



Drought investigation and trend assessment in Macta watershed (Algeria) by SPI and ITA methodology

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Abstract

In this study, severe and extreme episode (dry and wet) periods were analyzed by the Standardized Precipitation Index (SPI), using 42 weather stations in the Macta watershed (Northwest Algeria) over a period of 42 years (1970–2011). First, short- and medium-term (1, 3, 6, and 9 months) and long-term (12 months) SPIs were calculated, and then their trends were detected using the innovative trend analysis (ITA) method, which identifies trends in low, medium, and high values within series. Results show that in the short and medium term, the 42 studied stations, in the Macta watershed, are gradually subject to meteorological and then agricultural drought, marking a water deficit since 1970, affecting vegetation. On the other hand, and in the long term, this deficit is compensated by severe and extreme wet conditions (a water balance will be established between dry and wet episodes). In anticipation, the ITA shows that, on average, 82% of stations, with severe and extreme dry conditions, underwent a gradual reduction, accompanied by 59% of stations showing a reduction in severe and extreme wet conditions. In the long term, convergence between severe and extreme dry conditions and wet ones has been detected, making the situation towards normal conditions. In addition, the majority of the stations suffer from a severe meteorological drought in the center-East of the basin (drought frequency above 100), whereas on the hydrological scale (SPI-12), the situation is balanced (drought frequency below 50).

Keywords Algeria · Drought · ITA · Macta · SPI · Trend

Introduction

Today, the impacts of climate change have become the object of attention of scientists, because of the increase in the intensity and frequency of extreme phenomena such as droughts, heat waves and sand storms, forest fires, and floods (Alashan 2020; Benzater et al. 2019; Abbes et al. 2018; Kreibich et al.

2017; Labban 2016; Subyani 2012; Estrela and Vargas 2012). Among these extreme climatic hazards, the minimum extremity, represented by drought, is an insidious disaster affecting society, economy, social and health life, and agriculture (Alemu and Dioha 2020; Dabanli et al. 2017; Mishra and Singh 2010; Wilhite et al. 2000; Şen 1998). Especially in agriculture, drought is accepted as one of the main climatic constraints to crop yields (Matiu et al. 2017; Lesk et al. 2016).

Drought is defined as a deficit of precipitation over an extended period, usually a season or more, which causes water scarcity affecting an agricultural activity or an environmental sector (Mehdaoui et al. 2018). Drought is a progressive phenomenon that begins with a rainfall deficit in the form of meteorological drought. In general, four types of drought are distinguished, notably meteorological, agricultural, hydrological, and socio-economic (Nabipour et al. 2019; Heim 2002; Wilhite and Glantz 1985). By extending, it leads to a reduction in the volume of water storage system, the flow of surface water and groundwater, and then becomes hydrological, even socio-economic drought, including agricultural drought

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(Nabipour et al. 2019; Mishra and Singh 2010; Wilhite and Glantz 1985).

Subsequent droughts and increasing demand for water make forecasting and using precipitation essential for decision-makers (Ehteram et al. 2019a, 2019b). Previous studies have concluded that climate change is reducing water availability in areas where future annual precipitation is expected to decrease in arid regions, as evidenced by increased drought indices (Alifujiang et al. 2020; Eekhout et al. 2018; Forzieri et al. 2014).

Understanding the evolution of this extreme event and its crucial impacts is a decisive tool for planning, adapting, and mitigating drought impacts (Yevjevich et al. 1984). Several drought events were detected in recent decades (Mallenahalli 2020; Danandeh Mehr and Vaheddoost 2020; Adib and Marashi 2019; Marini et al. 2019; Bazrafshan 2017; Wang et al. 2019; Coll et al. 2017; Golian et al. 2015; Zaidman et al. 2012; Fink et al. 2004) which are expected to become more frequent in the twenty-first century in certain seasons and areas (Hannaford et al. 2011) depending on the variability of precipitation and/or evapotranspiration (Dabanli et al. 2017; IPCC 2013).

The North Africa regions are vulnerable to the devastating impacts of climate change (Hamed et al. 2018). In Algeria over the past three decades, the climate has negatively impacted water resources. Its impact was felt on the rivers of the Macta watershed (northwest of Algeria). Studies of annual precipitation during the period 1930–2002 show a clear decrease. Meddi et al. (2009) have shown that the runoff reduction is between 28 and 36% compared to the two periods (1949–1976 and 1976–2002) in several areas. Laborde (1995), by analyzing data from 120 rainfall stations in northern Algeria, showed that since the end of 1973, a long dry phase began and persisted. Elouissi et al. (2016) showed a downward trend in rainfall in the Macta watershed during the period (1970–2011). In addition, climate model projections suggest that during the summer season, precipitation should decrease (50%) and the temperature will increase steadily in the Mediterranean regions (Gampe et al. 2016; Dai 2011).

Among all the standardized drought indices, the Standardized Precipitation Index (SPI) proposed by McKee et al. (1993) (Dehghani et al. 2014) has been widely used to identify drought across different countries of the world (Achour et al. 2020; Zhao et al. 2019; Caloiero 2018; Pineda and Willems 2018; Mehdaoui et al. 2018; Dabanli et al. 2017; Svensson et al. 2017; Spinoni et al. 2015). Several authors have applied this SPI to characterize drought. These studies are mainly based on non-parametric tests, better adapted to deal with hydrometeorology not normally distributed than parametric methods (Golian et al. 2015; Zhai et al. 2010). Recently, Şen (2012) proposed the analysis of trends in innovative techniques (ITA), which allows a graphical evaluation of trends (Güçlü 2020).

In this article, the drought episodes, in the Macta watershed (northwest of Algeria), were analyzed by applying the Standardized Precipitation Index (SPI) at different time scales (1, 3, 6, 9, and 12 months) from a database of 42 rainfall stations

over a 42-year period (1970–2011), thus constituting series of 504 monthly precipitation. This work aims to identify dry and wet episodes in the Macta basin using the SPI and then determine their trends, at different time scales, by applying innovative trend analysis (ITA). In other words, this study utilizes precipitation data to investigate meteorological, agricultural, and hydrological drought conditions. For this purpose, the frequencies and trends (using the ITA method) of SPI values are used as the primary indicators of droughts. This study also discusses the spatial behavior of drought frequencies in the Macta watershed. The novelty of this work is to use the ITA method to detect SPI value trends in the Macta watershed which has not been the object of any research before in the region.

The objective of this study is to investigate the characteristics of meteorological, agricultural, and hydrological drought and their trends in Macta watershed (Northwest Algeria). Moreover, the study investigates climatic conditions that led to a record drought since 1970 affecting almost the entire country.

Study area and data

The Macta watershed is located in the northwest of Algeria (Fig. 1). Its geographical position is between -1.25° West and 0.6° East in longitude and between 34° and 36° North in latitude. It is a basin that covers an area of $14,410 \text{ km}^2$, limited to the northwest by the mountain ranges of Tessala, to the south by the high plateaus of Maalif, to the west by the plateaus of Telagh, and to the east by the mountains of Saida (Elouissi et al. 2017).

The climate of the study area is semi-arid. It is a region of transition between the Mediterranean climate system in the north and the Saharan in the south, and therefore the rainfall does not exceed 400 mm/year . The highest humidity values are recorded during the winter season and the lowest values during summer time. Average monthly relative humidity (1970–2004) varies between 46% for the month of July and 80% for the 2 months of January and December (Sabri and Medjerab 2012).

Annual rainfall is light. It varies from 206 mm on the southern part of the Beni Chougranne mountains (Bouhnifia and Sfisef) to 380 mm on Saïda mountains and the north-western part of Sidi Bel and Tessala mountains. The spatial variation is moderate (25%).

The Macta basin includes four major agricultural potentials, the Ghriss and Sidi Bel Abbes plains, located in the center of the basin and two irrigated areas (Habra and Sig), located in the North of the basin, including several industries.

Monthly rainfall data (in mm) were collected from the National Agency of Water Resources (ANRH). Initially, 123 stations are collected. Stations with more than 10% gaps are removed. Forty-seven stations are remained. After that the Shapiro-Wilk test is applied using the `shapiro.test` function (R Core Team 2020) to check the normality of SPI series. Normality was not satisfied in 5 stations (especially in short

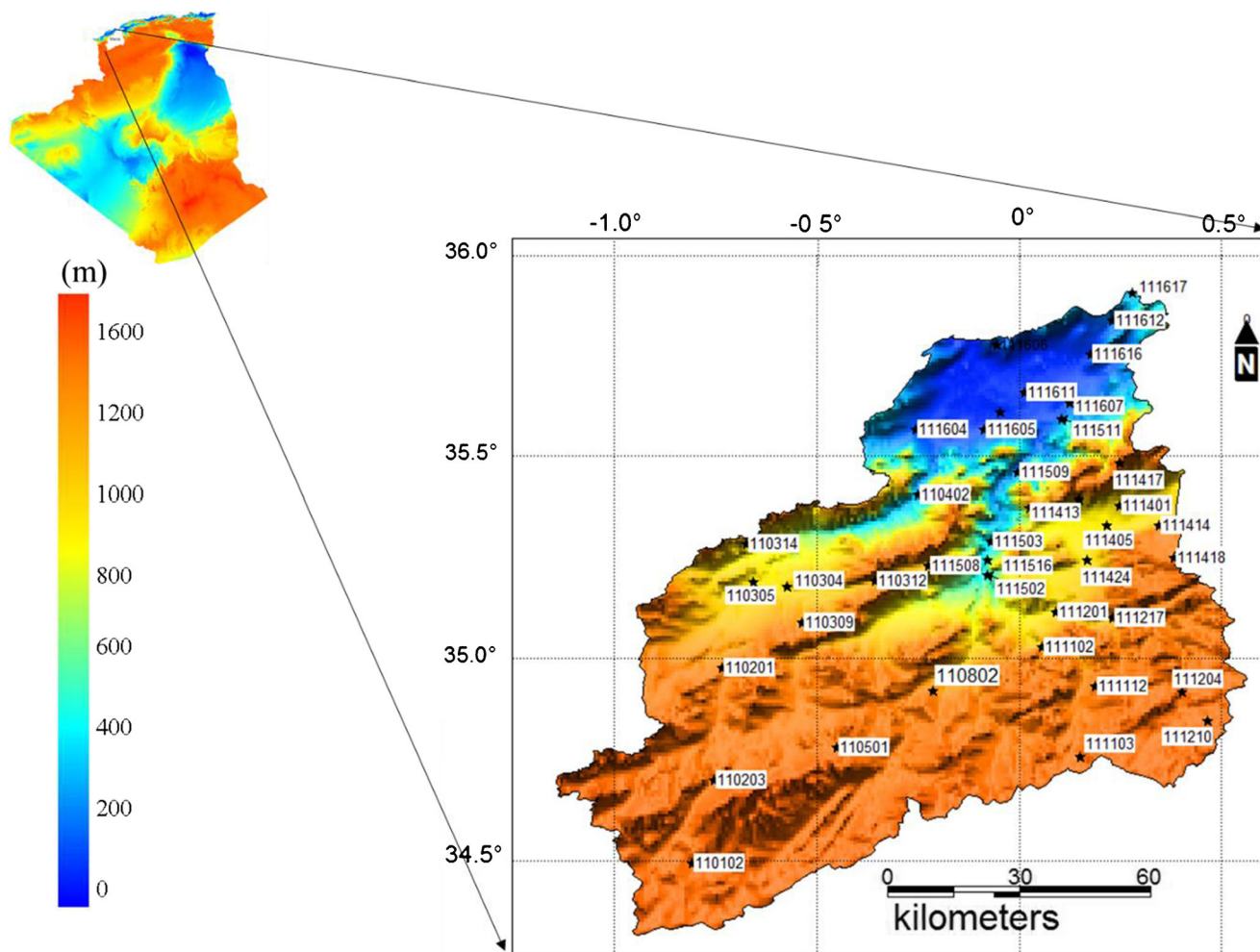


Fig. 1 Location of the 42 selected stations in the Macta watershed in Algeria.

time scale (SPI-1 and SPI-3) where the number of null values is high in most stations and affects the normality of the distributions. Thus, 42 stations that have been selected are distributed over all the Macta watershed for a period of 42 years (1970–2011) (Fig. 1). The rainfall stations used in this work are symbolized numerically (e.g., Sidi Bel Abbes, 110305; Mascara, 111429). Statistical characteristics of selected stations are presented in Supplementary material Appendix 1, Table A1.

Methodology

Standardized Precipitation Index

The Standardized Precipitation Index (SPI) methodology has been presented by McKee et al. (1993). This index can provide an accurate overview on the degree of wetness or dryness on different time scales (EAS 2011). For a given time scale ($t=1, 3, 6, 9,$ or 12 months), the cumulated precipitations (PC_m) are computed. For instance, the PC_m of a given month (ranked at the m^{th} row) is the sum of monthly precipitation

(P_m) for the months ranging between m and $m-t-1$.

$$PC_m = \sum_m^{(m-t-1)} P_m \tag{1}$$

The computational procedure for deriving SPI involves the following steps: (a) First, an appropriate probability density function (PDF) is fitted to the relative frequency distribution of precipitation summed over the time scale (PC_m) of interest and (b) each PDF is then transformed into a standardized normal probability distribution function (PDF) (Dabanli et al. 2017).

The SPI approach is based on fitting a gamma distribution to the cumulated precipitation data. The parameters of the gamma distribution (shape “ α ” and scale “ β ”) and the statistics U are calculated as follows (WMO 2015; Wu et al. 2007):

$$U = \ln\left(\frac{\bar{X}}{N}\right) - \frac{\sum \ln(X)}{N} \tag{2}$$

$$\alpha = \frac{1 + \sqrt{1 + \frac{4U}{3}}}{4U} \tag{3}$$

$$\beta = \frac{\bar{X}}{\alpha} \tag{4}$$

where N is the number of non-null values in a given station, X is non-null precipitation values, and \bar{X} is the mean of the precipitation series.

The resulting parameters are then used to find the cumulative gamma probability distribution (CGPD, (G(x)) of a precipitation event. G(x) is defined by:

$$G(x) = \frac{\int_0^x x^{\alpha-1} e^{-\frac{x}{\beta}} dx}{\beta^\alpha \Gamma(\alpha)} \tag{5}$$

where Γ is the ordinary gamma function of α .

Since gamma distribution is undefined for null values, the CGPD becomes:

$$H(x) = q + (1-q)G(x) \tag{6}$$

where q is the probability of the zero, expressed as the ratio between the number of null values (number of zero values of PCms) and the number of observations (n).

Finally, the modified CGPD (H(x)), is transformed to the standard normal distribution, which represents the SPI (Abramowitz and Stegun 1970):

$$Z = \text{SPI} = - \left(\sqrt{\ln \left(\frac{1}{(H(x))^2} \right) - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}} \right), \text{ for } 0 < H(x) \leq 0.5 \tag{7}$$

$$Z = \text{SPI} = + \left(\sqrt{\ln \left(\frac{1}{(1-H(x))^2} \right) - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}} \right), \text{ for } 0.5 < H(x) \leq 1 \tag{8}$$

where $c_0=2.515517$, $c_1=0.802583$, $c_2=0.010328$, $d_1=1.432788$, $d_2=0.189269$, and $d_3=0.001308$.

These constants are being widely employed for SPI computation (Abramowitz and Stegun 1970).

A Z value of -1.0 ($+1.0$) or less (more) imply a drought (wet) event. McKee et al. (1993) initially proposed a classification representing only dry events. The World Meteorological Organization (WMO 2012) has modified this classification by adding wet events symmetrically (Table 1). Stagge et al. (2015) proposed to limit the SPI values to the range $[-3.3]$ to ensure reasonableness. Any value greater (less) than 3 (-3) is corrected and therefore replaced by the value 3 (-3).

Innovative trend analysis

The ITA procedure has been developed by Şen (2012). It is used by many researchers because of its simplicity and efficiency. Compared to the other trend methods (such as Mann-Kendall, Spearman, Mann-Whitney), the ITA provides more information regarding changes for different portions of the

Table 1 SPI values and drought classification

SPI value	Class
$\text{SPI} \geq 2.00$	Extremely wet
$1.50 \leq \text{SPI} < 2.00$	Severely wet
$1.00 \leq \text{SPI} < 1.50$	Moderately wet
$0 < \text{SPI} < 1.00$	Mildly wet
$0 < \text{SPI} < -1.00$	Mild drought
$-1.50 < \text{SPI} \leq -1.00$	Moderate drought
$-2.00 < \text{SPI} \leq -1.500$	Severe drought
$\text{SPI} \leq -2.00$	Extreme drought

series. First, the series is divided into two equal parts. Each one is sorted in ascending order, and then a scatter plot is constructed having as the first part on the X-axis. A 1:1 line is drawn which represents the limit between decreasing and increasing trend areas (Fig. 2). In ITA visual method, any point above (below) 1:1 line implies trend existence. If the distance is increasing from 1:1 line, it shows the trend acceleration or strongness.

In this study, the ITA method is modified by adding two lines (red and blue) to distinguish two regions. The dry (wet) region represents SPI values less than or equal (greater than or equal) to -1.50 (1.50) (Caloiero 2018) (Fig. 2). Therefore, the term drought severity refers to SPI values below -1.50 .

Results and discussion

All the calculations for this work were carried out by programs written under R (R Core Team 2020).

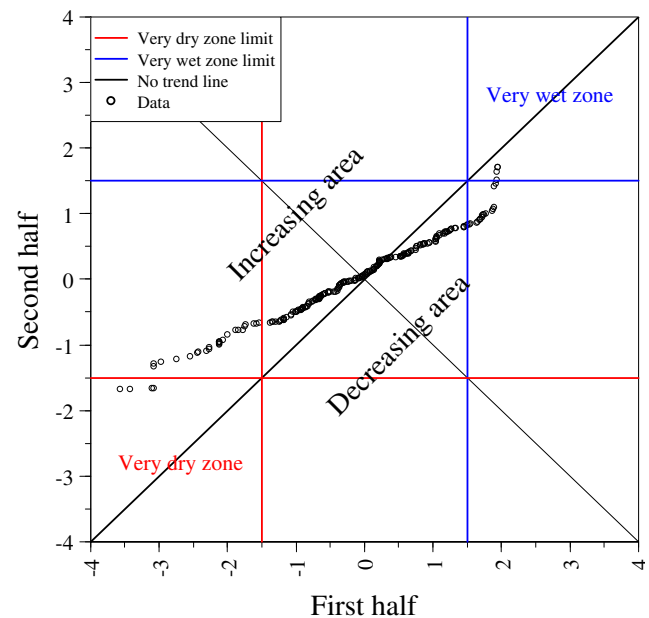


Fig. 2 ITA template

The Pettitt test (1979), from the trend package (Pohlert 2020), was applied to test the homogeneity of the series. The null hypotheses of homogeneity cannot be rejected for the rainfall data at any of the stations at 5% significance level.

Rainfall data were fitted to gamma distribution after calculating the scale and shape parameters (Supplementary material Appendix 1, Table A2). The adequacy of the gamma distribution was performed by the CDFt package (Vrac and Michelangeli 2021). The Kolmogorov-Smirnov test and Cramér-von Mises test were used. Both indicate the adequacy of the gamma distribution (all p values are above the significance level, 5%; therefore, the null hypothesis “Gamma distribution adequacy” cannot be rejected).

The SPIs, for the five times scales (1, 3, 6, 9, and 12 months), were calculated for the 42 selected stations of the Macta over a period of 42 years (1970 to 2011). Thus, five matrices (44 columns: year, month, and 42 stations), one for each time scale, were built. Therefore, each matrix contains N SPI values (n rows (or n months) and 42 columns (or stations)).

Frequencies of two categories (dry: $SPI \leq -1.50$ and wet: $SPI \geq 1.50$) were calculated at different time scales. Percentages of the frequencies are estimated by $\frac{f}{N} * 100$, in which f is the frequency (number of months of a given category) in an SPI's matrix.

Figure 3 a shows the comparison between the two categories using SPI-1 ($N=508*42=21,336$ months; 100%). It is clear that the number of months with dry conditions (3200 months or 15%) is higher than those with wet conditions (1001 months, i.e., 4.7%) for the 42 stations. The percentage difference between them is 10.3%. For dry conditions, SPI-1 frequencies (months number) vary between a minimum of 0 (110102; 110312, located south and 111604; 111606, located north) and a maximum of 121 (111402, located in the center of the basin). On the other hand, the number of months showing wet conditions varies between 17 (111102) and 32 months (110102) in the south of the basin. Severe and extreme dry conditions were detected at all stations (42) in the watershed. This result agrees perfectly with Achour et al.'s (2020) work, in northern Algeria.

Using SPI-3 values ($N=506*42=21,252$ months; 100%) (Fig. 3b), the number showing severe or extreme dry conditions (1842 months or 8.7%) remains higher but is starting to be close to those showing severe or extremely humid conditions (797 months or 3.8%), with a percentage difference of 4.9%. In all selected stations, the number of dry months is higher than that of the wet months, apart from station 110102, located to the south of the basin, which presented an opposite situation (39 “7.7%” against 37 “7.3%” months), where dry months number is less than wet ones. The number of months showing dry conditions varies between a minimum of 37 months (111210, located in the south basin) and a

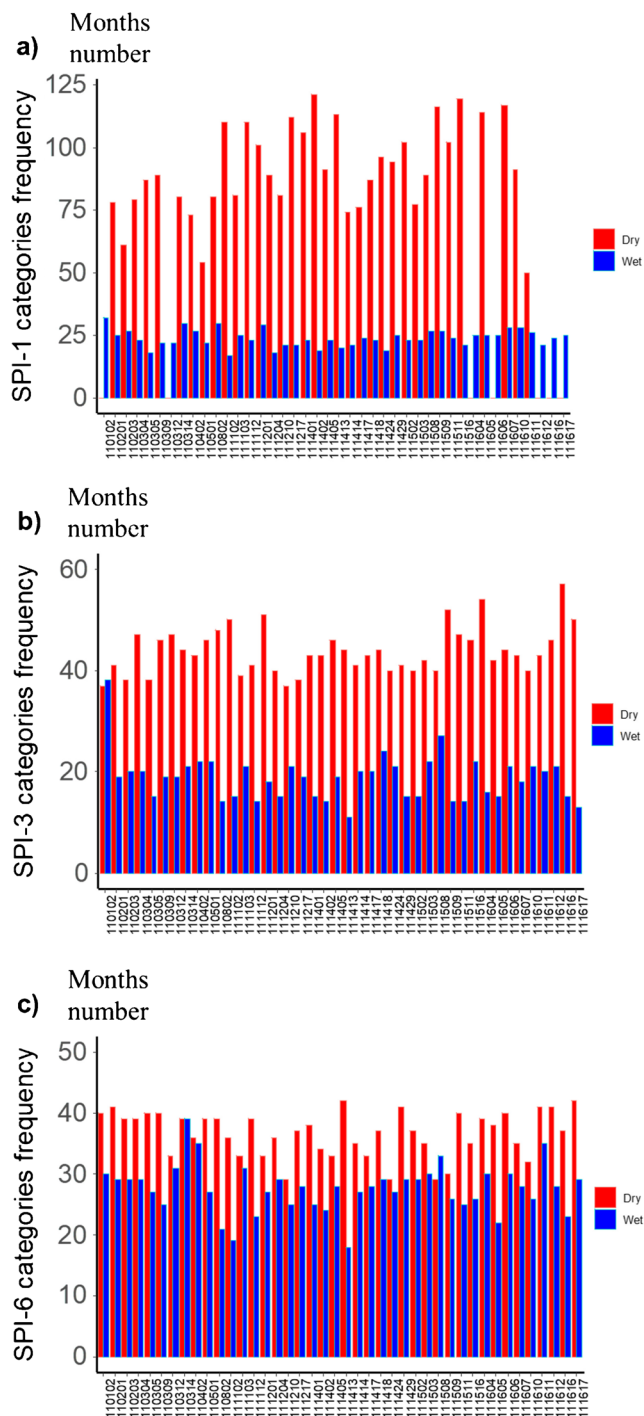


Fig. 3 SPI frequency for drought and humidity conditions. a SPI-1, b SPI-3, c SPI-6, d SPI-9, and e SPI-12.

maximum of 57 months (111616, located north of the basin). For dry months, SPI-3 frequency (months number) values range between 11 (111413, located in the center of the basin) and 39 (110102).

For SPI-6 ($N=503*42=21,126$ months; 100%) (Fig. 3c), the percentage difference between dry and wet frequencies continue to decrease, reaching 1.7%. The number of months

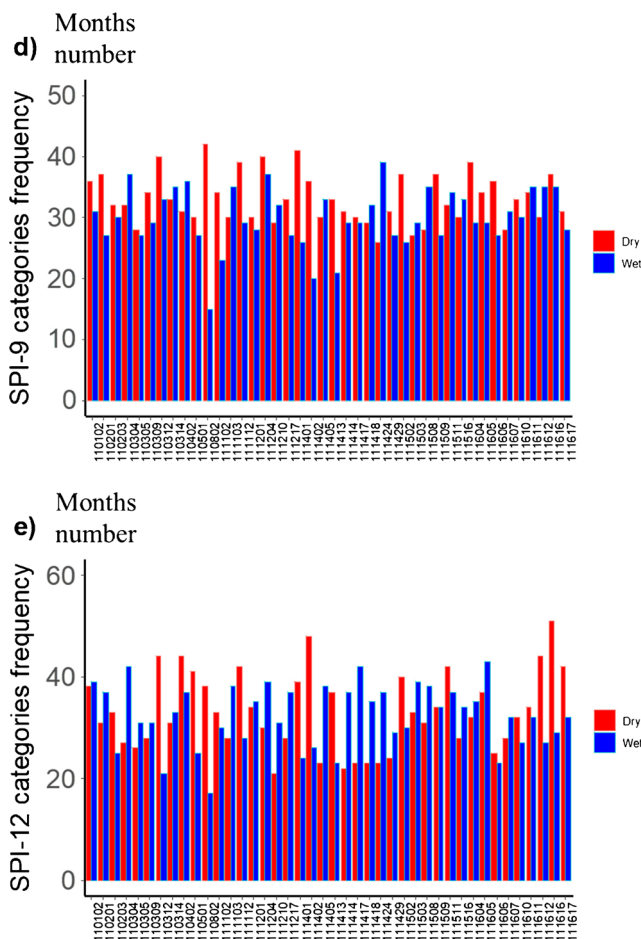


Fig. 3 (continued).

with severe or extreme dry conditions (1541 months or 7.3%) is greater than those showing severe or extremely wet conditions (1179 months or 5.6%). All stations showed dry conditions (dry frequency greater than wet one), except station 111508, located in the center of the basin which presented an opposite situation (34 versus 29 months or 6.8% against 5.8%).

Figure 3 d represents dry and wet conditions for SPI-9 values ($n=500 \times 42=21,000$ months; 100%). The difference, in percentage, between the dry category's frequencies (1390 or 6.6%) and that of wet conditions (1283 or 6.1%), becomes increasingly minimal (0.51%). On this scale, wet conditions begin to increase and become 14 stations (33%). It is obvious that from this scale, the balance between categories begins to be established.

In the long-term scale (SPI-12) ($n=497 \times 42=20,874$ months; 100%) (Fig. 3e), the situation is completely reversed. In fact, the difference, in percentage, between the dry (1392 or 6.7%) and wet (1374 or 6.6%) months number, becomes zero (0.09%). Indeed, the number of stations showing wet conditions (24) (57%) is starting to become higher than those with dry conditions (18) (43%). In the long term (SPI-12), a

decrease in the number of dry episodes has been detected in favor of wet ones.

Analysis of SPIs from 1 to 9 months shows that, since 1970, the Macta watershed has been suffering from severe and extreme drought in the short term (monthly (SPI-1), seasonal (SPI-3), semi-annually (SPI-6), and even at the level of SPI-9. It is obvious that it is a meteorological drought that spans 9 months (SPI-9). It may take the agricultural form and affects plants with a life cycle of less than 9 months, but it has not yet reached the hydrological and socio-economic form. In the long term, the basin is not yet affected by the annual drought (SPI-12); a balance is established between dry and wet episodes. In general, the dry episode frequencies dominate those wet.

Our results, in a southern Mediterranean region, indicate that the number of drought episode decrease with increasing time scale. During the period (1970–2011), the index identified a severe drought, with a very large number of months. These results agree perfectly with the work carried out in Apulia in Italy (southern Mediterranean) (Marini et al. 2019).

In order to identify possible trends in SPI values at 1, 3, 6, 9, and 12 months, for each station, the ITA method was applied to the monthly series of this index (Fig. 5 and more details in Supplementary material Appendix 1, Fig. A1 to A5).

In order to mark the trend of each SPI at each station, the symbols, +, -, and 0 have been used to denote the increasing, decreasing, and no trend, respectively. Table 2 shows the trends for each time scale (SPI) and for each station.

Table 2 can be transformed into a histogram (Fig. 4).

Figure 4 shows that the wet conditions are more affected by the decreasing trend than the dry ones, while the situation is reversed dry conditions.

As a result of the ITA method, Figure 5 shows a sample of the results obtained at the Macta watershed for SPIs of 1, 3, 6, 9, and 12 months (for more details, see Supplementary material Appendix 1, Fig. A1 to A5).

In general, it was detected a decrease in the severity of drought (64%) accompanied by a decrease in wet episodes (60 %) for the SPI-1 values (Table 2, Fig. 4 and Supplementary material Appendix 1, Fig. A1). For the low values of the index (severe and extreme drought conditions), 14 stations (33%) showed no trend, and 27 stations (64%) showed an increasing trend, distributed evenly over the entire basin. A ratio test, using prop.test function under R Language, showed a significant difference ($\chi^2 = 6.861$, $df = 1$, $n=42$, p -value < 0.01). On the other hand, no station showed a decreasing trend (0%). For the high values (severe and extreme humidity conditions), 7 stations (17%) have no trend, 10 stations (24%) show a positive trend, and 25 stations (60%) show a negative trend. These results are in line with those obtained by Adib and Marashi (2019) in southwestern Iran.

The findings of the earlier SPI-1 are confirmed for SPI-3 (Fig. 5b and Supplementary material Appendix 1, Fig. A2), by

Table 2 Trends in SPI (1, 3, 6, 9, and 12 months)

Station	SPI-1		SPI-3		SPI-6		SPI-9		SPI-12	
	S/E D*	S/E W**	S/E D*	S/E W**	S/E D*	S/E W**	S/E D*	S/E W**	S/E D*	S/E W**
110102	0	+	+	+	+	-	+	-	+	-
110201	+	+	+	+	+	+	+	+	+	+
110203	+	0	+	0	+	0	+	+	+	+
110304	+	-	+	-	+	-	+	-	+	-
110305	+	-	+	-	+	0	+	+	+	+
110309	0	0	-	+	+	+	+	+	+	+
110312	0	-	+	-	+	-	-	-	-	-
110314	0	-	-	-	-	-	-	-	-	-
110402	+	-	+	-	+	-	+	-	+	-
110501	+	+	+	+	+	+	+	+	+	+
110802	+	+	+	-	+	+	+	+	+	+
111102	+	0	+	+	+	0	+	+	+	+
111103	+	+	+	+	+	+	+	+	+	+
111112	+	-	+	-	+	+	+	+	+	+
111201	+	-	+	-	+	-	+	-	+	-
111204	0	0	+	-	+	0	+	+	-	-
111210	+	+	+	+	+	+	+	+	+	+
111217	+	+	+	+	+	+	+	+	+	+
111401	+	-	+	-	+	-	+	-	+	-
111402	+	-	+	0	+	+	+	+	+	+
111405	+	-	+	-	+	-	+	-	+	-
111413	+	-	+	0	+	0	+	+	+	-
111414	+	+	+	+	+	+	+	+	+	+
111417	+	0	+	-	+	-	+	-	+	-
111418	+	+	+	+	+	+	0	+	-	+
111424	0	-	+	-	+	-	+	-	+	-
111429	+	0	+	-	+	-	+	-	+	-
111502	0	-	0	0	+	-	+	-	+	-
111503	+	-	+	-	+	-	+	-	+	-
111508	0	-	-	-	+	-	+	-	-	-
111509	+	-	+	-	+	-	+	+	+	+
111511	0	-	+	-	+	-	+	-	+	-
111516	+	-	+	-	+	-	+	-	+	-
111604	0	0	0	0	+	-	+	+	+	0
111605	+	-	-	-	+	-	+	-	+	-
111606	0	-	0	-	+	-	+	-	0	-
111607	1	-	0	-	-	-	+	-	0	-
111610	+	+	+	+	+	+	+	+	+	+
111611	+	-	+	-	+	-	+	-	+	-
111612	0	-	+	-	+	-	+	-	+	-
111616	0	-	+	-	+	-	+	-	0	-
111617	0	-	+	-	+	-	+	-	0	-

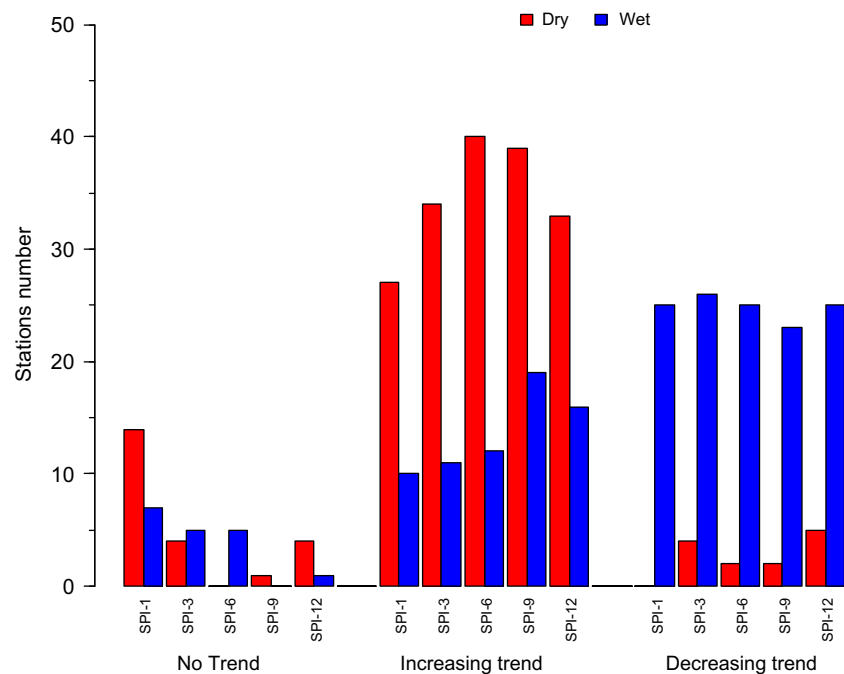
*Severe and extreme dry

**Severely and extremely wet

an accentuation of the drought severity reduction (81%), together with wet episode decrease (62%). It is clear that the

number of stations with a positive trend at low values (Supplementary material Appendix 1, Fig. A2) continued to

Fig. 4 Categories frequency of each SPI (1, 3, 6, 9, and 12 months)



increase (from 27 “64%” to 34 “81%” stations). The stations showing no trend have decreased (4, 10%). On the other hand, for severe and extreme humidity conditions, the trend situation is similar to the previous SPI-1 index, with a positive trend of 26% against a negative trend of 62%. The same observation was detected by Jasim and Awchi (2020), during the period (1970–2013), in Iraq.

The SPI-6 and SPI-9 trend analysis (Fig. 5 c and d) (Supplementary material Appendix 1, Fig. A3 and A4), which directly affect the vegetation, is essential for our study area. Zone with agricultural vocation is an important sector of the national economy, which shelters important agricultural potentialities (plain of Ghriss and that of Sidi Bel Abbes (at the center of the basin) and two irrigated perimeters Habra and Sig in North).

Figure 5 c and d summarize the trend analysis results of SPI-6 and SPI-9. A further reduction was observed in the drought severity in 95% (93%) of stations, accompanied with the wet episode decrease in 60% (55%) of stations. This observation was noticed at all stations in the Macta watershed (more details in Supplementary material Appendix 1, Fig. A3 and A4).

In the long term, the analysis of SPI trend at 12 months, with the ITA method (Fig. 5e and Supplementary material Appendix 1, Fig. A5), showed results similar (79% of stations have reduction in drought severity and 60% have decrease in wet condition) to those of the previous ones (SPI-1, SPI-3, SPI-6, and SPI-9) and those of Caloiero et al. (2015) in southern Italy. The 12-month SPI is a broad indirect indicator of water resource management (Caloiero 2018). In fact, global assessments suggest that droughts are likely to both increase

and decrease in the future due to climate change and depending on location (Wang 2005).

The results of this article highlight that agricultural regions, such as plains (Ghriss and Sidi Bel Abbes) and irrigated perimeters (Habra and Sig), are the area’s most constantly vulnerable to drought, including the industry in the study area.

In order to describe the dry frequencies (displayed in Fig. 3) spatially, five additional maps are presented in Figure 6. As presented above, the dry frequencies are the SPI values less than or equal to -1.5 . The parts in red (blue) have more (less) frequent drought episodes compared to other regions of the basin. The color is red when a drought frequency exceeds 100 months.

On monthly scale (SPI-1), the eastern center of the basin presents the highest frequencies of meteorological drought where station 111402 recorder the maximum number of dry months (121), while the northern part is less affected. The conditions are homogenized on the quarterly and semiannual time scales (SPI-3 and SPI-6). From the medium term (SPI-9), drought frequencies persist in decreasing throughout the study area. At the hydrological scale (SPI-12), Figure 6 shows that the east of the basin is less affected by the phenomenon of drought. This can be justified by the altimetric situation (higher than 800 m).

Conclusion

In this paper, the concept of the Standardized Precipitation Index (SPI) is applied to 42 meteorology stations monthly

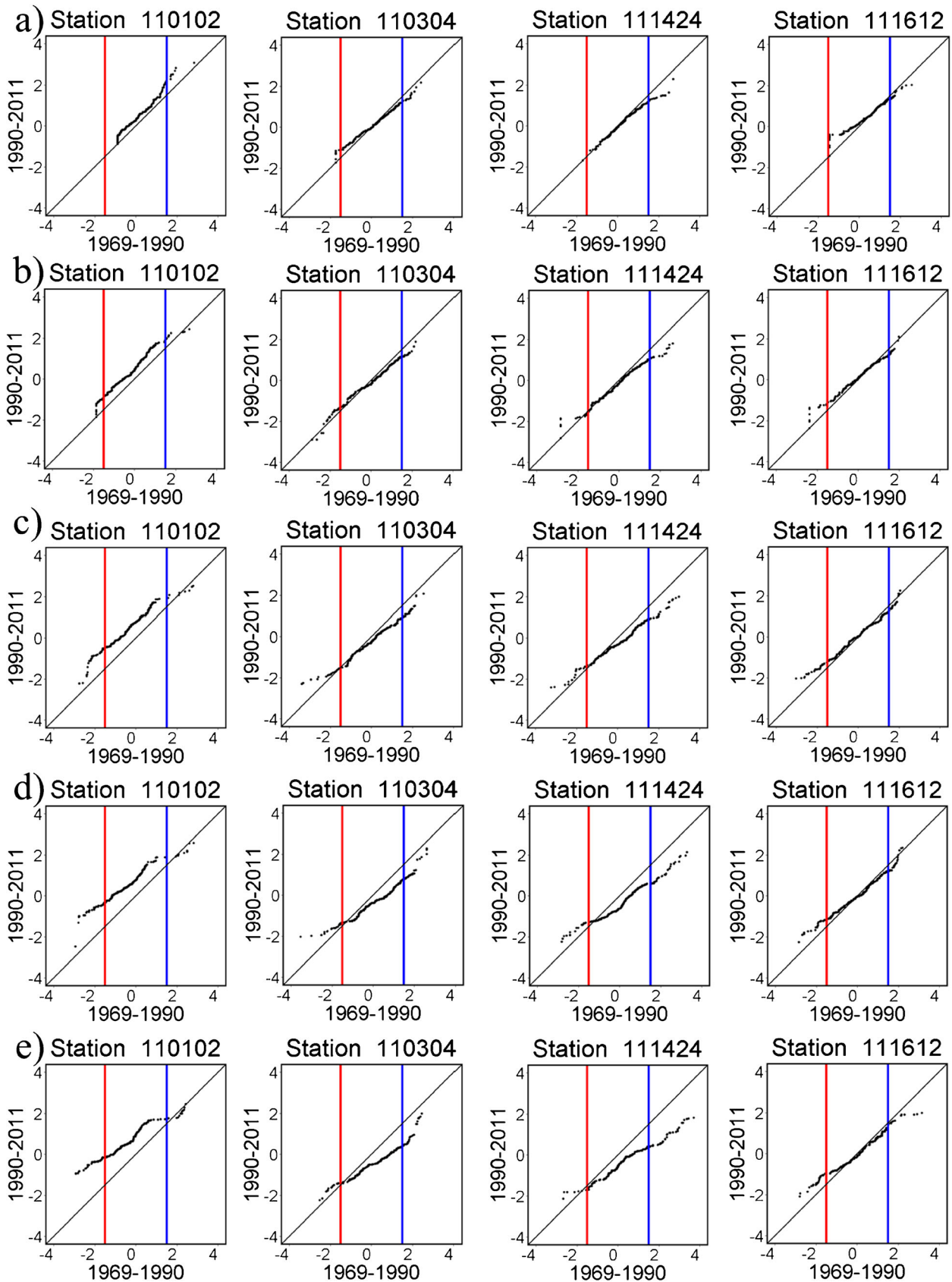


Fig. 5 SPI innovative trend analysis (ITA) sample. **a** SPI-1, **b** SPI-3, **c** SPI-6, **d** SPI-9, and **e** SPI-12 (see online Supplementary material Appendix 1, Fig. A5-A9 for more details)

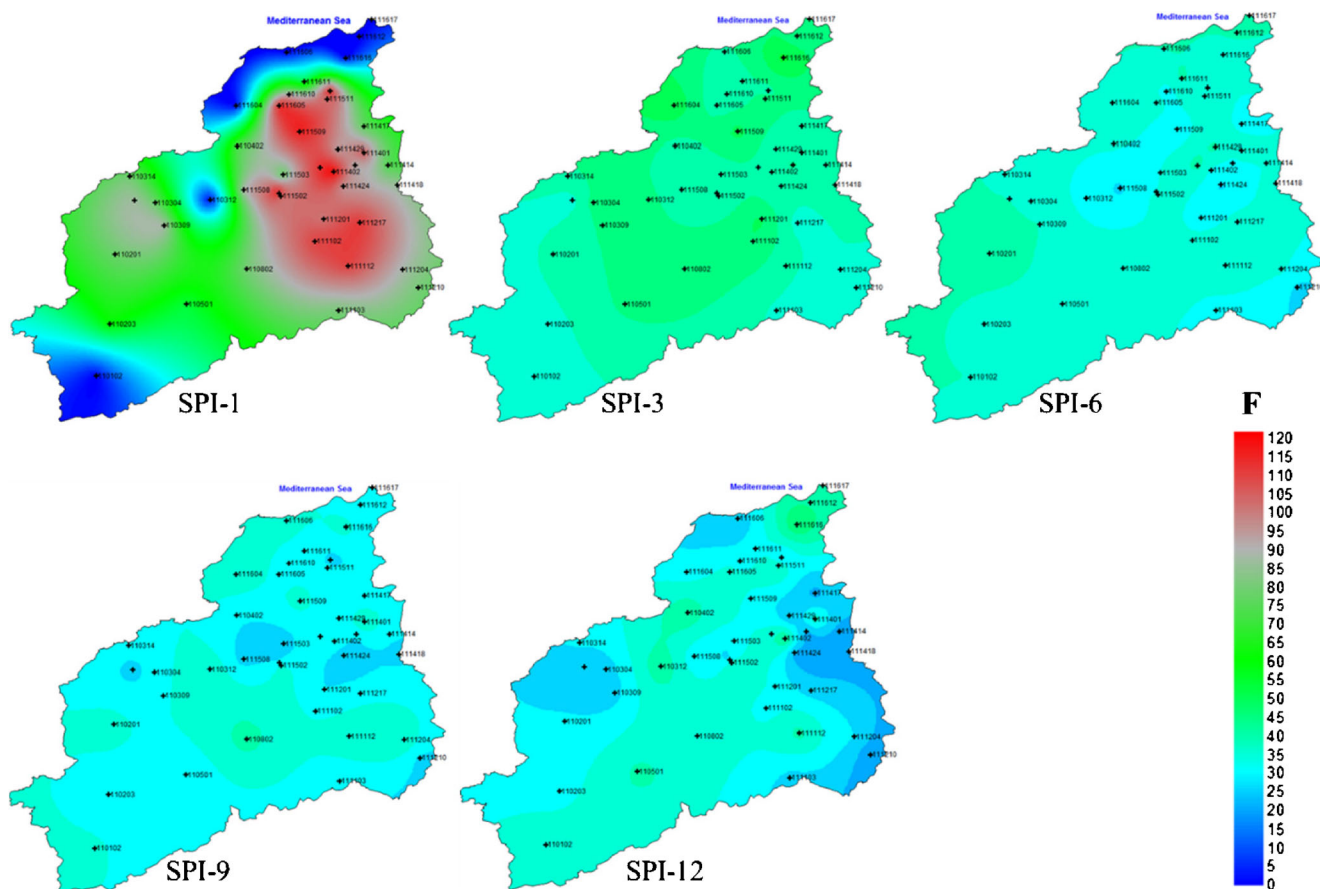


Fig. 6 Dry condition frequencies (SFI less than or equal to -1.5).

precipitation records from Macta watershed (Northwest Algeria). The SFI calculations were performed at different time scales (1, 3, 6, 9, and 12 months). Then, for each rainfall gauge, the number of months of severe or extreme drought and humidity was calculated. Subsequently, the application of the ITA method made it possible to detect trends in the SFI series.

Results show that similar behavior dominated the 42 stations in the basin. In fact, for the short- and medium-term time scales (1, 3, 6, and 9 months), and in all the stations, the number of months showing severe and extreme dry conditions (3200 “15%,” 1842 “8.7%,” 1541 “7.3%,” 1390 “6.6%,” respectively) is higher than those showing severe and extreme wet conditions (1001 “4.7%,” 797 “3.8%,” 1179 “5.6%,” 1283 “6.1%,” respectively), while in the long term (12-month time scale), the number of months showing severe and extreme wet conditions (1374 “6.6%”) becomes almost equal to that showing severe and extreme dry conditions (1392 “6.7%”).

These results directly impact the agricultural potential of the plains of Ghriss and Sidi Bel Abbes, as well as Habra and Sig perimeters, by experiencing short-term agricultural

drought SFI (1, 3, 6, and 9 months). Fortunately, this situation improves over the long term (SFI-12).

In fact, in the short term, the Macta watershed has experienced agricultural drought since 1970, and in the long term, a reduction in this drought has been detected.

In anticipation, using ITA method, in the short, medium, and long term, a similar situation was detected for the five SFIs, marking a downward trend in the severity of drought at most stations (64%, 81%, 95%, 93%, and 79% for SFI-1, SFI-3, SFI-6, SFI-9, and SFI-12, respectively) together with a reduction in severe and extreme wet episodes (60%, 62%, 60%, 55%, and 60% for SFI-1, SFI-3, SFI-6, SFI-9, and SFI-12, respectively).

It is also noticed that the majority of the stations suffer from a severe meteorological drought in the center-East (drought frequency above 100) of the basin, whereas on the hydrological scale (SFI-12), the situation is balanced (drought frequency below 50).

In general, this study showed that the trend of drought severity is decreasing (SFI values from 1991 to 2011 become higher than those from 1970 to 1991), but the dominance of dry periods at time scales 1, 3, 6, and 9 months persists.

Given this situation, which shows a unique behavior for all the stations in the Macta watershed, a detailed regional analysis remains essential.

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Declarations

1. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
2. The manuscript has not yet been published or submitted to any other journal.
3. The authors acknowledge that they all have seen and approved the final version of the paper and have agreed to its submission for publication.
4. The co-authorship of the publication has been based on a fair contribution and agreement between the major co-contributors of this work.

References

- Abbes M, Hamimed A, Lafrid A, Mahi H, Nehal L (2018) Use of high spatial resolution satellite data for monitoring and characterization of drought conditions in the Northwestern Algeria. *Min Sci* 25:71–99. <https://doi.org/10.5277/msc182507>
- Abramowitz M, Stegun IA (1970) Handbook of mathematical functions with formulas, graphs, and mathematical tables. Dover Publications, INC., New York, p 1970
- Achour K, Meddi M, Zeroual A, Bouabdelli S, Maccioni P, Moramarco T (2020) Spatio-temporal analysis and forecasting of drought in the plains of northwestern Algeria using the standardized precipitation index. *J Earth Syst Sci* 129. <https://doi.org/10.1007/s12040-019-1306-3>
- Adib A, Marashi SS (2019) (2019). Meteorological drought monitoring and preparation of long-term and short-term drought zoning maps using regional frequency analysis and L-moment in the Khuzestan province of Iran. *Theor Appl Climatol* 137:77–87. <https://doi.org/10.1007/s00704-018-2572-8>
- Alashan S (2020) Combination of modified Mann-Kendall method and Şen innovative trend analysis. *Engineering Reports* 2(3). <https://doi.org/10.1002/eng2.12131>
- Alemu ZA, Dioha MO (2020) Climate change and trend analysis of temperature: the case of Addis Ababa, Ethiopia. *Environ Syst Res* 9:27. <https://doi.org/10.1186/s40068-020-00190-5>
- Alifujiang Y, Abuduwaili J, Maihemuti B, Emin B, Groll M (2020) Innovative trend analysis of precipitation in the Lake Issyk-Kul Basin, Kyrgyzstan. *Atmosphere* 2020(11):332. <https://doi.org/10.3390/atmos11040332> www.mdpi.com/journal/atmosphere
- Bazrafshan J (2017) Effect of air temperature on historical trend of long-term droughts in different climates of Iran. *Water Resour Manag* 31: 4683–4698. <https://doi.org/10.1007/s11269-017-1773-8>
- Benzater B, Elouissi A, Benaricha B, Habi M (2019) Spatio-temporal trends in daily maximum rainfall in northwestern Algeria (Macta watershed case, Algeria). *Arab J Geosci* 12(11):1–18. <https://doi.org/10.1007/s12517-019-4488-8>
- Caloiero T (2018) SPI trend analysis of New Zealand applying the ITA technique. *Geosciences* 2018(8):101. <https://doi.org/10.3390/geosciences8030101> www.mdpi.com/journal/geosciences
- Caloiero T, Coscarelli R, Ferrari E, Sirangelo B (2015) Analysis of dry spells in Southern Italy (Calabria). *Water* 2015(7):3009–3023. <https://doi.org/10.3390/w7063009>
- Coll JR, Aguilar E, Ashcroft L (2017) Drought variability and change associated across the Iberian Peninsula. *Theor Appl Climatol* 130:901–916. <https://doi.org/10.1007/s00704-016-1926-3>
- Dabanli I, Mishra AK, Şen Z (2017) Long-term spatio-temporal drought variability in Turkey. *J Hydrol* 552(2017):779–792. <https://doi.org/10.1016/j.jhydrol.2017.07.038>
- Dai A (2011) Drought under global warming: a review. *Wiley Interdiscip. Rev Clim Change* 2(1):45–65. <https://doi.org/10.1002/wcc.81>
- Danandeh Mehr A, Vaheddoost B (2020) Identification of the trends associated with the SPI and SPEI indices across Ankara, Turkey. *Theor Appl Climatol* 139:1531–1542. <https://doi.org/10.1007/s00704-019-03071-9>
- Dehghani M, Saghafian B, Nasiri Saleh F, Farokhnia A, Noori R (2014) Uncertainty analysis of streamflow drought forecast using artificial neural networks and Monte Carlo simulation. *Int J Climatol* 34: 1169–1180. <https://doi.org/10.1002/joc.3754>
- Eekhout JPC, Hunink JE, Terink W, Vente J (2018) Why increased extreme precipitation under climate change negatively affects water security. *Hydrol Earth Syst Sci* 22:5935–5946. <https://doi.org/10.5194/hess-22-5935-2018>
- Ehteram M, Binti Koting S, Afan HA, Mohd NS, Malek MA, Ahmed AN, El-shafie AH, Onn CC, Lai SH, El-Shafie A (2019a) New evolutionary algorithm for optimizing hydropower generation considering multireservoir systems. *Appl Sci* 2019(9):2280
- Ehteram M, Singh VP, Ferdowsi A, Mousavi SF, Farzin S, Karami H, Mohd NS, Afan HA, Lai SH, Kisi O et al (2019b) An improved model based on the support vector machine and cuckoo algorithm for simulating reference evapotranspiration. *PLoS One* 2019(14): e0217499
- Elouissi A, Habi M, Benaricha B, Boualem SA (2017) Climate change impact on rainfall spatio-temporal variability (Macta watershed case, Algeria). *Arab J Geosci* 10:496. <https://doi.org/10.1007/s12517-017-3264-x>
- Elouissi A, Şen Z, Habi M (2016) Algerian rainfall innovative trend analysis and its implications to Macta watershed. *Arab J Geosci* 9. <https://doi.org/10.1007/s12517-016-2325-x>
- EAS, Environmental Agency of Slovenia (2011) Implementation of standardized precipitation index - SPI (Joint report). Project title: Drought Management Centre for South East Europe. Retrieved June 25, 2018, from http://www.dmcsee.org/uploads/file/305_wp321_implementationofspi.pdf
- Estrela T, Vargas E (2012) Drought management plans in the European Union. *Water Resour Manag* 2011(26):1537–1553. <https://doi.org/10.1007/s11269-011-9971-2>
- Fink AH, Brücher T, Krüger A, Leckebush GC, Pinto JG, Ulbrich U (2004) The 2003 European summer heatwaves and drought-synoptic diagnosis and impacts. *Weather* 2004(59):209–216. <https://doi.org/10.1256/wea.73.04>
- Forzieri G, Feyen L, Rojas R, Flörke M, Wimmer F, Bianchi A (2014) Ensemble projections of future streamflow droughts in Europe. *Hydrol Earth Syst Sci* 18:85–108. <https://doi.org/10.5194/hess-18-85-2014>
- Gampe D, Ludwig R, Qahman K, Afifi S (2016) Applying the triangle method for the parameterization of irrigated areas as input for spatially distributed hydrological modeling – assessing future drought

- risk in the Gaza Strip (Palestine). *Sci Total Environ* 543:877–888. <https://doi.org/10.1016/j.scitotenv.2015.07.098>
- Golian S, Mazdiyasi O, AghaKouchak A (2015) Trends in meteorological and agricultural droughts in Iran. *Theor Appl Climatol* 2015(119):679–688. <https://doi.org/10.1007/s00704-014-1139-6>
- Güçlü YS (2020) Improved visualization for trend analysis by comparing with classical Mann-Kendall test and ITA. *J Hydrol* 584:124674. <https://doi.org/10.1016/j.jhydrol.2020.124674>
- Hamed Y, Bouguerra W, Limame E (2018) Pilot project “Transfer of sea water from the Gulf of Gabes to Gafsa: socio-economic aspects and exploitation”, Tunis, March 2, 2018. ANPR-Tunisia
- Hannaford J, Lloyd-Hughes B, Keef C, Parry S, Prudhomme C (2011) Examining the large-scale spatial coherence of European drought using regional indicators of precipitation and streamflow deficit. *Hydrol Process* 2011(25):1146–1162. <https://doi.org/10.1002/hyp.7725>
- Heim RR (2002) A review of twentieth-century drought indices used in the United States. *Bull Am Meteorol Soc* 83(8):1149–1166
- IPCC, Intergovernmental Panel on Climate Change (2013) In: Stocker TF, Qin Q, Plattner GK, Tignor M, Allen SK, Boschung J, Midgley PM et al (eds) *The physical science basis. Contribution of working Group I to the Fifth Assessment Report of the IPCC*. Cambridge University Press, UK
- Jasim AI, Awchi TA (2020) Regional meteorological drought assessment in Iraq. *Arab J Geosci* 13:284. <https://doi.org/10.1007/s12517-020-5234-y>
- Kreibich H, Di Baldassarre G, Vorogushyn S, Jeroen CJHA, Apel H, Aronica GT, Arnberg-Nielsen K, Bouwer LM, Bubeck P, Caloiero T, Chinh DT, Cortès M, Gain AK, Giampà V, Kuhlicke C, Kundzewicz ZW, Llasat MC, Mård J, Matczak P, Mazzoleni M, Molinari D, Dung NV, Petrucci O, Schröter K, Slager K, Thielen AH, Ward PJ, Merz B (2017) Adaptation to flood risk: results of international paired flood event studies. *Earth’s Future* 5:953–965. <https://doi.org/10.1002/2017EF000606>
- Labban AH (2016) Dust storms over Saudi Arabia: temporal and spatial characteristics, climatology and synoptic case studies. In: Thesis in Meteorology. School of Science College of Science Engineering and Health RMIT University, Australia
- Laborde JP (1995) The different stages of an automatic cartography: example of the rain map of Northern Algeria. In: Public. From AIC8, pp 37–46
- Lesk C, Rowhani P, Ramankutty N (2016) Influence of extreme weather disasters on global crop production. *Nature* 529:84–87. <https://doi.org/10.1038/nature16467>
- Mallena NK (2020) Comparison of parametric and nonparametric standardized precipitation index for detecting meteorological drought over the Indian region. *Theor Appl Climatol* 142:219–236. <https://doi.org/10.1007/s00704-020-03296-z>
- Marini G, Fontana N, Mishra AK (2019) Investigating drought in Apulia region, Italy using SPI and RDI. *Theor Appl Climatol* 137:383–397. <https://doi.org/10.1007/s00704-018-2604-4>
- Matiu M, Ankerst DP, Menzel A (2017) Interactions between temperature and drought in global and regional crop yield variability during 1961–2014. *PLoS One* 12:e0178339. <https://doi.org/10.1371/journal.pone.0178339>
- McKee TB, Doesken NJ, Kleist J (1993) The relationship of drought frequency and duration to time scales. In: Proceedings of the 8th Conference on Applied Climatology, Anaheim, CA, USA, 17–22 January 1993, pp 179–184
- Meddi M, Talia A, Martin C (2009) Recent changes in climatic conditions and flows in the Macta watershed (northwest of Algeria). *Physio-Géo* [Online], vol 3. Retrieved February 25, 2020, from <http://www.physio-geo.revues.org/686#entries>
- Mehdaoui, R., Mili, E., Seghir, A. (2018). Characterization using the SPI of climate drought in the Ziz watershed (South-East, Morocco). *European Scientific Journal* July 2018 edition Vol.14, No.21 ISSN: 1857 – 7881 (Print) e - ISSN 1857- 7431.
- Mishra AK, Singh VP (2010) A review of drought concepts. *J Hydrol* 391(1–2):202–216. <https://doi.org/10.1016/j.jhydrol.2010.07.012>
- Nabipour N, Dehghani M, Shamshirband S, Mosavi A (2019) Short-term hydrological drought forecasting based on different nature-inspired optimization algorithms hybridized with artificial neural networks. *IEEE Access* 8:15210–15222. <https://doi.org/10.1109/ACCESS.2020.2964584>
- Pineda LE, Willems P (2018) Rainfall extremes, weather and climate drivers in complex terrain: a data driven approach based on signal enhancement methods and EV modeling. *J Hydrol* 563(2018):283–302. <https://doi.org/10.1016/j.jhydrol.2018.05.062>
- Pettitt AN (1979) A non-parametric approach to the change-point problem. *J Roy Stat Soc C-App* 28(2):126–135. <https://doi.org/10.2307/2346729>
- Pohler T (2020) Trend: non-parametric trend tests and change-point detection. R package version 1.1.4. Retrieved February 25, 2020, from <https://CRAN.R-project.org/package=trend>
- R Core Team (2020) R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieved July 20, 2020, from <http://www.r-project.org/index.html>
- Sabri AF, Medjerab A (2012) Assessment of the vulnerability of Algerian watersheds to the effects of climate change and formulation of adaptation strategies. Retrieved March 05, 2019, from <http://hdl.handle.net/123456789/1581>
- Şen Z (2012) An innovative trend analysis methodology. *J Hydrol Eng* 17(9):1042–1046. [https://doi.org/10.1061/\(ASCE\)HE.1943-5584.0000556](https://doi.org/10.1061/(ASCE)HE.1943-5584.0000556)
- Şen Z (1998) Probabilistic formulation of spatio-temporal drought pattern. *Theor Appl Climatol* 61(3–4):197–206. <https://doi.org/10.1007/s007040050064>
- Spinoni A, Naumann G, Vogt JV, Barbosa P (2015) The biggest drought events in Europe from 1950 to 2012. *J Hydrol Reg Stud* 3(2015): 509–524. <https://doi.org/10.1016/j.ejrh.2015.01.001>
- Stagge JH, Tallaksen LM, Gudmundsson L, Van Loon AF, Stahl K (2015) Candidate distributions for climatological drought indices (SPI and SPEI). *Int J Climatol* 35(13):4027–4040. <https://doi.org/10.1002/joc.4267>
- Subyani AM (2012) Flood vulnerability assessment in arid areas, Western Saudi Arabia. *Int J River Basin Manag* 10:197–203. <https://doi.org/10.1080/15715124.2012.688749>
- Svensson C, Hannaford J, Prosdociimi I (2017) Statistical distributions for monthly aggregations of precipitation and streamflow in drought indicator applications. *Water Resour Res* 53:999–1018. <https://doi.org/10.1002/2016WR019276>
- Vrac M, Michelangeli PA (2021) CDFt: downscaling and bias correction via non-parametric CDF-transform. R package version 1.2. Retrieved February 25, 2021, from <https://CRAN.R-project.org/package=CDFt>
- Wang L, Huang G, Chen W (2019) Towards a theoretical understanding of multiscalar drought indices based on the relationship between precipitation and standardized precipitation index. *Theor Appl Climatol* 136:1465–1473. <https://doi.org/10.1007/s00704-018-2578-2>
- Wang G (2005) Agricultural drought in a future climate: results from 15 global climate models participating in the IPCC 4th assessment. *Clim Dyn* 2005(25):739–753. <https://doi.org/10.1007/s00382-005-0057-9>
- Wilhite DA, Glantz MH (1985) Understanding the drought phenomenon: definitions. *Water Int* 10:111–120 <http://digitalcommons.unl.edu/droughtfacpub/20>
- Wilhite DA, Hayes MJ, Svoboda MD (2000) Drought monitoring and assessment in the US. In: *Drought and drought mitigation*, The Netherlands, pp 149–160

- WMO, World Meteorological Organization (2015). An introduction to drought indices. WMO-ETSCI Workshop, Barbados 17 February 2015.
- World Meteorological Organization (WMO) (2012) Standardized precipitation index user guide (M. Svoboda, M. Hayes and D. Wood). WMO-No. 1090, Geneva
- Wu H, Svoboda MD, Hayes MJ, Wilhite DA, Wen F (2007) Appropriate application of the standardized precipitation index in arid locations and dry seasons. *Int J Climatol* 27(1):65–79
- Yevjevich V, Da Cunha L, Vlachos E (1984) Coping with droughts. Water Resources Publications, Littleton, p 1983
- Zaidman MD, Rees HG, Young AR (2012) Spatio-temporal development of streamflow droughts in north-west Europe. *Hydrol Earth Syst Sci* 2012(5):733–751
- Zhai J, Su B, Krysanova V, Vetter T, Gao C, Jiang T (2010) Spatial variation and trends in PDSI and SPI indices and their relation to streamflow in 10 large regions of China. *J Clim* 23(3):649–663. <https://doi.org/10.1175/2009JCLI2968.1>
- Zhao P, Lü H, Wang W, Fu G (2019) From meteorological droughts to hydrological droughts: a case study of the Weihe River Basin, China. *Arab J Geosci* 12:364. <https://doi.org/10.1007/s12517-019-4524-8>