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ASSESSMENT OF THE METEOROLOGICAL DROUGHT IN THE NORTHERN PART OF ALGERIA "CASE OF THE ISSER WADI WATERSHED"

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ABSTRACT

In the perspective of current climate variability and the impact of human activities on water overexploitation, it is essential to analyze dry and wet episodes for a better prevention and rationalization of water resources. The Mediterranean region and particularly the southern shore, is a drought sensitive area.

Algeria, like most Mediterranean countries has experienced alternating dry and wet periods in recent decades. Several climatic events have had a negative impact on agriculture, industry and drinking water supply. As a result, human societies and ecosystems are under increasing threat requiring new adaptations of life and economic models to support these upheavals.

The present study focuses on monitoring of the meteorological drought evolution in the Isser wadi watershed, located in the north-central part of Algeria, based on available rainfall data covering a 43-year period from 1973 to 2016.

The current study has made it possible to account for the extreme variability of rainfall in this watershed. In order to do this, different indices were studied in this work, namely the normalized precipitation index SPI, the rainfall deficit index RDI, and the drought index DI. All The obtained results have highlighted the severe and sustainable character of the climatic drought observed in the Isser basin from 1973 to 2002 as well as the return to a wet phase, well pronounced in the north of the basin from 2003 to 2016. Finally, in order to better understand this work, index maps tools for decision-making have been established.

Key words: Drought, Water deficit, Rainfall indices, Isser, Mapping.

INTRODUCTION

Climate variability and fluctuations have become a real concern for researchers in recent decades. The possibility of climate change is now the subject of much scientific research, notably by the Intergovernmental Panel on Climate Change (IPCC.,2013; 2014; 2021), which has identified climate change as one of the major global issues affecting the world today (Mehta et al.,2021; 2022).

Climate change has always been recognized as one of the major global issues affecting many countries around the world.

One of the consequences is a decrease in rainfall, which leads to drought. Drought is a natural phenomenon that is part of the dynamics and evolution of climate. This notion is relative, but its main characteristic is the decrease in the availability of water resources, due to the deficit of rain in wet periods. It leads to hydrological unbalances.

Meteorological drought is defined as a temporary deficit of precipitation compared to its long-term average that persists for a certain period in a certain region (Bazrafshan, 2017).

Drought is a universal phenomenon that affects several countries in the Mediterranean region, which is a particularly sensitive area to water scarcity and drought (Caloiero et al., 2021) and Algeria is one of them. The latter has suffered from persistent meteorological drought for more than three decades (Meddi and Meddi, 2009; Ghenim, 2010; Merabti and Meddi, 2016; Achite et al., 2021; Berhail et al., 2021; Zerouali et al., 2021; Amiar et al., 2023; Bouregaa, 2023). It has negative effects on all sectors, i.e. environmental, social and economic (Benali Khodja et al., 2022; Chadee et al., 2023), as a large part of the territory is dominated by an arid and semi-arid climate. The analysis of drought, as an extreme event, generally consists in the characterization of its severity, duration and intensity.

Actually, the detection and monitoring of drought conditions is mainly based on some indices. These also provide drought monitoring and detection at different stages of its evolution and constitute a decision support tool for managers. Among the most commonly used indices for drought monitoring is the standardized precipitation index "SPI" (McKee et al.,1993) which is the most popular drought index worldwide, particularly in Algeria, due to its easy calculation but also to the access and availability of precipitation data as a single input variable.

It is in this context that the present study was initiated and set as an objective to analyze the meteorological drought sequences on an annual scale in the Isser wadi watershed, in order to better understand the evolution of the climate and its consequences, and to define adaptation strategies mainly agriculture, which is the main activity of the local population, feeding the dams and meeting the population's drinking water needs.

MATERIAL AND METHODS

Study area

The Isser wadi watershed is located in the central part of northern Algeria. It covers a total surface area of 4149 Km², located between 35°53'50 "and 36°54'50" North and meridians 2°24' 25 "and 4°6'5" East (Benali Khodja et al., 2022). It is approximately 70 km to the South East of Algiers. It is bordered to the north by the Mediterranean Sea and the Algerian coastal watershed, to the southwest by the Cheliff watershed, to the southeast by the Chott Hodna watershed and to the east by the Soummam watershed (Fig.1).

The northern part of the catchment area (Baghlia station) is characterized by an average annual temperature of about 17.7°C, while in the southern part of the catchment area (Beni Slimane station) the average annual temperature is about 14°C.

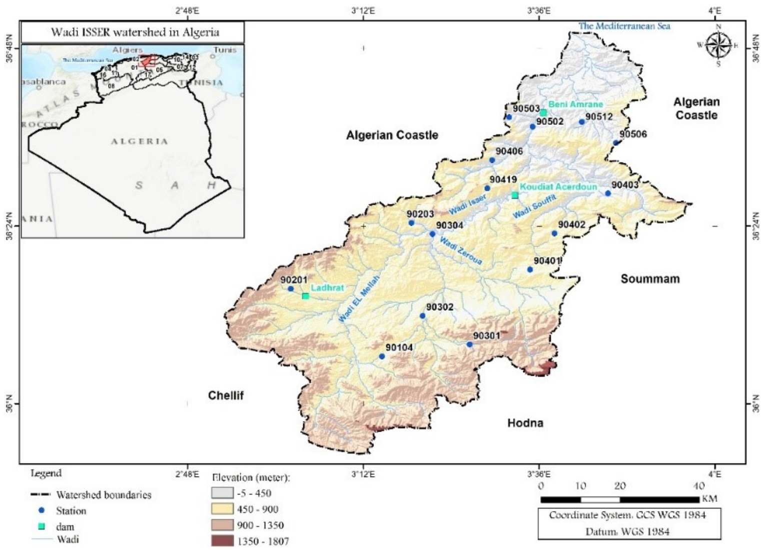

Figure 1: Geographical situation of the Isser wadi watershed

Data

The basic rainfall data set comes from the National Agency of Hydraulic Resources of Blida (NAHR). The study variable is the annual rainfall for the period 1973 to 2016. The location of stations allows a homogeneous coverage of the study area. We proceeded to fill the gaps in the chronological series using the Multiple Monte Carlo Markov Chain Interpolation (MCMC) method (Benali Khodja et al., 2022). Table 1 presents the main characteristics of the rainfall data series of the studied stations.

Table 1: Characteristics of rain gauge stations (NAHR)

Stations	Code	Latitude (DMS)	Longitude (DMS)	Elevation (m)	Observation period	Mean	CV (%)
Souagui	090104	36°06'35.142″ N	3°14'32.429″ E	810	1973-2016	313	23.3
EL Omaria	090201	36°15'43.144″ N	3°02'4.809" E	790	1973-2016	475.9	25.7
Tablat DRS	090203	36°24'38.039" N	3°18'32.750" E	450	1973-2016	584.5	25
Djouab	090301	36°08'13.529" N	3°26'33.302" E	825	1973-2016	504.8	34
Beni Slimane	090302	36°12'6.201" N	3°20'5.061” E	600	1973-2016	387.7	21.5
Pont de la Traille	090304	36°23'6.240" N	3°21'28.643" E	370	1973-2016	479.9	24.7
Khebouzia	090401	36°18'20.390" N	3°34'48.197" E	720	1973-2016	428.6	38
Souk El Khemis	090402	36°23'12.632"N	3°38'6.132" E	782	1973-2016	525.8	25
Djebahia	090403	36°28'35.201" N	3°45'23.958" E	320	1973-2016	615.2	26.7
Tazerout	090406	36°33'8.605" N	3°29'34.341" E	520	1973-2016	780.5	26.3
Bsibsa	090419	36°29'16.793" N	3°28'57.845" E	820	1973-2016	708.6	21.2
Lakhdaria Gorges	090502	36°37'37.285" N	3°35'7.193" E	50	1973-2016	708.9	25.3
OuledBouhaddada	090503	36°38'53.280" N	3°31'56.758" E	400	1973-2016	776	24.8
Tizi Ghenif	090506	36°35'25.179" N	3°46'29.833" E	390	1973-2016	739.5	22.8
Chabet El Ameur	090512	36°38'16.337" N	3°41'50.303" E	235	1973-2016	705.4	23

In our study area, the coefficient of variation is relatively low; it varies from 21.2% at the Bsibsa station to 38% at the Khebouzia station. The study area presents an interannual variability with averages varying between 313 mm and 780 mm (Fig.2).

It could be noted that the coefficient of variation is characterized by a strong fluctuation. It allows us to appreciate the degree of variability in a series and the dispersion of values in relation to the average.

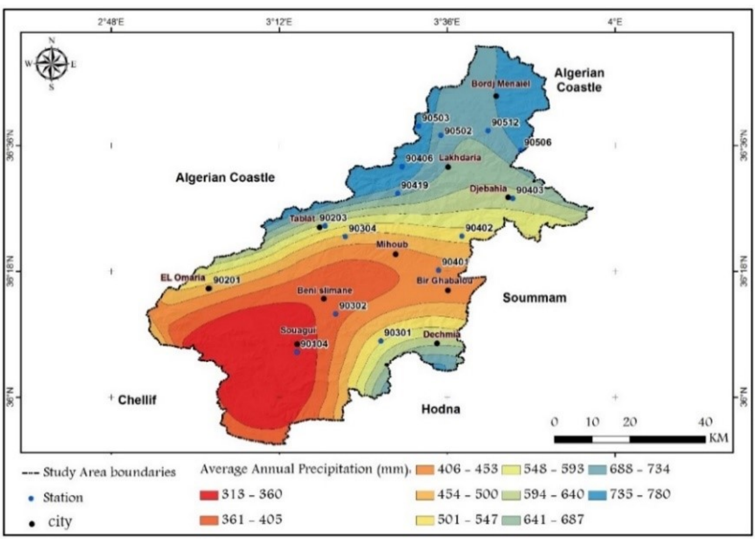

Figure 2: Spatial distribution of average annual rainfall in the Isser Watershed

METHODOLOGY

Drought characterization methods

Standardized precipitation index

The Standardized Precipitation Index (SPI) was developed to characterize precipitation deficits for a given period (Mckee et al., 1993).

$$SPI = (Pi - P_m) / \delta$$

SPI: Rainfall Index,

Pi: is the cumulative rainfall for a year i;

Pm: the mean of the annual rainfall observed for a given series;

δ: the standard deviation of the observed annual rainfall for a given series.

Table 2: Classification of drought in relation to the value of the Standardized Precipitation Index (SPI) (McKee et al., 1993)

SPI Classes	Drought Severity
SPI > 2	Extremely wet
1 < SPI < 2	Very wet
0 < SPI < 1	Moderately wet
- 1 < SPI < 0	Moderately dry
-2 < SPI < -1	Severely dry
SPI < -2	Extremely dry

The rainfall deficit index

The rainfall deficit index or the best-known Recognition Drought Index "RDI" which was established in 2005 (Tsakiris and Vangelis, 2005) and published in 2007 (Tsakiris et al, 2007). This Index allows displaying and calculating the number of deficit years and their alternation. A year is considered wet if the index is positive and dry if it is negative. It is expressed by the following formula:

$$RDI (\%) = (Pi - Pm)/Pm) \times 100$$

Where:

RDI: Rainfall Deficit Index (in percent);

Pi: annual rainfall (in mm);

Pm: average rainfall (in mm).

Drought index

The drought index (DI) is used to estimate the annual rainfall deficit. This deviation from the average is the difference between the annual rainfall Pi and the average annual rainfall of the series according to the formula:

$$DI = Pi - P$$

The index is positive in wet years and negative in dry years.

Interpolation technique

For the cartographic representation of the drought index, we used the Inverse Distance Weighting (IDW) interpolation method with the open-source software Qgis 3.10.12–1. The latter is a deterministic interpolation method that is suitable as a local interpolation method (Cavus and Akso., 2019 ; Zerouali et al., 2021).

In this method, the estimated value is determined using the weighted average of the points closest to the reference point.

The closest points with known values are more influenced than the furthest points. The estimated values are calculated according to the equation:

$$\hat{Z}(X_0) = \frac{\sum_{i=1}^{N}\left(\frac{Z(X_i)}{D_{x_0}}\right)}{\sum_{i=1}^{N}\left(\frac{1}{D_{x_0}}\right)}$$

Where:

$Z(X_i)$ is the value measured at the location,

D_{X0} is the distance between the value of the known point and the estimated point,

$\hat{Z}(X_0)$ is the estimated value at location X_0,

and N is the number of measured values.

RESULTS AND DISCUSSION

Temporal evolution of drought by climate indices

Standardized Precipitation Index SPI

To study the interannual variability of the rainfall regime, the distribution of wet and dry years over the period 1973-2016 is analyzed.

The previously defined rainfall index (SPI) is used. By following the evolution of the SPI for all stations (Table 3), the standardized rainfall index shows a situation dominated by moderate drought.

Table 3: Frequency of rainfall years according to the Standardized Precipitation Index (SPI)

Stations	Extremely wet	Very wet	Moderately wet	Moderately dry	Severely dry	Extremely wet	Total
Souagui	1	3	18	18	2	1	43
EL Omaria	0	9	8	19	7	0	43
Tablat DRS	1	4	18	15	5	0	43
Djouab	2	3	14	19	4	1	43
Beni Slimane	0	5	15	17	5	1	43
Pont de la Traille	0	7	15	16	4	1	43
Khebouzia	0	9	8	20	6	0	43
Souk El Khemis	0	10	9	17	7	0	43
Djebahia	1	6	16	15	4	1	43
Tazerout	1	5	15	16	5	1	43
Bsibsa	0	8	15	14	4	2	43
Lakhdaria Gorges	1	5	16	15	4	2	43
OuledBouhaddada	1	5	14	17	4	2	43
Tizi Ghenif	1	7	12	17	5	1	43
Chabet El Ameur	2	5	16	19	0	1	43

The graphic illustration of the standardized precipitation index, for the two selected stations Beni Slimane and Djebahia considered as reference stations (less incomplete), has made it possible to highlight two very distinct periods; a first dry period and a second wet period (Fig.3 and Fig. 4).

The rainfall series for these two selected stations is characterized at the Beni Slimane station by seventeen years of average drought and fifteen years of average humidity. The year 2001 experienced a severe drought (P= 194.7 mm) while the year 2003 was characterized by extreme humidity with an evaluated rainfall of 554.4 mm.

For the Djebahia station, it is characterized by sixteen years of average drought and fifteen years of average humidity, like the previous station, the station experienced a severe drought in 2001 evaluated at 254.3mm, while the year 2010 is marked by extreme humidity, that is to say a remarkable rainfall return, which reached a rainfall of 1012.5mm.

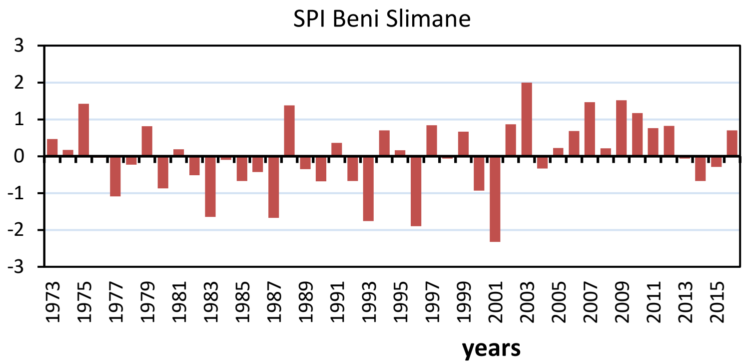

Figure 3: Standardized Precipitation Index (SPI) during the period 1973-2016 for Beni Slimane station

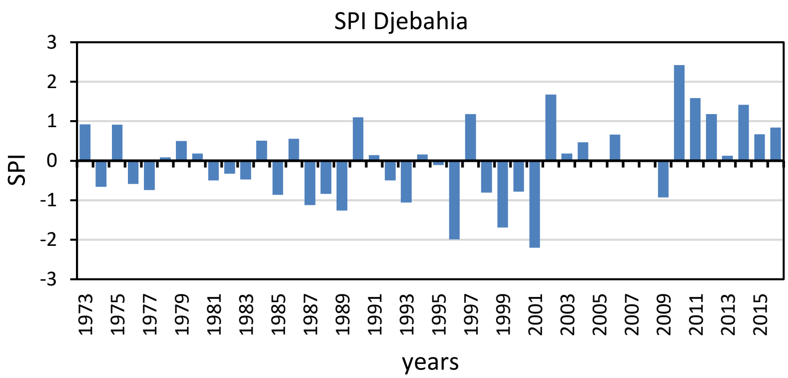

Figure 4: Standardized Precipitation Index (SPI) during the period 1973-2016 for Djebahia station

Rainfall deficit index

The rainfall deficit index made it possible to estimate the point variation of rainfall in relation to the normal. The most important deficit recorded during the whole observation period is - 49.7% at the Beni Slimane station and - 58.7% at the Djebahia station (Fig. 5 and Fig. 6).

The rainfall deficit is more important in number of successive years from 1982 to 1987 and from 1989 to 2001 with some alternation of moderately wet years (<20%) for Beni Slimane station. While for Djebahia, the rainfall deficit is remarkable from 1981 to 1989 with some oscillations of wet years that do not exceed 20%, on the other hand from 1998 to 2001 the drought is remarkable.

Excessive rainfall in Beni Slimane is observed in: 1975, 1988, and 2002 to 2012, i.e., a decade marked by excessive humidity, where the maximum rainfall reaches 43% in 2003 and thus a pronounced rainfall return. At Djebahia, surplus years were observed in 1973, 1975, 1990, 1997, and from 2002 to 2016 where the maximum rainfall is 64.6% in 2010. In total, 14 years of significant rainfall marked by the return of the wet phase, with the exception of 2009, when a slight deficit of -25% was noted.

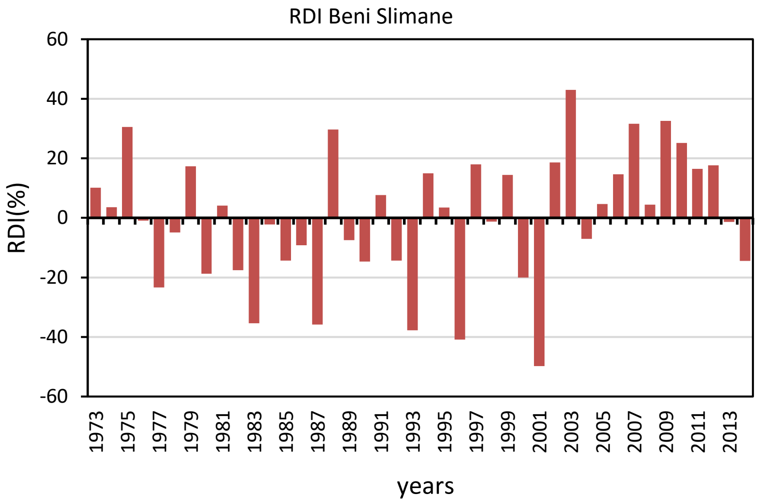

Figure 5: Rainfall Deficit Index (RDI %) during the period 1973-2016 "Beni Slimane station"

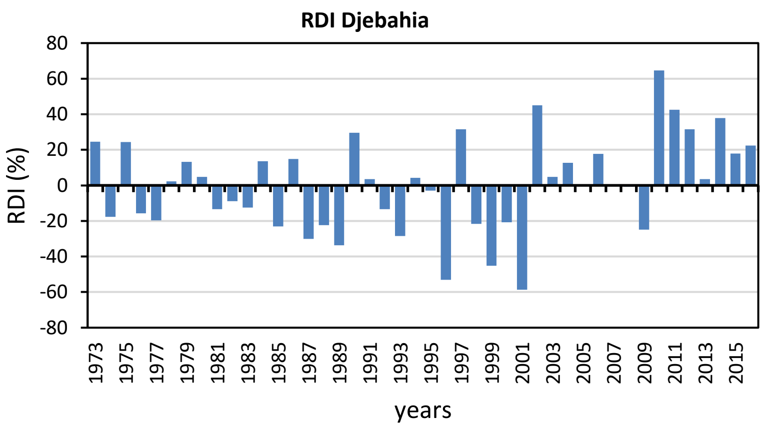

Figure 6: Rainfall Deficit Index (RDI %) during the period 1973-2016"Djebahia station"

Drought index DI

The assessment of the degree of droughts is obtained by calculating the index of deviation from the mean. The analysis of Figs. 7 and 8 highlighted the presence of light to moderate drought observed in the 1973-2016 rainfall series for both stations.

The drought episodes are moderately long, ranging from three to seven consecutive years at Beni Slimane and from three to five years at Djebahia.

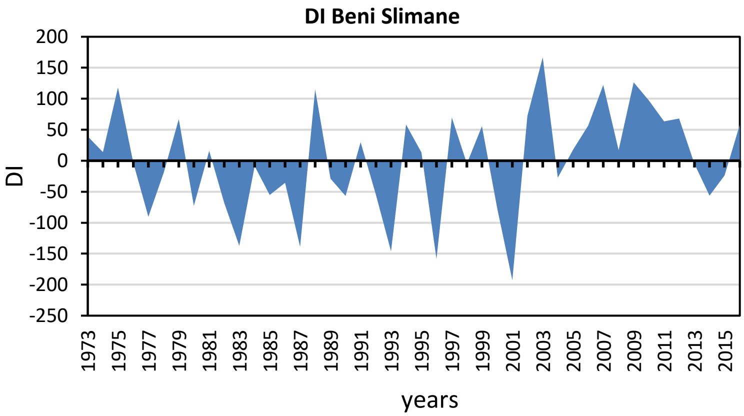

Figure 7: Drought index during the period 1973-2016 "Beni Slimane station"

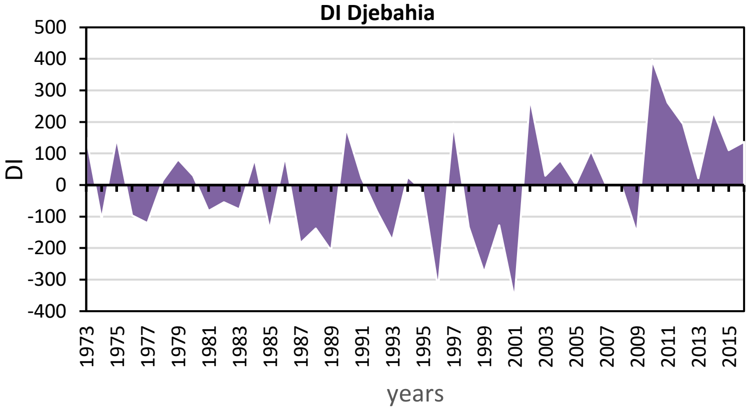

Figure 8: Drought index during the period 1973-2016 "Djebahia station"

The rainfall analysis during the period 1973-2016 through the drought indices "SPI", "RDI" and "DI" revealed that the region experienced a significant rainfall deficit during the 1970s which persisted until the year 2002 with remarkable peaks. Extremely severe drought types characterize these peaks.

These results confirm the research conducted by several researchers for northern Algeria from west to east (Ghenim and Megnounif., 2011; Merabeti et al., 2016 ; Bouguerra and Benislimane., 2017 ; Mrad et al., 2019 ; Derdous et al., 2020 ; Achite et al., 2021 ; Zerouali et al., 2021).

Meddi and Humbert (2000) found from a study on drought that a rainfall deficit appeared from 1970 and still persists today. This deficit generates a major economic and social problem, given the increasing pressure on water resources (Mehta et al., 2021). However, the indices have shown not only rainfall deficits over the period 1973-2002, but also the appearance of a much more humid phase which will be in the process of manifesting and thus an increase in rainfall.

Spatial evolution of drought

For a better appreciation of this phenomenon and more particularly of the SPI described previously, spatial variability maps of drought intensity during the dry cycle (1973-2002) and the wet cycle (2003-2016) were generated in a GIS environment (with the open-source software Qgis 3.10.12–1). The maps are shown in Figs. 9 and 10 respectively.

The map representation of the SPI during the period 1973-2002 indicates that the entire basin is dominated by moderate drought conditions.

SPI values varying from -0.31 to -0.21 cover more than half of the total area, occupying the central and northern parts of the basin.

The highest values between -0.42 and -0.31 were observed at the south-eastern limits of the basin which can be considered as a more or less arid part, particularly around Bir Ghebalou and Dechmia where the dryness is more accentuated compared to the whole study area.

However, the southern part of the basin at Souagui recorded SPI values ranging from -0.01 to 0.09 which implies a less important drought than those recorded in the other parts of the basin.

During the period 2003-2016, the SPI map shows the prevalence of moderate wet conditions covering about 90% of the basin with values ranging from 0.02 to 0.9. The SPI decreases spatially from north to south and from east to west. This is a reversal of the previous period when positive values were recorded, approaching wet conditions.

On the other hand, there is a moderate drought in the southern part of the basin where the SPI varies from -0.2 to -0.02 and thus towards moderate drought conditions compared to the previous situation.

It can be said that the spatial interpolation carried out over the two dry (1973-2002) and wet (2003-2016) periods illustrates a well-contrasted spatial variability and confirms the previously calculated results.

The alternation of dry and wet sequences observed has just affirmed a rainy return; a similar and comparable observation already established by different works (Nouaceur., 2011; Khoualdia et al., 2014 ; Nouacer and Laignel., 2015 ; Nouaceur and Murărescu., 2016 ; Regad and Tatar., 2019 ; Benali Khodja et al., 2022). This finding is in line with an increase in the frequency of intense rainfall events, which likely have an effect on the amplification of runoff and thus slope erosion.

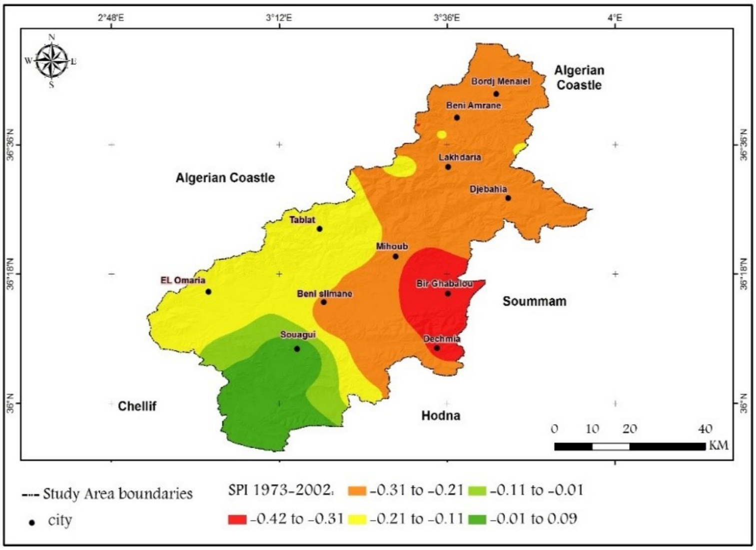

Figure 9: Spatial variability of the SPI (1973-2002)

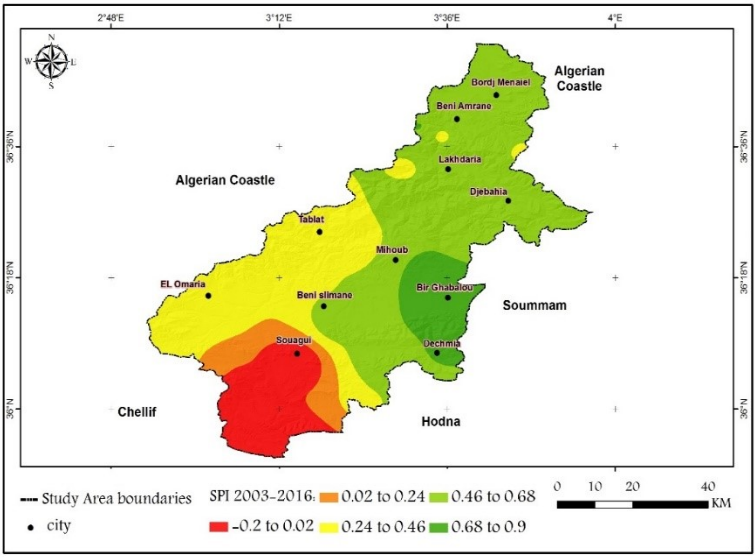

Figure 10: Spatial variability of the SPI (2003-2016)

CONCLUSION

At the end of this work, we conclude that this study focused on the analysis of the spatio-temporal evolution of meteorological droughts in the Isser wadi watershed over a period from 1973 to 2016 based on the calculation and analysis of drought indices.

This watershed has a large surface area (4149Km²) drained by major wadis (wadi Mellah, wadi Zeroua and mainly wadi Isser), with hydraulic structures (Ladrat dam, Koudiet Acerdoun and Beni Amrane), and vast agricultural land (mainly cereal and fodder crops which occupy 80% of the total surface area of the basin), where climate change and particularly the drought has a direct impact on water and agricultural activities.

This study, which is based on the calculation of a number of indices, has allowed us to realize the extreme variability of rainfall. We note that the Isser wadi watershed has been affected by alternating dry and wet periods over the period from 1973 to 2016. The intensity of the drought during the studied period, which is organized in a dry cycle (1973-2002), deduces the severe and long-lasting character of the climatic drought observed during this period, followed by a wet cycle (2003-2016) where it highlights the return to a rainy episode.

The spatial study of drought conducted in a GIS environment highlighted the strong spatial component of recent droughts, which is mainly related to the high spatio-temporal variability of precipitation in the Isser wadi watershed.

Declaration of competing interest

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.

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