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DETERMINING THE IMPACTS OF CLIMATE CHANGE ON SPATIO-TEMPORAL PATTERNS OF METEOROLOGICAL DROUGHT USING SPI: A CASE STUDY OF AIN DEFLA, ALGERIA

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Abstract

As an associated aspect of climate change, drought has become a severe challenge in different parts of the world, especially in regions where life depends on predominantly rain-fed agriculture. The Ain Defla study area is mostly agricultural land, most of its activity depends on rain. In recent years, droughts of varying impact and severity have affected crops. Therefore, this study aimed to identify and study the regions that are most vulnerable to drought in terms of time and space. Moreover, it provides a detailed picture of the drought in the region and finds appropriate solutions in the event of its return in the future. The Standardized Precipitation Index (SPI) and the deviation from the average (EM) were calculated annually for 38 years for 13 stations from 1981 to 2019 within the study area. GIS was used to compile digital maps to visualize the spatial distribution of rainfall (P) and the difference in rainfall (EM) and determine the aridity using SPI values within the region based on the statistical method of Kriging. The Ain Defla region was subjected to drought of varying intensity and impact during the years (1983, 1989 and 2000), which extends with a decreasing value from east to west. Some wet years were also observed (2013 and 2018). Most years were in the moderate category by 60%. It is possible to rely on rain-fed agriculture in the western regions, that were less prone to drought during the study period compared to the eastern part, an area where drought is stable on an ongoing basis.

Keywords: drought, meteorology, SPI, kriging, GIS, Ain Defla

INTRODUCTION

There is no longer any doubt that climate change is happening in the world. After several imbalances in the natural system, it is important to notice them (Moonen et al., 2002). The Intergovernmental Panel on Climate Change (IPCC) states that the earth's temperature has increased by 1.09 °C during recent years, and this change has helped increase the frequency of certain phenomena (floods, earthquakes, droughts, etc.) on an irregular basis (Abbes et al., 2018; Chen et al., 2021). For this reason, reference was made to the Mediterranean countries. Especially those in North Africa, were found to be the most affected by climate change which became the main cause of drought (Stringer et al., 2009; Hamed et al., 2018). Drought is among the world's costliest natural disasters (Hakam et al., 2022). It was monitored in Algeria and affected climatic conditions in the northwestern part, where the lowest precipitation rates were recorded at 100 mm/year (Medejerab and Henia, 2011; Meddi et al., 2013; Zeroual et al., 2019).

The IPCC has recognized meteorological drought as one of the most extreme weather phenomena (Porter et al., 2012; Achour et al., 2020). Therefore, it becomes necessary to take valuable measures to classify the drought's temporal and spatial characteristics. Many researchers of the phenomenon of meteorological drought based their research on the definition of the World Meteorological Organization (WMO), which relied on "rainfall" as a reference for its definition, where meteorological drought was considered "a decrease in rainfall for long periods" (Mellak and Souag-Gamane, 2020; Ballah, and Benaabidate, 2021). So, there needs to be a consistent scientific way to find, track, and measure aridity (Yihdego et al., 2019). Many indicators used worldwide have spread as essential tools in studying drought, which now helps in the early warning of drought and optimal contingency planning (Hayes et al., 2011; Dikshit et al., 2021)

Among the indicators for meteorological drought is the standard precipitation index, recommended by the World Meteorological Organization as the world's most widely used and most reliable (WMO, 2006). Also, the index of deviation from the average (EM) is seen as one of the most important ways to tell if there is too much or too little rain. If GIS is used, the performance of indicators becomes more efficient in terms of visualization (Niaz et al., 2022).

Some studies have relied on GIS to better represent SPI and EM in the form of maps to conclude the drought distribution (Wattanakij et al., 2006; Ha et al., 2014). With the reliance on the statistical approaches, kriging was the best interpolation method considered suitable for the spatial SPI index (Joly et al., 2008).

Drought has become more complex, especially in areas where people depend on rain-fed agriculture for their livelihood, within small areas where drought was formerly unknown (Saadi, 2015; Merabti et al., 2018). Especially since the study area is an agricultural area par excellence, it has become necessary to know the distribution of drought in these areas in terms of time and place and to take precautions required in the future. Furthermore, they are adopting new methods for cultivating rain-fed crops in the study area and knowing the areas prone to drought and the areas least affected.

DATA AND METHODS

Study Area

Ain Defla (36°15'55"N, 1°58'13"E) is located in the middle of Algeria's west, about 145 km from the capital. It is geographically confined to five provinces (wilayat); Tipaza in the north, Blida, and Medea in the northeast, Tissemsilet in the south, and Chlef in the west (DSA, 2015).

It covers an area of 4544.28 km² (Fig. 1) and the area of agricultural land represents approximately 51.85% of the total area (Gheraba et al., 2019). This zone has a semi-arid Mediterranean climate with a continental feature of an annual rainfall of 500–600 mm. It is located between two mountain ranges: Dahra-Zaccar in the north, with a height between 700 and 1576 meters, and Ouarsenis in the south, with a height of 1700 meters. In the center appears a basin-shaped plain that crosses the Chilef valley from east to west (ANDI, 2014).

Data

Climatic data from satellites has been relied upon because it is good enough to provide data in places without meteorological stations (Chandler et al., 2010; Moeletsi & Walker, 2012). This data has become a substitute and complementary to traditional ground station data (Bai et al., 2010), where annual rainfall data were obtained and extracted (Table 1) from the national aeronautics and space administration (NASA) power dataset. This dataset has the "accuracy and similarity of data from traditional meteorological stations". It has the advantage of having global spatio-temporal coverage (Ndiaye et al., 2020). It provides data from 1981 onwards that is always up to date and can be accessed from the website: https://power.larc.nasa.gov/data-access-viewer. Satellite data can be the best alternative to ground monitoring stations, especially in areas without no ground-monitoring stations. The study area is the most important example of this, as it does contain has one ground monitoring station over a vast area, and even the climatic data of this station has gaps. Therefore, the use of satellites becomes imperative and the data extracted from the satellites is very similar to the data from the ground stations.

Standard Precipitation Index (SPI)

The standard precipitation index has been proposed by McKee et al. (1993) to estimate the rainfall deficit for a different period (e.g., weekly, monthly and yearly). In 2009, the World Meteorological Organization recommended its use to characterize droughts worldwide to be the indicator for tracking and meteorological monitoring of drought (Ouatiki et al., 2019). Due to its simplicity and ease of use, the standardized precipitation index is classified as an effective indicator for

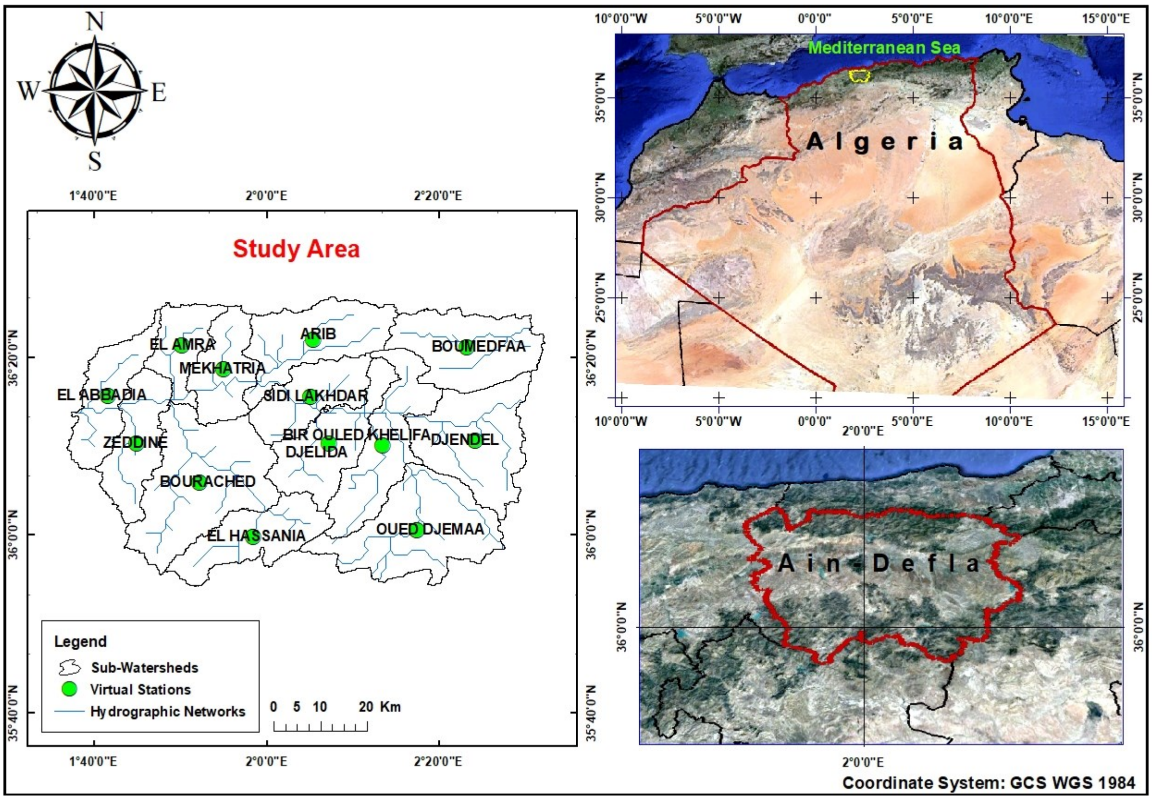

Fig. 1 Geographical location of Ain Defla region

Table 1 Rainfall stations selected for study (in Nord Sahara 1959 / UTM zone 31N)

Sub-watersheds	Surface (m^2)	Stations	Latitude (m)	Longitude (m)	Altitude (m)	Average annual rainfall (mm)
El Abadia	219101.6	ST 01	382722.6	4013347.9	170.2	502.0
Zeddine	226116.7	ST 02	387475.1	4003358	236.2	495.4
El Amra	152995.6	ST 03	395676.6	4023634.3	526.5	618.6
Mekhatria	198586.7	ST 04	402883.9	4018576	334.9	595.2
Bourached	527801.3	ST 05	398428.7	3995073.8	485.5	520.2
El Hassani	254368.0	ST 06	407589.9	3983677.6	584.7	543.8
Djelida	268567.9	ST 07	420963.4	4003010.2	342.5	570.5
Sidi Lakhdar	221414.0	ST 08	417766.6	4012797.3	245.3	598.6
Arib	310517.1	ST 09	418405.5	4024704.5	625.7	711.9
Bir Ouled khelifa	315177.3	ST 10	430324.8	4002434.8	315.8	590.9
Djendel	380279.2	ST 11	446413.9	4003482.7	379.1	605.6
Oued Djemaa	452905.2	ST 12	436143.1	3984900.8	551.7	567.9
Boumedfaa	332375.6	ST 13	445083.1	4022730.1	494.8	718.3

determining periods of rain and drought (Hamlet et al., 2007; Negreiros et al., 2010). This indicator is calculated by the following formula (1):

$$SPI = \frac{(X_i - X_m)}{S} \quad (1)$$

Xi: rain period i;
Xm: average rain during the period studied, reference period (1 year);
S: standard deviation of the series on the considered time scale.

SPI is calculated with one type of climatic data (rainfall), which converts it into numerical values that express the cases of drought (Daksh et al., 2018; Tigkas et al., 2022). It is defined according to seven categories that define the type of drought (Table 2), ranging from very wet to very dry. Positive SPI values indicate above-average rainfall (wet period), while negative values indicate below-average rainfall (dry period) (McKee et al., 1993).

The deviation from the average Index (EM)

The difference in rainfall (EM) is the best indicator for determining the water deficit on the annual scale. It represents the difference between the average rainfall during the year (Xi) and the annual rate of rainfall over at least 30 years (Xm), and it is expressed by the following equation (2):

$$EM = X_i - X_m \quad (2)$$

The positive difference expresses wet years or surplus, and the negative difference is an expression of water deficit or dry years (Jouilil et al., 2013).

Table 2 Classification of drought sequences on SPI

SPI value	Drought category	Symbols
2.0 and above	Extremely wet	E-H
1.5 to 1.99	Very wet	S-H
1 to 1.49	Moderately wet	M-H
0.99 to -0.99	Near to normal	Normal
-1.49 to -1	Moderate drought	S-M
-1.99 to -1.5	Severe drought	S-S
-2.0 and less	Extreme drought	S-E

Spatial interpolation: Ordinary Kriging

Kriging has been considered the most effective interpolation method for forecasting hydrological and meteorological drought (Yuan et al., 2016). It was first used by mining engineer Krige (1951) from South Africa, and it was adopted and used by Matheron (1962) at the center for geographical statistics in Paris and the soviet meteorologist Gandin (1963). There are different types of kriging: simple kriging, ordinary kriging, universal kriging, co-kriging, indicator kriging. We selected ordinary kriging for the intra-regional drought analysis and it is defined as follows:

$$Zo^* = \sum \lambda_i \; Z(x_i) \quad (3)$$

Zo^* : estimated value
$Z(x_i)$: known values at the location x_i
λ_i : weighting factor depending on the distance and direction.

Kriging relies on a semivariogram function to describe the general relationship between the known values according to their mutual distance (Curran, 1988; Katipoğlu et al., 2021). For this research the spherical model was fitted through the data (Kumar et al., 2016). It is expressed by the following equation:

$$\Upsilon(h) = c\left(\frac{2}{3}\frac{h}{a} + \frac{1}{2}\frac{h^3}{a^3}\right) \quad (4)$$

c: the sill (dimensionless like SPI)
h: distance between experimental points (in meters)
a: the range (linear dimension in meters)

The variables included in the composition of the equation form the semivariogram parameters according to Figure 2.

Application

Within the GIS program, the study area was divided into 13 sub-watersheds based on the entire valleys to obtain points representing meteorological stations within each watershed. This method was based on the lack of sufficient ground monitoring stations within the area.

In order to download the climatic data, points with X, Y, Z geographic coordinates were identified within each water basin. These virtual stations ST01 … ST13 were selected to represent ground monitoring stations within each watershed.

Climatic data (annual rainfall) without gaps was downloaded on March 23, 2020, from the (NASA) power dataset website for 38 years from 1981 to 2019.

Using the ArcMap program, the annual values of rainfall during the study years are entered, in order to draw a map of the spatial distribution of rainfall within the region.

The rain deficit is calculated using the EM indicator formula, then the results are represented as a digital map that determines the distribution of the deficit and surplus years of Rainfall.

The rainfall data is entered into Excel to calculate the SPI value over the annual time period (reference period 1 year) during the study period from 1981 to 2019. After that, the SPI values are classified according to (McKee et al., 1993) to know the type of drought within each station and identify wet and dry years. After obtaining the SPI values, we can determine the spatial distribution of it within the study area by representing it in the form of digital maps, meaning wet and dry years.

We can get these maps by using the geostatistical method (Kriging) to represent the spatial distribution of the values SPI, EM and P themselves within the GIS of the study area and the location, spread and movement of drought as well as the water deficit.

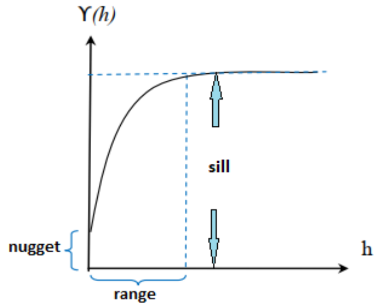

Fig. 2 Semivariogram parameters of the spherical model (Azouzi, 2003)

The indicators SPI and EM were used in the study of meteorological drought, and the agreement between them gives the obtained results more credibility and accuracy.

RESULTS

By analyzing the results of the SPI and based on the rainfall, the distribution of rain and the mean difference in rainfall, as well as the average distribution of SPI images (Figure 3, 4 and 5), were represented.

The type of drought in each station, the rate of rainfall, and the difference in rainfall were visualized in the maps compiled by interpolation using Kriging (Figure 6, 7, and 8). An evaluation of the percentages of dry years and wet years was carried out for each station, and the results are summarized in Table 3).

Observation of the annual distribution of rainfall over the study area during a period of 38 years showed that the weather conditions differ between dry and rainy in different years, as several rainy periods were recorded during several years (82-84-85-86-92-96-99-01-03-04-07-08-09-10-11-12-13-16-18), which had an average rainfall ranging from 575 to 1000 mm/year. Arib station and Bir Ouled khelifa well witnessed the highest rate of rainfall exceeding 900 mm/year.

Periods with of lack of rainfall with an average of 280 to 575 mm/year were observed in 81-83-87-88-89-90-91-93-94-95-97-98-00-02-05-06-14-15-17 and 19.

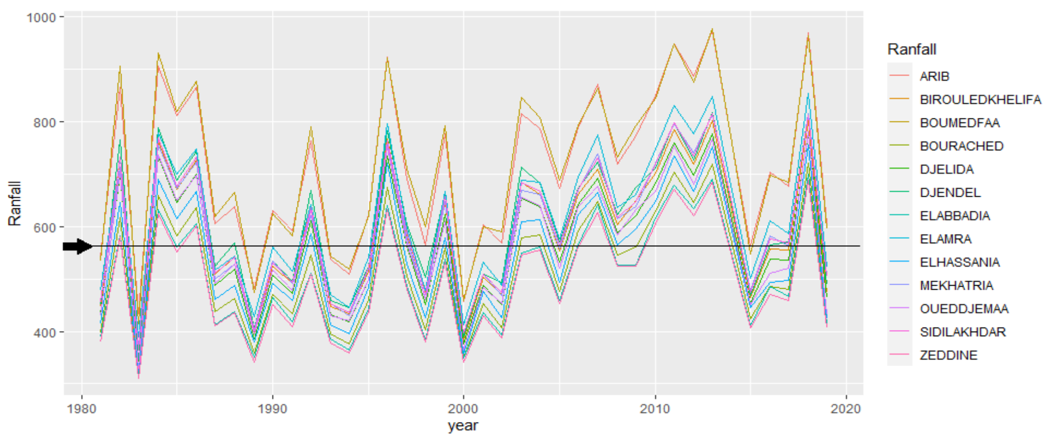

Fig. 3 Annual distribution rainfall (mm) for all stations of the study area during the years from 1981–2019

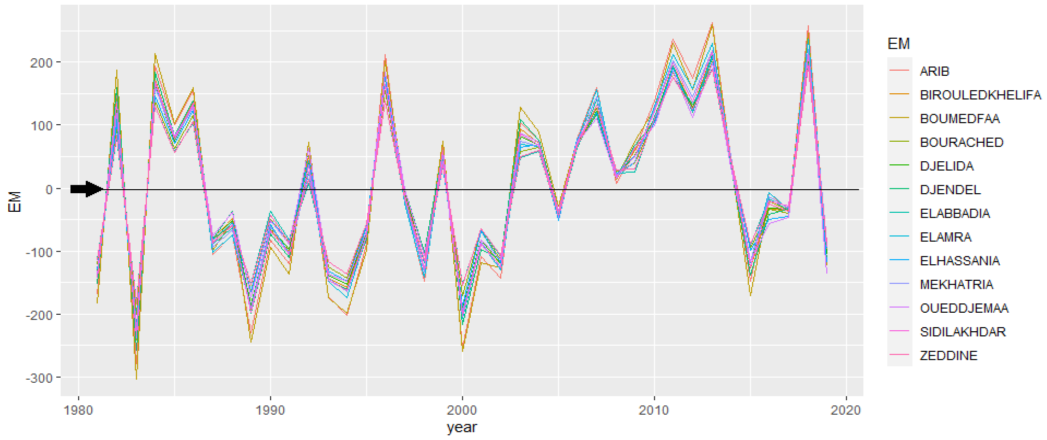

Fig. 4 Deviation from the long-term average rainfall (EM) for each year for the period 1981-2019

During the study period, with 930 mm 2013 was the year with the most rainfall, while 1983 was the driest year with only 330 mm.

The annual distribution of the mean rainfall difference (EM) is summarized in Figure 3 for each year during the period from 1981 to 2019. Rainy years, which are periods when rainfall rates are higher than normal with a range of 50 to 275 mm/yr was observed during the years 82-84-85-86-92-99-03-04-06-07-08-09-10-11-12-13- 14 and 18. Deficit years are the years in which the rainfall is less than normal (a decrease in precipitation). This decrease was determined ranging from -10 to -300 mm / year for each of the years 81-83-87-88-89-90 -91-93-94-95-97-98-00-01-02-05-15-16-17 and 19.

The year 2013 was the year with the largest increase in rainfall with a maximum value of 275 mm/year compared to the normal rate, and the year 1983 was the year with the largest decrease in rainfall with a value of -300 mm/year.

As for the annual distribution of SPI values over 38 years from 1981 to 2019, two climatic phases were observed in the SPI range determined by McKee et al. (1993): a wet phase ranging between 0 and 1.90 that happened during the years 82-84- 85-86-92-96-99-03-04-06-07-08-09-10-11-12-13-14 and 18, and a dry phase with a range of 0 to -2 in the years 81-83-87-88-89-90-91-93-94-95-97-98-00-01-05-15-16-17 and 19.

The years 2013 and 2018 were the wettest years in which the SPI value reached a maximum value of 1.90, while 1983 was the driest year with a value of -2.

It turns out that the eastern region has high rates of rainfall in the different years of study, with a decreasing trend towards the west. The stations of Arib and Sidi Lakhdar were the most important in the eastern region, which witnessed periods of very heavy rain compared to the stations of Bourached, Zeddine and Al-El Abadia on the western side.

Despite the limited extent of the study area and the proximity of the virtual meteorological stations to each other, the spatial variation of rainfall is evident in the different study areas.

The spatial distribution (EM) in the study period shows the presence of wet years (82-84-85-86-92-96-99-03-04-06-07-08-09-10-11- 12-13-18), in which the rate of rainfall varied with irregular increases from year to year. The eastern region was the most important region that witnessed high rates of increase during most years, especially the Djendel and Arib stations, and this rate was decreasing towards the west.

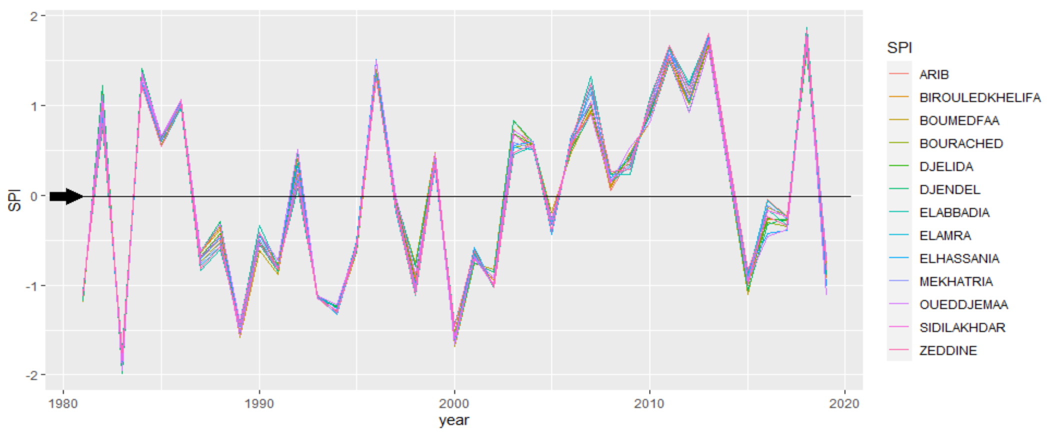

Fig. 5 Annual distribution of the standard rain index SPI for all stations of the study area during the years from 1981-2019

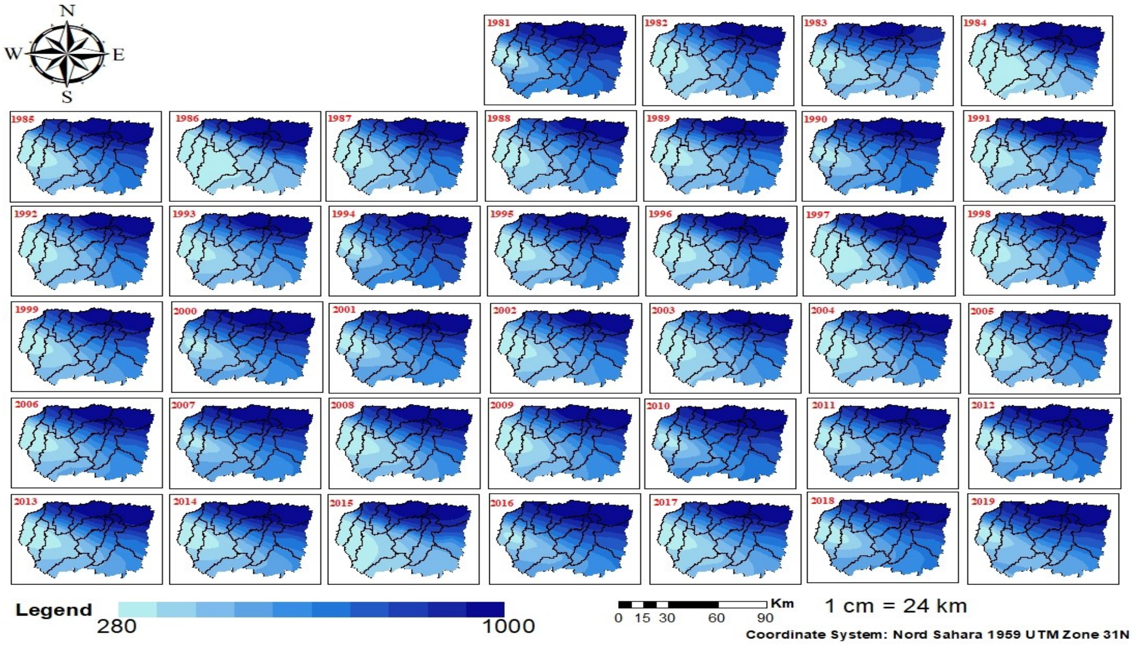

Fig. 6 Spatial distribution of rainfall over the study area during a period of 38 years (1981-2019)

The region also witnessed dry years in which rainfall was less than the normal rate and varied at different rates from year to year (81-83-87-88-89-90-91-93-94-95-97-98-00-01-02 -05-14-15-16-17-19). The eastern region was the most important region that experienced a strong lack of rainfall, especially at the stations of Djendel and Boumedfaa, and the situation becomes better towards the western side of the region.

For maps representing the spatial distribution of SPI values, with a range between -2 to 2, three periods were recorded that dominated the area during the 38 year study period:

(1) The dry phase that prevailed during the years (81-83-89-93-94-98-00-02) was at a different rate from year to year with SPI values from -1 to -2. The driest year in the region was in 1983. The highest SPI values are in the eastern region during most of the drought years, especially in Boumedfaa and Djendel stations, as SPI values decrease towards the west.

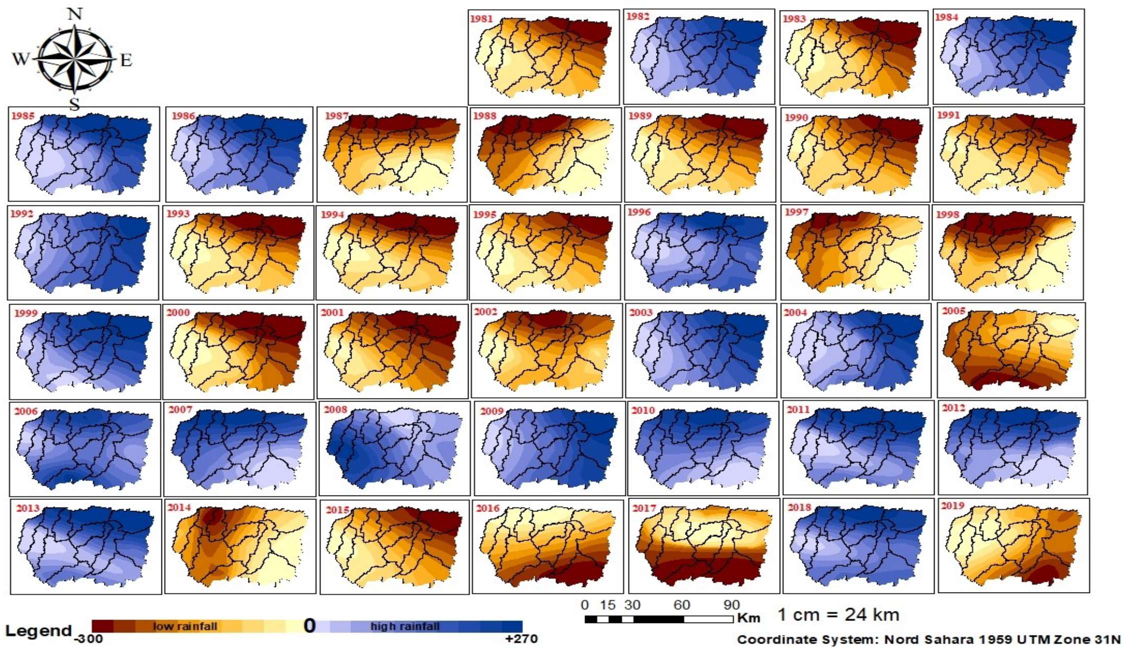

Fig. 7 Spatial distribution of a difference in rainfall (EM) from the normal rate in the study area during a period of 38 years (1981-2019)

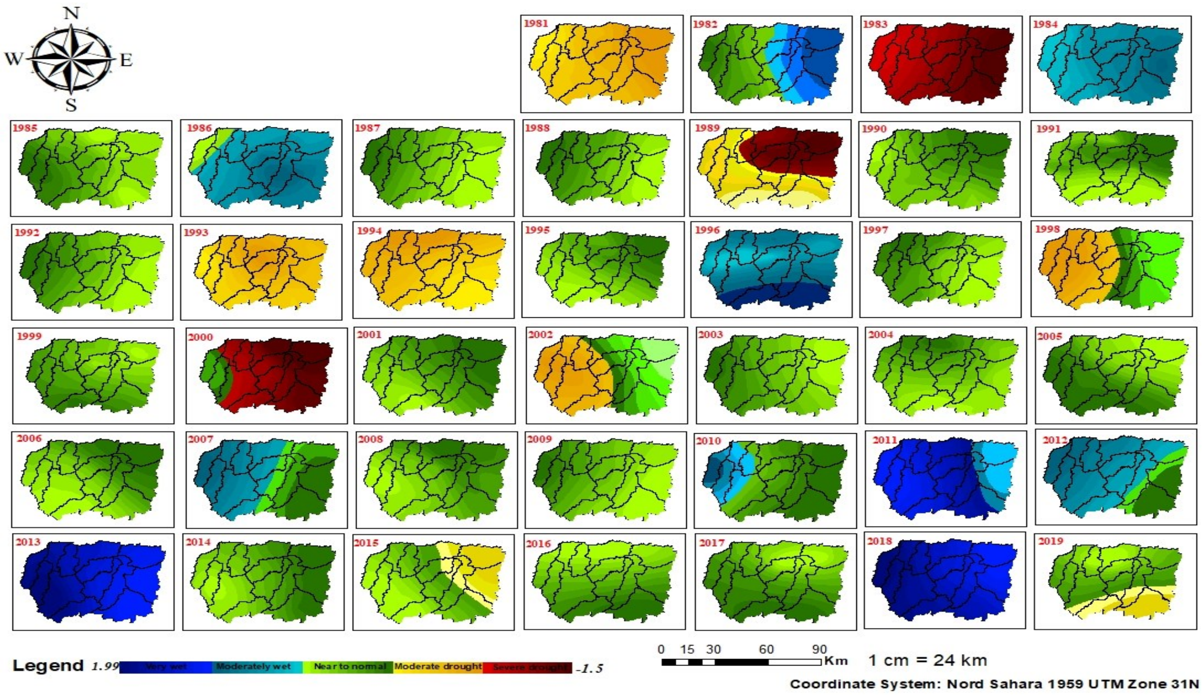

Fig. 8 Spatial distribution map of the Standard Precipitation Index (SPI) for each year in the period 1981-2019

(2) The normal period recorded during the years (87-88-90-91-95-97-99-01-03-04-05-06-08-14-15-16-17-19) with different SPI values of -1 to 1. The index values declined from the highest in the eastern region to the lowest in the western region.

(3) The last stage, when wet periods were witnessed during the years 82-84-86-96-07-10-11-12-13 and 18 at a different pace from wet to very wet on the SPI scale from 1 to 2 within the study areas. The highest value of the index was in the eastern province during most of the years, and Djendel and Boumedfaa were among the most prominent stations that witnessed great rates on the SPI scale. High humidity levels have been identified in the eastern regions and lower in the western regions during most years.

Table 3 shows the percentage (%) of years that witnessed the same categories of drought for the SPI within each station as well as the sum of the percentages for the following three categories: dry category: moderate drought + severe drought + extreme drought, wet category: moderately wet + very wet + extremely wet, moderate category: near to normal.

The percentages for the different drought categories show that extreme drought and extremely wet did not occur in the study area. At most stations the very wet category occurred in 5.13% to 10.2% of the years, except

Table 3 Percentage (%) of years that witnessed the same category of drought within each station from 1981 to 2019

Drought category	Extremely	Very	Moderately	Moderate	Moderate	Severe	Extreme
Stations		wet		Near to normal		dry | drought	
ST 01	0	7.69	12.8	58.9	17.9	2.56	0
ST 02	0	7.69	15.3	56.4	17.9	2.56	0
ST 03	0	7.69	10.2	61.5	15.3	5.13	0
ST 04	0	7.69	15.3	56.4	12.8	7.69	0
ST 05	0	7.69	12.8	58.9	15.3	5.13	0
ST 06	0	10.2	10.2	58.9	15.3	5.13	0
ST 07	0	7.69	15.3	61.5	7.69	7.69	0
ST 08	0	7.69	15.3	58.9	10.2	7.69	0
ST 09	0	7.69	15.3	61.5	7.69	7.69	0
ST 10	0	7.69	12.8	64.1	7.69	7.69	0
ST 11	0	5.13	12.8	64.1	10.2	7.69	0
ST 12	0	10.2	7.69	64.1	12.8	5.13	0
ST 13	0	5.13	15.3	61.5	10.2	7.69	0
Total rate (%)		20.91		60.55		18.54	

for stations ST06 and ST12, where it reached the largest percentage with 10.26%. The moderate category showed fluctuating percentages between 7.69% and 15.38%, with the highest percentage at stations ST04, ST07, ST08 and ST09, and the lowest percentage in station ST12. For the category near to normal, the values recorded within the region were between 56.4% to 64.1% at most stations, and this category represents the majority in terms of percentage within the study area. In the category of moderate drought, we find percentages in the range of 7.69% to 17.9%. The highest percentage was 17.95% at stations ST01 and ST02. In the severe drought category, the range of percentages was between 2.56% at stations ST04, ST07, ST09, ST11, and 7.69% at ST13. As for the categories prevailing in the total region, 60.55% of all years fell in the normal category, followed by 18.55% for the dry category, and 20.91% for the wet category.

DISCUSSION

Meteorological drought is a natural phenomenon resulting from a lack of rainfall in specific areas and over long periods. To mitigate and prevent drought, it is necessary to know its temporal and spatial characteristics with its severity and duration in any region of the world. Drought analysis is considered the best method for predicting and managing risks. It is a warning for politicians and decision-makers to find solutions and take the necessary decisions in the event of a recurrence of drought.

Therefore, the study area was chosen within the Mediterranean basin domain, which was classified as the global drought localization area, as drought was monitored in many locations in the basin, as indicated by most of the studies.

Several studies analyzed the drought locally and recognized its existence in northern Algeria in 1999. Drought is more severe in the study area's northwestern part, where the region experienced droughts during the years 89-90-91-92-94-99. The years 81-89 were Algeria's most water deficit years (Kettab & Ait Mouhoub, 2002; Zargar et al., 2011; Djellouli et al., 2016; Hallouz et al., 2020; Fellag et al). Ghenim & Megnounif (2013) stated that the period of drought that struck the region began in the eighties and continued until the end of the nineties. The drought period from 1986 to 2001 was determined by Kettab (2004) and Khezazna (2017) as well. The severe drought category was most influential in 1983 (Zerouali et al. 2021).

Various indicators have been used in several studies to monitor drought within the study area. In order to confirm the validity and accuracy of the results provided by the SPI index, with the determination of the drought situation in the northwest of Algeria, as well as its temporal stages. Djellouli (2016) used the Effective Drought Index (EDI) and SPI to monitor drought, which was recorded at high rates during the years 83 and 89. The agreement between the two indicators was good. Bougara (2018) conducted an experiment in order to find out the best indicator for measuring drought among four indices SPI, PN, DI and RAI on a scale (monthly, seasonal and annual). All the results indicated agreement between these indicators with a preference for the SPI indicator, and drought was identified within the region in the early eighties. As for the study conducted by Abbes (2018), he used the SPI index to determine the drought years (1987, 2000, 2006, and 2016). Then he used the NDVI index based on Landsat satellite images, in order to verify the accuracy of the results provided by SPI. These years witnessed a decrease in the vegetation cover caused by the drought. All of these studies used ground station data and were consistent with each other in terms of results. The study that we conducted using climatic data extracted from satellites indicated the same results and agreement with studies that relied on ground station data.

This study was conducted in the Mediterranean region on the northwestern outskirts of Algeria. After evaluating meteorological drought on an annual scale for 38 years, the SPI index was used to determine aridity's temporal and spatial characteristics and the EM index to determine the rainfall deficit.

It was unanimously agreed on severe drought periods that prevailed during the years 83-89-00-81-93-94-98-2002, where the percentage of dry years in categories (moderate drought, severe drought and extreme drought) reached 18.54%. It was distributed spatially according to SPI values, with the lowest value from the west at -1.5 to the highest value at -1.99 towards the east.

Wet years were monitored with a percentage of 20.61%. The two most notable wet years are 2013 and 2018, with minimum SPI values of 1.58 recorded in the western region and higher in the eastern region at a maximum value of 1.87. Despite this, the study area is dominated by moderate drought with a percentage of 60.55%.

After determining the years of drought and its spatial distribution according to the SPI index, calculating the EM index, and determining the years of deficit, it became clear that there is agreement between the two indicators in terms of the results that refer to the drought period and its distribution within the study area.

It can be said that the eastern region is the region most affected by the meteorological drought, especially in the stations of Boumedfaa and Djendel. although it is the region most exposed to rain with the highest rates and the largest surplus of rain compared to the western region, which had less rainfall and was less affected by drought, especially on the borders of each of the stations. The four were El Abadia, Zeddine, El Amra, and Bourached. Therefore, relying on rain-fed crops within the eastern region is not recommended in dry periods. It is better to use the western region for rain-fed agriculture during periods of drought to avoid its effects.

Satellite data remains the best alternative in areas without ground monitoring stations and data with time gaps, because it has a spatial coverage that includes all regions of the world, and its data enjoys continuity through time. On the other hand, this work is essential for assessing meteorological drought and its temporal and spatial characteristics and distribution in small areas. Selection of small spaces containing many stations that cover all of the study areas and that are close to each other allow us to accurately monitor rain and avoid large differences. For spatial interpolation using Kriging to be free of errors, it is important to use many immediate points, which reduces the error rate and increases the accuracy and credibility.

CONCLUSION

This study was conducted in an attempt to understand the phenomenon of meteorological drought within the Ain Defla region and to obtain the necessary information about the spatial distribution of drought and knowledge of wet and dry years, with the identification of the estimated deficit during drought periods, as well as to acquire knowledge of the rate of rain surplus during wet years, and all this to take measures necessary in the event of a recurrence of drought in the region.

We find that the study area is dominated by moderate drought in 60.5% of the studied years compared to 18.54% dry periods and 20.91% wet years. The years 1981, 1983 and 2000 were the driest, unlike 2013 and 2018, which were rainy and humid.

As for the spatial distribution, the eastern region was identified as the region most affected by meteorological drought, although high rates of precipitation were recorded there. The region shows the highest values on the SPI scale, compared to the western region, which was little affected by drought.

Although the eastern region is an agricultural region par excellence in humid periods, it is undesirable in dry periods, so the western region is better for rain-fed agriculture in dry periods. We can say that the meteorological drought within the region settles in the most humid places, and its intensity is high in these areas.

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REFERENCES

Abbes, M., Hammed, 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. *Mining Science*, 25, 85–113. DOI 10.5277/msc182507

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. *Journal of Earth System Science*, *129*(1), 1–22. DOI: 10.1007/s12040-019-1306-3

Agence National de Développement d'Investissement – ANDI. 2014. [National Investment Development Agency]. Annuaire Statistique de l'Algerie [Statistical Yearbook of Algeria] (in French with English summary). Online available at https://www.ons.dz/IMG/pdf/AnRes10-12No30.pdf

Azouzi, B., Schröter, J. 2003. Regionalisierung der Transmissivität mit Fuzzy-Kriging in der Region Mitidja (Algerien). *Grundwasser*, 8(4), 224–231. DOI: 10.1007/s00767-003-0003-x

Bai, J., Chen, X., Dobermann, A., Yang, H., Cassman, K. G., Zhang, F. 2010. Evaluation of NASA satellite-and model-derived weather data for simulation of maize yield potential in China. *Agronomy Journal*, 102(1), 9–16. DOI: 10.2134/agronj2009.0085

Ballah, A., Benaabidate, L. 2021. Assessing the performance of various meteorological drought indices in capturing historic droughts in the south of Algeria. *Arabian Journal of Geosciences*, 14(13), 1–11. DOI: 10.1007/s12517-021-07556-8

Bougara, H., Baba-Hamed, K., Borgemeister, C., Tischbein, B., Kumar, N. 2021. A comparative assessment of meteorological drought in the Tafna basin, Northwestern Algeria. *Journal of Water and Land Development*. 51, 78–93. DOI: 10.24425/jwld.2021.139018

Chandler, W. S., Hoell, J. M., Westberg, D., Whitlock, C. H., Zhang, T., Stackhouse Jr, P. W. 2010. Near real-time global radiation and meteorology Web services available from NASA. In *Proceedings of the Solar 2010 Conference (American Solar Energy Society), May,* pp. 18–22.

Chen, D., M. Rojas, B. H. Samset, K. Cobb, A. Diongue-Niang, P. Edwards, S. Emori, S. H. Faria, E. 7 Hawkins, P. Hope, P. Huybrechts, M. Meinshausen, S. K. Mustafa, G. K. Plattner, A. M. Tréguier, 2021. Framing, Context, and Methods. In: *Climate Change 2021: The Physical Science Basis. IPCC,* Online available at https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter01.pdf

Curran, P. J. 1988. The semivariogram in remote sensing: an introduction. *Remote sensing of Environment*, 24(3), 493–507. DOI: 10.1016/0034-4257(88)90021-1

Daksh, K., Kumari, V., Kumari, A., Mayoor, M., Singh, H. P., Mahapatra, S. 2018. Drought risk assessment in Vidarbha region of Maharashtra, India, using standardized precipitation index. *International Journal of Innovative Knowledge Concepts*, 6(10), 13–23. DOI: 10.13140/RG.2.2.15337.13922

Dikshit, A., Pradhan, B., Alamri, A. M. 2021. Long lead time drought forecasting using lagged climate variables and a stacked long short-term memory model. *Science of The Total Environment*, 755(2), 142638. DOI: 10.1016/j.scitotenv.2020.142638

Direction des Services Agricoles – DSA. 2015. Rapport annuelle des services Agricoles. [Annual report of agricultural services]. (in French with English summary). Online available at https://madr.gov.dz/wp-content/uploads/2022/04/SERIE-B-2016.pdf

Djellouli, F., Bouanani, A., Babahamed, K. 2016. Climate change: assessment and monitoring of meteorological and hydrological drought of Wadi El Hammam basin (NW-Algeria). *Journal of Fundamental and Applied Sciences*, 8(3), 1037–1053. DOI: 10.4314/jfas.v8i3.20

Djellouli, F., Bouanani, A., Baba-Hamed, K. 2016. Efficiency of some meteorological drought indices in different time scales, case study: Wadi Louza basin (NW-Algeria). *Journal of Water and Land Development*. 31, 33–41. DOI: 10.1515/jwld-2016-0034

Fellag, M., Achite, M., Walega, A. 2021. Spatial-temporal characterization of meteorological drought using the Standardized precipitation index. Case study in Algeria. *Acta Scientiarum Polonorum. Formatio Circumiectus*, 20(1), 19–31. DOI: 10.15576/ASP.FC/2021.20.1.19

Gandin, L. S. 1963. Objective analysis of meteorological field. *Gidrometeorologicheskoe Izdate'stvo.* 286.

Ghenim, A. N., Megnounif, A. 2013. Ampleur de la sécheresse dans le bassin d'alimentation du barrage Meffrouche (Nord-Ouest de l'Algérie) [Magnitude of the drought in the supply basin of the Meffrouche dam (north-west of Algeria)] (in French with English summary). *Physio-Géo. Géographie physique et environnement*, 7, 35–49. DOI: 10.4000/physio-geo.3173

Gheraba, L., Khaouane, L., Benkortbi, O., Hanini, S., Hamadache, M. 2019. Prediction of Climatic Parameters from Physicochemical Parameters using Artificial Neural Networks: Case Study of Ain Defla (Algeria). *Kemija u industriji: Časopis kemičara i kemijskih inženjera Hrvatske*, 68(7-8), 303–316. DOI: 10.15255/KUI.2019.004

Ha, H., Olson, J. R., Bian, L., Rogerson, P. A. 2014. Analysis of heavy metal sources in soil using kriging interpolation on principal components. *Environmental science & technology*, 48(9), 4999–5007. DOI: 10.1021/es405083f

Hakam, O., Baali, A., Ahouach, Y., Azennoud, K. 2022. Comparative evaluation of precipitation-temperature based drought indices (DIs): A case study of Moroccan Lower Sebou basin. *Kuwait Journal of Science*, 49(3), 1–25. DOI: 10.48129/kjs.13911

Hallouz, F., Meddi, M., Mahé, G., Ali Rahmani, S., Karahacane, H., Brahimi, S. 2020. Analysis of meteorological drought sequences at various timescales in semi-arid climate: case of the Cheliff watershed (northwest of Algeria). *Arabian Journal of Geosciences*, 13(6), 1–15. DOI: 10.7202/1065202ar

Hamed, Y., Hadji, R., Redhaounia, B., Zighmi, K., Bâali, F., El Gayar, A. 2018. Climate impact on surface and groundwater in North Africa: a global synthesis of findings and recommendations. *Euro-Mediterranean Journal for Environmental Integration*, 3, 1–15. DOI: 10.1007/s41207-018-0067-8

Hamlet, A. F., Lettenmaier, D. P. 2007. Effects of 20th century warming and climate variability on flood risk in the western US. *Water Resources Research*, 43(6), W06427, DOI: 10.1029/2006WR005099

Hayes, M., Svoboda, M., Wall, N., Widhalm, M. 2011. The Lincoln declaration on drought indices: universal meteorological drought index recommended. *Bulletin of the American Meteorological Society*, 92(4), 485–488. DOI: 10.1175/2010BAMS3103.1

Jouilil, I., Bitar, K., Salama, H., Amraoui, A., Mokssit, A., Tahiri, M. 2013. Sécheresse météorologique au bassin hydraulique OUM ER RBIA durant les dernières décennies. [Meteorological drought in the OUM ER RBIA hyduring the last decades.], (in French with English summary). *LARHYSS Journal.* 12, 109–127. P-ISSN 1112-3680/E-ISSN 2521-9782

Katipoğlu, O. M., Acar, R., Şenocak, S. 2021. Spatio-temporal analysis of meteorological and hydrological droughts in the Euphrates Basin, Turkey. *Water Supply*, 21(4), 1657–1673. DOI: 10.2166/ws.2021.019

Kettab, A., Ait Mouhoub, D., Ouarda, T., Bobbee, B. 2004. Contribution à l'étude du phénomène de la sècheresse sur les régions littorales de l'Algérie. [Contribution to the study of the phenomenon of drought in the coastal regions of Algeria], (in French with English summary). In: *CMU-RMEI Meeting on Innovation as a tool for a sustainable development within the Mediterranean, Foggia (Italy)* (Vol. 14)

Kettab, A., Ait Mouhoub, D. 2002. L'eau objet de toutes les convoitises. [Water object of all desires], (in French with English summary). In: *Colloque international sur l'eau, Chlef* (Vol. 5, No. 06)

Khezazna, A., Amarchi, H., Derdous, O., Bousakhria, F. 2017. Drought monitoring in the Seybouse basin (Algeria) over the last decades. *Journal of water and Land Development*, 33, 79–88. DOI: 10.1515/jwld-2017-0022

Krige, D. G. 1951. A statistical approach to some basic mine valuation problems on the Witwatersrand. *Journal of the Southern African Institute of Mining and Metallurgy*, 52(6), 119–139. DOI: 10520/AJA0038223X_4792

Kumar Adhikary, S., Muttil, N., Gokhan Yilmaz, A. 2016. Ordinary kriging and genetic programming for spatial estimation of rainfall in the Middle Yarra River catchment, Australia. *Hydrology Research*, 47(6), 1182–1197. DOI: 10.2166/nh.2016.196.

Matheron, G. 1962. Treatise on Applied Geostatistics. [Traite de Geostatistique Appliquee]: Memoires du Bureau de Recherches Geologique et Minieres, vd. 14: Editions Technip. Paris, 333 p.

McKee, T. B., Doesken, N. J., Kleist, J. 1993. The relationship of drought frequency and duration to time scales. In: *Proceedings of the 8th Conference on Applied Climatology*, 17(22), 179–183.

Mellak, S., Souag-Gamane, D. 2020. Spatio-temporal analysis of maximum drought severity using Copulas in Northern Algeria. *Journal of Water and Climate Change*, 11(S1), 68–84. DOI: 10.2166/wcc.2020.070

Medejerab, A., Henia, L. 2011. Variations spatio-temporelles de la sécheresse climatique en Algérie nord-occidentale. [Spatio-temporal variations of climatic drought in north-western Algeria] (in French with English summary). *Courrier du Savoir scientifique et technique*, 11(11), 71–79.

Meddi, M., Toumi, S., Mehaiguene, M. 2013. Hydrological drought in Tafna basin-Algeria. In: International Conference on Environmlental Science and Technology. Online available at https://www.academia.edu/23053918/Hydrological_Drought_in_Tafna_Basin_Northwest_of_Algeria

Merabti, A., Martins, D. S., Meddi, M., Pereira, L. S. 2018. Spatial and time variability of drought based on SPI and RDI with various time scales. *Water resources management*, 32(3), 1087–1100. DOI: 10.1007/s11269-017-1856-6

Moeletsi, M. E., Walker, S. 2012. Evaluation of NASA satellite and modelled temperature data for simulating maize water requirement satisfaction index in the Free State Province of South Africa. *Physics and Chemistry of the Earth, Parts A/B/C*, 50, 157–164. DOI: 10.1016/j.pce.2012.08.012

Moonen, A. C., Ercoli, L., Mariotti, M., Masoni, A. 2002. Climate change in Italy indicated by agrometeorological indices over 122 years. *Agricultural and Forest Meteorology*, 111(1), 13–27. DOI: 10.1016/S0168-1923(02)00012-6

Negreiros, J., Painho, M., Aguilar, F., Aguilar, M. 2010. Geographical information systems principles of ordinary kriging interpolator. *Journal of Applied Sciences*, 10(11), 852–867. DOI: 10.3923/jas.2010.852.867

Ndiaye, P. M., Bodian, A., Diop, L., Deme, A., Dezetter, A., Djaman, K., Ogilvie, A. 2020. Trend and sensitivity analysis of reference evapotranspiration in the Senegal river basin using NASA meteorological data. *Water*, 12(7), 1957. DOI: 10.3390/w12071957

Niaz, R., Almazah, M. M., Al-Duais, F. S., Iqbal, N., Khan, D. M., Hussain, I. 2022. Spatiotemporal analysis of meteorological drought variability in a homogeneous region using standardized drought indices. *Geomatics, Natural Hazards and Risk*, 13(1), 1457–1481. DOI: 10.1080/19475705.2022.2079429

Ouatiki, H., Boudhar, A., Ouhinou, A., Arioua, A., Hssaisoune, M., Bouamri, H., Benabdelouahab, T. 2019. Trend analysis of rainfall and drought over the Oum Er-Rbia River Basin in Morocco during 1970–2010. *Arabian Journal of Geosciences*, 12(4), 1–11. DOI: 10.1007/s12517-019-4300-9

Porter, D., Gowda, P., Marek, T., Howell, T., Moorhead, J., Irmak, S. 2012. Sensitivity of grass-and alfalfa-reference evapotranspiration to weather station sensor accuracy. *Applied Engineering in Agriculture*, 28(4), 543–549. DOI: 10.1007/s00382-007-0340-z

POWER | Data Access Viewer. Online available at: https://power.larc.nasa.gov/data-access-viewer/

Saadi, S., Todorovic, M., Tanasijevic, L., Pereira, L. S., Pizzigalli, C., Lionello, P. 2015. Climate change and Mediterranean agriculture: Impacts on winter wheat and tomato crop evapotranspiration, irrigation requirements and yield. *Agricultural water management*, 147, 103–115. DOI: 10.1016/j.agwat.2014.05.008

Stringer, L. C., Dyer, J. C., Reed, M. S., Dougill, A. J., Twyman, C., Mkwambisi, D. 2009. Adaptations to climate change, drought and desertification: local insights to enhance policy in southern Africa. *Environmental science & policy*, 12(7), 748–765. DOI: 10.1016/j.envsci.2009.04.002