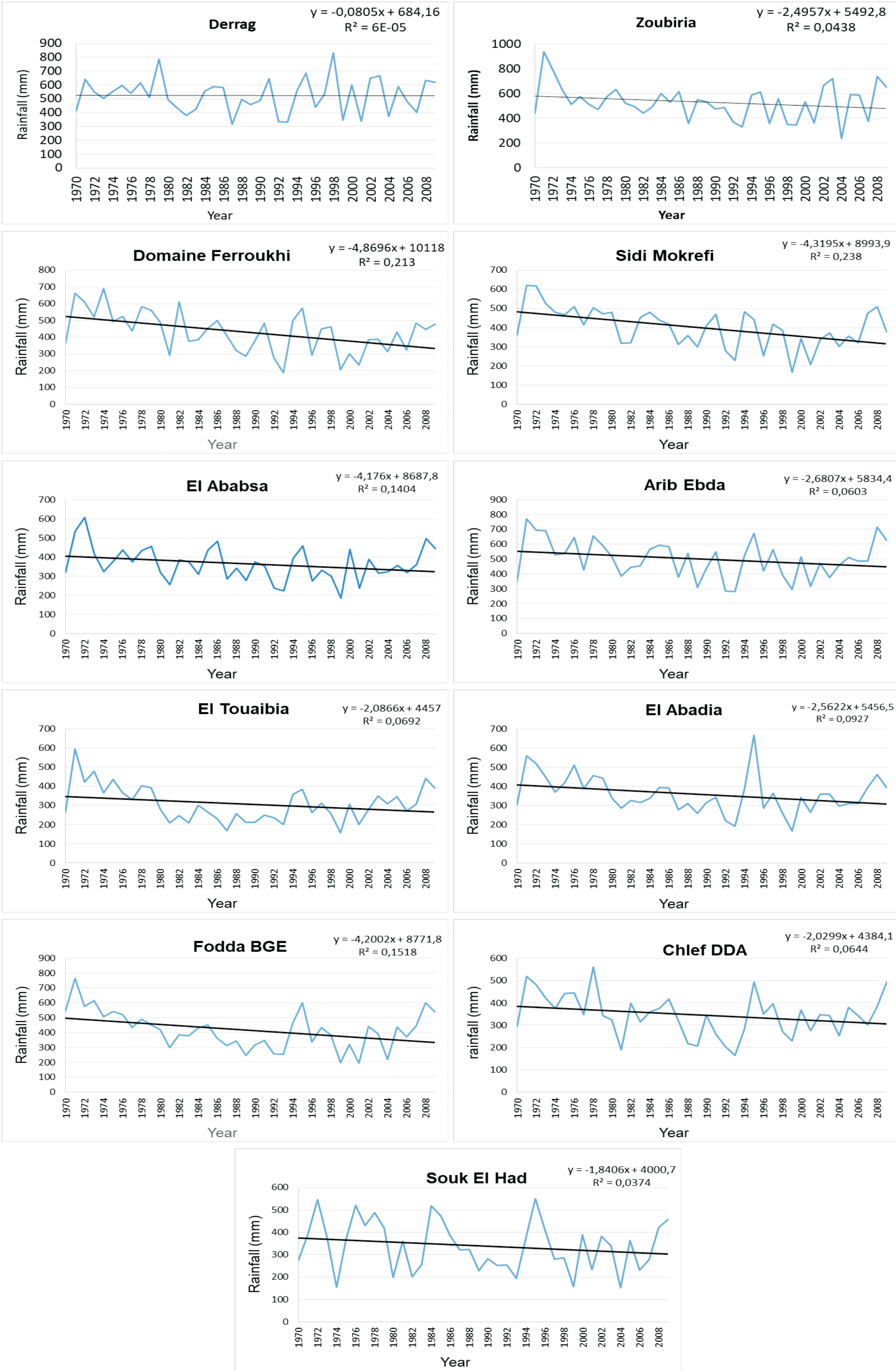

Fig. 2. Time series of annual rainfall and trend for studied stations

Table 3. Years of rainfall ruptures over the period 1970–2009

Station	Buishand test	Pettitt test	Lee and Heghinian test	Hubert segmentation	Average before break	Average after break	Rate reduction [%]
S1	–	–	–	–			
S2	–	–	1973	1973	699,3	508,6	–27,3
S3	+	1982	1980	1980	540,7	387,9	–28,3
S4	+	1980	1980	1980	496,4	363,8	–26,7
S5	+	–	1979	1979	429,13	343,4	–20,0
S6	–	–	1979	1979	589,4	471,8	–20,0
S7	+	1979	1979	1979	404,7	272,7	–32,6
S8	+	1979	1979	1979	441,9	331,3	–25,0
S9	+	1979	1979	1979	544,3	372,7	–31,5
S10	+	1979	1979	1979	431,3	320,7	–25,6
S11	–	–	1979	1979	397,5	319,2	–19,7

absence of drought recorded between 2005 and 2009. In order to better visualize the results obtained by the standardized precipitation index (SPI) and to compare the sub-basins with each other, a mapping has been established. In Figure 4, we distinguished the succession of the particular dry and wet episodes, and areas affected by drought. The years 1989, 1992, 1993, 1999, 2001 and 2004 were marked by a severe drought. The wet years are also listed (1971, 1972, 1995, and 2009). During the years 1993 and 1999, the whole area was severely affected by drought.

Rainfall analysis during the studied period (1970–2009) showed decreasing trends in rainfall data over the study area. The temporal evolution of the standardized precipitation index (SPI) has revealed the existence of dry episodes followed by wet intervals. Extreme values of the Standardized Precipitation Index have been recorded in the studied stations, which are characterized by extremely severe droughts (see: Fig. 4). These results are consistent with several studies on rainfall and drought in northern Algeria (Demmak, 1982; Khaldi, 2005; Meddi and Meddi, 2009; Meddi and Toumi, 2013; Khoualdia, 2015).

Statistical methods have confirmed the transition of the rainfall regime between the 1970s and the 1980s, indicating that drought had appeared in the majority of Mediterranean countries since the early 1980s (IPCC, 2007, IPCC 2008, Kadi 1995, Blöchliger and Neidhöfer 1998) and in Algeria (Djellouli and Daget, 1993; Talia and Meddi, 2004; Hirche et al., 2007; Zeineddine, 2011; Zeineddine et al., 2013).

The rainfall deficit during the 1980s and 1990s was estimated at 30% in eastern Algeria, and also 30% for the central and western regions (Kettab, 2002). Severe meteorological drought, recorded over several years, can implicate important problems with water quantity also in the context of climate change projections. As demonstrated by Hadour et al. (2020) in the case of the Haciabia, Sidi Djillali, Ammi Moussa, Ouled Ben AEK and Chouly basins in Algieria, decrease of rainfall and increase of ETP can influence downward trend of flow for the two scenarios RCPs8.5 and 4.5. Therefore it is very important to prevent drought and water scarcity with a rational use of water resources.

According to the estimates by the Intergovernmental Panel on Climate Change (IPCC) for the period 1990–2020, we should expect an increase in the average temperature by 0.8 to 1.1°C, and a reduction of rainfall by 10%. Decreased precipitation and increased evaporation will affect dams and groundwater (Sahnoune et al., 2013).

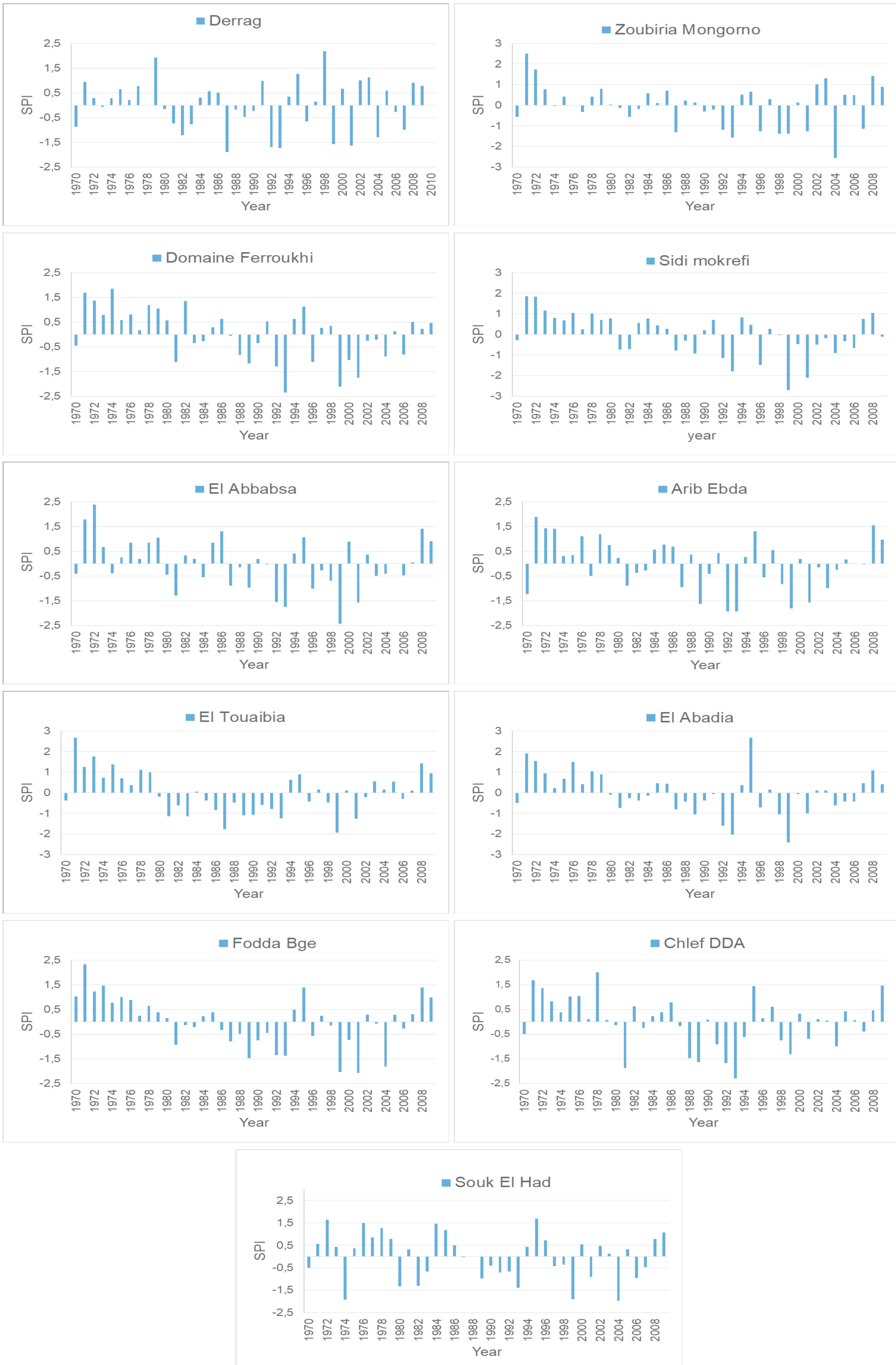

Fig. 3. 1-year SPI for the rain stations in study area

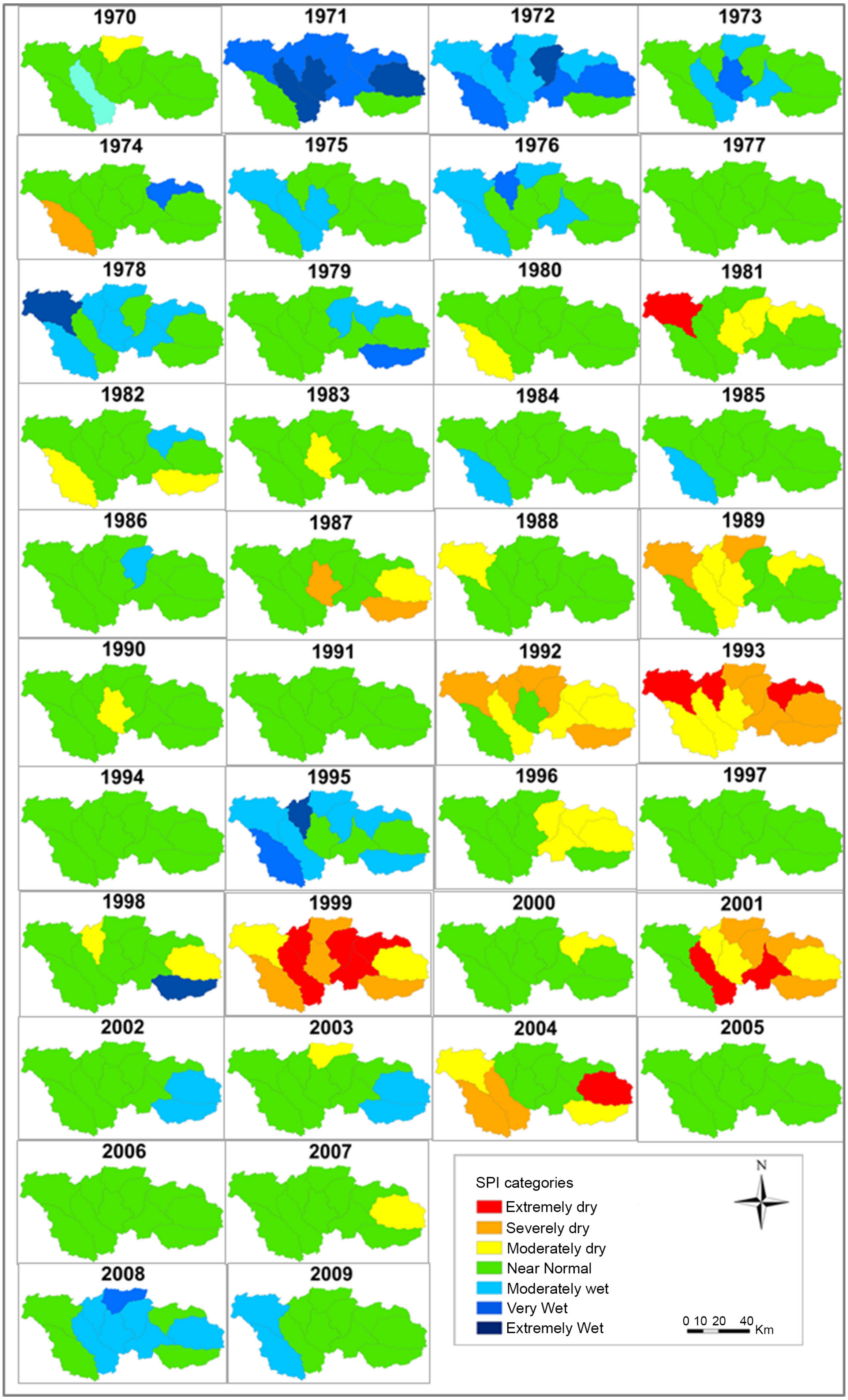

Fig. 4. Spatial variability of drought based on SPI value (Author: M. Achite)

CONCLUSION

In order to characterize the spatial and temporal variability of meteorological drought in the Upper and Middle Cheliff region at an annual time scale, the severity of drought has been calculated using the standardized precipitation index based on precipitation data (1970 to 2009). Rainfall variability analysis showed that precipitation tends to decrease from year to year, and that the rupture of the precipitation series appeared between the late 1970s and the early 1980s.

The study revealed that the onset of drought was detected in 1979/80, and that the drought peaked in 1989, 1992, 1993, 1999, 2001 and 2004. The spatial distribution of drought indicated that during 1993 and 1999; the entire surface of the studied area was affected by drought. Drought is a frequent phenomenon that has always affected humans and their environment. The application of SPI is useful for developing an appropriate water management strategy and can help decision-makers around the world to take drought risks into account.

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CZASOPRZESTRZENNA CHARAKTERYSTYKA SUSZY METEOROLOGICZNEJ PRZY WYKORZYSTANIU STANDARYZOWANEGO WSKAŹNIKA OPADU (SPI). PRZYKŁAD BADAŃ W ALGIERII

ABSTRAKT

Cel pracy

Celem pracy była czasoprzestrzenna analiza występowania suszy meteorologicznej w górnym i środkowym Cheliff; półsuchym regionie północno-zachodniej Algierii. Suszę meteorologiczną analizowano w oparciu o standardowy wskaźnik opadów (SPI).

Metody badań

Do określenia wskaźnika SPI wykorzystano roczne sumy opadów z 11 stacji opadowych z lat 1970–2009. W celu zidentyfikowania możliwych zmian trendu opadów badanych szeregów wykorzystano testy statystyczne. Określono dotkliwość i czas trwania suszy na badanym obszarze.

Najważniejsze wyniki i wnioski

Analizy wykazały, że na przełomie lat 70. i 80. XX wieku stwierdzono występowanie zmian w reżimie opadów z na tendencję malejącą. Wskaźnik SPI wykazał występowanie lat suchych po 1979 i 1980 roku. Lata 1993, 1999 i 2001 charakteryzowały się wyjątkowo dotkliwą suszą (SPI < –2). Ponadto wykazano dominację lat normalnych (67%), suchych (17%) i mokrych (16%) w okresie 40 lat. Susza występowała na całym obszarze w latach 1993 i 1999). Badany obszar charakteryzuje się nieregularnością i niejednorodnością suszy, ze względu na dużą zmienność opadów atmosferycznych.

Słowa kluczowe: dotkliwość suszy, zmienność opadów, wskaźnik standaryzowanego opadu, Algeria