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# Multi-scale analysis of drought events in Northern Algeria based on ERA5-Land SPI data

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## Abstract

Drought poses significant environmental and socio-economic challenges in Mediterranean countries such as Algeria, where rain-fed agriculture dominates, and climate change exacerbates water scarcity. In this paper, an investigation of meteorological drought in Northern Algeria in the period 1950–2022 was carried out focusing on its spatiotemporal characteristics. The analysis focuses on drought events identification through the Standardized Precipitation Index (SPI), calculated at several timescales with the run theory methodology. Using the Copernicus Climate Change Service high-resolution ERA5-Land monthly data set, SPI values were computed across 3,983 grid points to derive key drought characteristics, including frequency, and maximum duration values, severity, and intensity. An additional analysis was carried out to detect possible temporal tendencies in the SPI across multiple time scales, ranging from short to long term. The findings reveal that while drought frequency remains relatively consistent across timescales, shorter-term droughts exhibit lower maximum duration and severity compared to longer-term events. In addition, maximum drought intensity tends to decrease as the SPI timescale increases. The spatial granularity offered by the ERA5-Land data significantly enhances the precision of drought characterization compared to traditional rain gauge networks, which are often unevenly distributed. Finally, a decrease in the 6- and the 12-month SPI values, meaning more severe droughts, has been identified in the north-western area. These insights underscore the importance of scale-dependent analysis in drought assessment, and support more informed water resource planning and climate adaptation strategies for vulnerable regions like Northern Algeria.

**Keywords** Drought · SPI · ERA5-Land · Algeria

## Introduction

Drought in the Mediterranean basin has been extensively researched, given the area's high vulnerability to climate change (e.g. Buttafuoco et al. 2018; Merabti et al. 2018). Studies have evidenced more recurrent, longer and extreme drought in the Mediterranean basin (Spinoni et al. 2014); similarly, a substantial decrease in summer precipitation and rising temperatures have also been highlighted (Giorgi and Lionello 2008). These drying patterns are associated with stronger anticyclonic systems and a change in the Atlantic storm tracks, moving toward the north. Projected future climate scenarios for North Africa suggest a rise in drought severity caused by ongoing climate change and declining precipitation levels (Balting et al. 2021; Driouech et al. 2020).

Drought is a phenomenon occurring when precipitation levels fall below the norm with devastating consequences on the environment and communities (Svoboda et al. 2012),

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especially when its duration is prolonged over an entire season. Furthermore, drought is considered a regional phenomenon owing to the diverse climatic characteristics of regions, where it occurs (Buttafuoco and Caloiero 2014). It is also historically proven that the types and duration of drought can vary. For these reasons, drought has been classified in different ways (Merabti et al. 2023). Most commonly, four types of droughts have been identified (Zargar et al. 2011): meteorological (temporary precipitation deficits), hydrological (reduced surface and groundwater resources), agricultural (lack of water for crop production), and socio-economic (impacts related to water demand and usage in society).

Within such a framework, the present paper aims to investigate hydrological basins in Northern Algeria. According to the FAO Water Reports No. 45 (FAO 2018), droughts in Northern Algeria have reduced dam reserves, depleted rural water sources, increased water salinity, and lowered grain and fodder yields. The 1945–1947 drought devastated the Ain Sefra region, with nearly 90% of cattle lost, 900,000 sheep perishing, and 3,000 fatalities from starvation out of a population of 80,000. The year 1966 saw the region's second lowest rainfall amount since 1945, causing crop shortage and agricultural losses. In addition, several dry spells occurred, remarkably in 1910–1920, 1939–1948, and 1973–1992. The latter period, marked by extreme dryness, severely affected water resources, agriculture, and local populations, leading to social unrest, wildfires, and famine.

Demmak (1982) compared rainfall data from 1974 to 1992 with those from 1913 to 1963, highlighting a trend toward drier conditions in the more recent period, even though isolated dry years occurred earlier as well (e.g., 1913 and 1940).

Such precipitation shortages has brought about major challenges, such as drinking and irrigation water scarcity (Khaldi 2005).

Since the 1980s, Northern Algeria has experienced multiple severe droughts (Achite et al. 2024a). Significant drought examples include: a prolonged and severe drought in the 1980s, which caused widespread agricultural losses, water shortages with crop failures, livestock death, and communities struggling to access water for sustenance and agriculture; the 1990s one with a considerable reduction in crop yield, particularly non-irrigated farming. Hydric stress intensified, with decreased reservoir and underground water levels; in 2003, exceptional heat caused drought followed by harsh water insufficiencies across Northern Algeria and areas in Europe (Ciais et al. 2005; Rebetez et al. 2006). This event resulted in diminished crop productivity, food supply shortages, and elevated staple crop prices, further intensifying both domestic and agricultural water demands.

A widely utilized tool in the analysis of prolonged dry conditions is the SPI. It measures precipitation deficits, offering a consistent measure of drought severity (McKee et al. 1993). Its widespread use stems from its normalization, which allows for consistent evaluation across different locations and timeframes (Wu et al. 2007). The WMO (2006) endorses the SPI as a drought indicator. Shorter timeframes are applied to meteorological and agricultural droughts, while longer time scales focus on hydrological droughts and water resource impacts (Mishra and Singh 2010). The SPI's simplicity, reliance solely on precipitation data, and flexibility across multiple timescales make it an invaluable tool for drought assessment (Lloyd-Hughes and Saunders 2002; Hayes et al. 1999).

This study utilizes the SPI to assess the spatial and temporal drought variations over Northern Algeria from 1950 to 2022, utilizing the ERA5-Land monthly data set. Unlike ground-based observations from Algeria's National Hydraulic Resources Agency (ANRH), the ERA5-Land data set provides comprehensive, homogenized data covering the entire northern region. This approach enables a detailed assessment of the drought frequency, and of the maximum values of severity, intensity, and duration over 73 years. Thus, the current paper sets out to validate the different behaviour of the drought characteristics for different SPI timescales, and to identify possible trends in the SPI values to detect drought-prone areas. The innovative aspect of this investigation lies in its integration of the run theory with high-resolution ERA5-Land data to overcome the limitations posed by previous gauge-based studies. Therefore, this study offers a fresh understanding of drought behaviour in a climate-vulnerable region. These findings have important effects on sectors, such as agriculture, water resource management, disaster preparedness, and socio-economic planning in Northern Algeria and similar semi-arid regions. By identifying drought risks and patterns, this research aims to support decision makers in mitigating water shortages, enhancing resilience, and implementing effective strategies for drought-prone regions.

## Study area

The study area, i.e., 16 basins of North of Algeria, presents peculiar geographical and topographical conditions, which cause precipitation and temperature to vary significantly. The period July to October corresponds to the dry season, whereas rainfall mostly occurs between October and April (Ghenim and Megnounif 2016), typical of Mediterranean climates, where winters are mild and wet, and summers dry and hot.

The selected 16 basins of Northern Algeria span an area of 294,700 km$^2$. These basins are geographically delineated by the Mediterranean Sea to the north, the Moroccan border to the west, the Tunisian border to the east, and the Sahara Desert forming the southern boundary. This region boasts a diverse landscape, featuring 1200 km of coasts along the Mediterranean Sea, two Atlas Mountain ranges whose peaks reaching 1000–1800 m above sea level, respectively, as well as vast high plateaus and plains (Fig. 1 and Table 1).

## Materials and methods

Drought occurrences across Northern Algeria have been examined in this section through the analysis of precipitation data across 3,983 grid points over an extended time series. A flowchart has been added as Supplementary Material to help the reader to understand the steps of the research (Figure S1).

### The ERA5-Land reanalysis

The ERA5-Land reanalysis data set offers high-resolution climate data for multiple climate parameters. In this research, the data set has been employed to evaluate SPI values to characterize drought patterns in terms of frequency, severity, duration, and intensity across several catchments in Northern Algeria. The data set delivers a consistent representation of land variables over numerous years, with a 9 km (0.08°) heightened spatial resolution. Readers may refer to Muñoz-Sabater et al. (2021) for further details.

**Table 1** Selected basins in Northern Algeria

| Basin code | Basin name |
|---|---|
| 01 | Cheliff basin |
| 02 | Algerian coastal basin |
| 03 | Constantine coastal basin |
| 04 | Oran coastal basin |
| 05 | El Hodna basin |
| 06 | Melrhir Chott basin |
| 07 | Constantine high plateaus basin |
| 08 | Ech Chergui Chott basin |
| 09 | Isser basin |
| 10 | Kebir Rhumel basin |
| 11 | Macta basin |
| 12 | Medjerda Mellegue basin |
| 14 | Seybous basin |
| 15 | Soummam basin |
| 16 | Tafna basin |
| 17 | Zahrez basin |

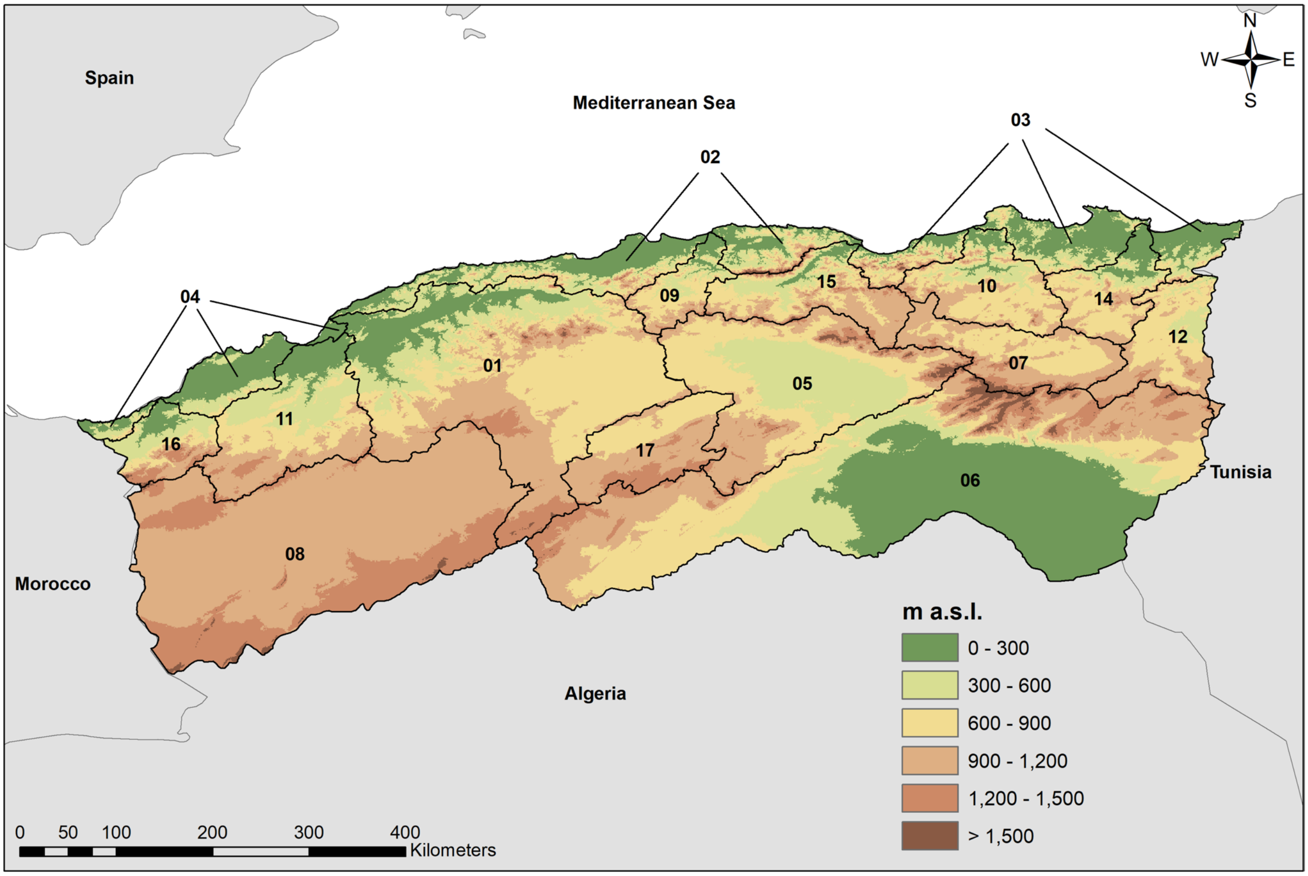


**Fig. 1** Northern Algeria catchment map, with numbers indicating hydrological basin codes based on the ANRH classification system

The present analysis covers monthly data (January 1, 1950–December 31, 2022) encompassing 73 years over 3983 grid points. The comprehensive data set is invaluable for understanding climate variability, particularly regarding heat and rainfall, for hydrological and water resource studies in the region under analysis. Because the availability of observed rainfall data is limited, uneven distribution, and the incomplete nature of archival records in the predominantly desert study area, ERA5-Land values are used directly without applying post-processing algorithms or comparisons with rain gauge measurements. At any rate, Ceppi et al. (2025) recently validated the ERA5-Land data set's accuracy in representing rainfall over the study area.

## The SPI index

Based on Angelidis et al. (2012), to calculate the SPI, the gamma function has been used to fit the historical precipitation data, and its parameters have been estimated for every month and aggregation considering the Thom's (1958) approximation. Moreover, after adjusting the cumulative distribution function (CDF) of the gamma distribution, to properly handle zero precipitation values in the data set, the new CDF is converted into a standard normal distribution (Abramowitz and Stegun 1970):

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

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

where $c_i$ and $d_j$ (with $i = 0$, 1 and 2 and $j = 1$, 2 and 3) are constants.

The SPI classification is applied to classify both wet and dry period periods, as Table 2 evidences.

**Table 2** SPI value-based climate classification and their occurrence probability

| SPI value | Class | Probability (%) |
|---|---|---|
| $SPI \geq 2.0$ | Extremely wet | 2.3 |
| $1.5 \leq SPI < 2.0$ | Severely wet | 4.4 |
| $1.0 \leq SPI < 1.5$ | Moderately wet | 9.2 |
| $0.0 \leq SPI < 1.0$ | Mildly wet | 34.1 |
| $-1.0 < SPI < 0.0$ | Mild drought | 34.1 |
| $-1.5 < SPI \leq -1.0$ | Moderate drought | 9.2 |
| $-2.0 < SPI \leq -1.5$ | Severe drought | 4.4 |
| $SPI \leq -2.00$ | Extreme drought | 2.3 |

## The run theory

The run theory, introduced by Yevjevich (1967), offers an objective and statistically rigorous approach to the evaluation of drought events and it is, therefore, paramount for drought analysis. At its core, the theory provides a structured way to define and analyse sequences of hydrological data, such as rainfall or streamflow, falling below a predetermined threshold. This is particularly useful in detecting the beginning and end of droughts, which can often be challenging to identify precisely without a systematic approach. Rather than relying on visual inspection or arbitrary judgment, run theory offers a consistent method for determining drought periods based on well-defined criteria. What makes run theory especially powerful is its capacity to quantify key characteristics of droughts. By identifying continuous sequences (or "runs") of low values, the method allows for the calculation of important metrics, such as drought duration, frequency, and deficit volume. These parameters are not only useful for research analysis; they are fundamental for practical water resource management and risk planning. In fact, understanding the frequency of droughts, about how long they typically last, and how severe they are, can inform policies, infrastructure design, and emergency response strategies. Furthermore, the run theory relies on probabilistic principles, enabling a statistical treatment of drought data. This is valuable for modelling drought behaviour, estimating recurrence intervals, and evaluating the likelihood of future events, essential for long-term planning and designing systems resilient to climate variability. The statistical framework allows drought analysis in the context of risk and uncertainty, rather than as isolated historical events.

Another strength of the run theory lies in its adaptability. It can be applied across various types of hydrological data, whether it is precipitation, streamflow, or soil moisture, and the threshold used to define a drought can be tailored to different environmental or operational contexts. This flexibility makes it suitable for diverse regions and climate conditions. Finally, since the run theory is a standardized and reproducible method, it facilitates meaningful comparisons of drought characteristics across different regions and time periods. This comparative capability is increasingly important as we seek to understand how climate change may be altering drought patterns globally. By applying a consistent analytical framework, researchers and policymakers can draw more accurate conclusions about trends, vulnerabilities, and the effectiveness of mitigation strategies. Figure 2 illustrates the use of the run theory applied to a specific threshold level.

In this work an SPI threshold of −1 has been considered to identify drought events, focusing exclusively on moderate and extreme categories, as mild droughts are often considered part of normal conditions. As a result, any event with SPI value falling below (or above) −1 is considered a run, provided it lasts at least 1 month. Values above or below the threshold characterize positive (wet periods) or negative (dry periods) runs, respectively (Caloiero et al. 2021). Once the runs are identified, several drought features are examined. Drought duration (DD) denotes the consistent time length of below-the-threshold values, time length can be weekly, monthly, yearly or custom measured. Drought frequency (DF) results from the percentage of dry spells over the investigation period. Drought severity (DS) is represented by the accumulated drought values for each event. The DS to DD ratio for every single event determines the Drought intensity (DI).

In the present paper, various time-scale SPI series (3, 6, 12, and 24 months) are used to calculate the drought duration, maximum values, severity, and intensity based on the run theory; as a result, DD is expressed in months, while DS and DI are dimensionless.

### Trend analysis

To identify trends in time series data, the non-parametric Mann–Kendall test is frequently utilized due to its robustness and reliability (Mann 1945; Kendall 1962). It evaluates whether there is a consistent trend (upward or downward) without requiring the data to follow a specific distribution. This test is widely applied in environmental and climate studies to assess the sign and the significance of trends over time. In particular, in this study, to assess the presence of a trend, a two-sided test has been applied considering a significance level equal to 95%.

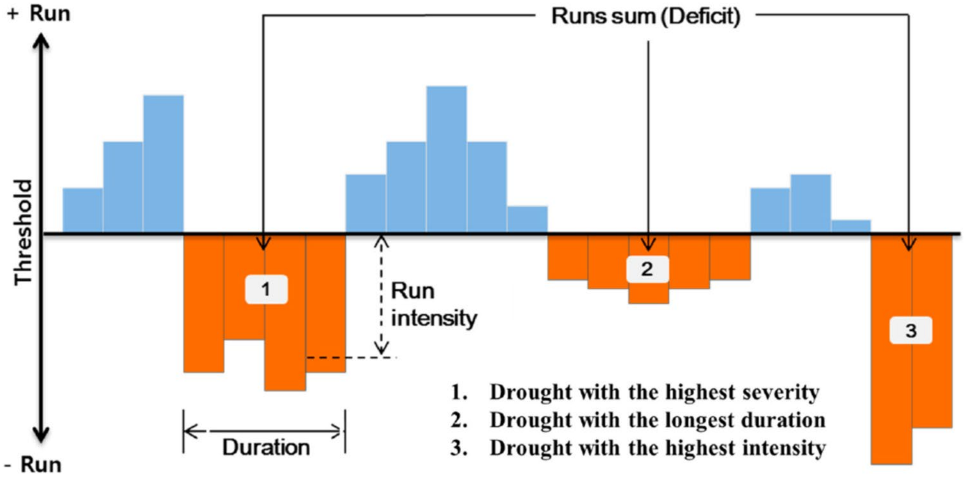
## Results

The number of grid points with lower-than -1 SPI values, for every month and time aggregation over the observation period, is illustrated in Fig. 3. The yellow, orange and red lines represent the thresholds corresponding to the 70%, 80% and 90% of the grid points, respectively.

In general, dry events are observed every 10 years for all time aggregations, with a notable increase in frequency and extent from 1980 onward, when several peaks exceeding the 90% threshold are recorded. Specifically, for the 3-month SPI, drought conditions affected more than 90% of the grid points in several years before 1980 (i.e., 1954, 1956, 1960, and 1964), but also in 2002, 2016, and especially in 2000, when drought conditions were widespread across the whole study area in March. For the 6-month SPI, many drought events exceeding the three thresholds have been identified. In particular, more than 90% of the grid points experienced drought conditions in 1954, 1956, 1958, 1962, 1964, 1997, 2001, and 2008, thus confirming the results obtained for the 3-month SPI. For both the 12-month and 24-month SPI, the period from 2000 to 2002 stands out as the one when the thresholds were exceeded the most. In particular, 1957, 1962, 1983, 2000, and 2002 were the years when drought characterised more than 90% of the grid points for the 12-month SPI. From 2000 onward, including 2001, 2002, 2021, and 2022, similar percentages were observed for the 24-month SPI.

Figure 4 presents a synthesis of the DF and of the maximum values of DD, DS, and DI for every time aggregation. Box plots offer a concise visual summary of how drought characteristics vary across space and time. For example, in a region like Northern Algeria, which spans coastal, mountainous, and semi-arid zones, the distribution of drought duration or severity may differ significantly from one subregion to another. A box plot allows these differences to

**Fig. 2** Example of the run theory to evaluate drought characteristics for a fixed threshold



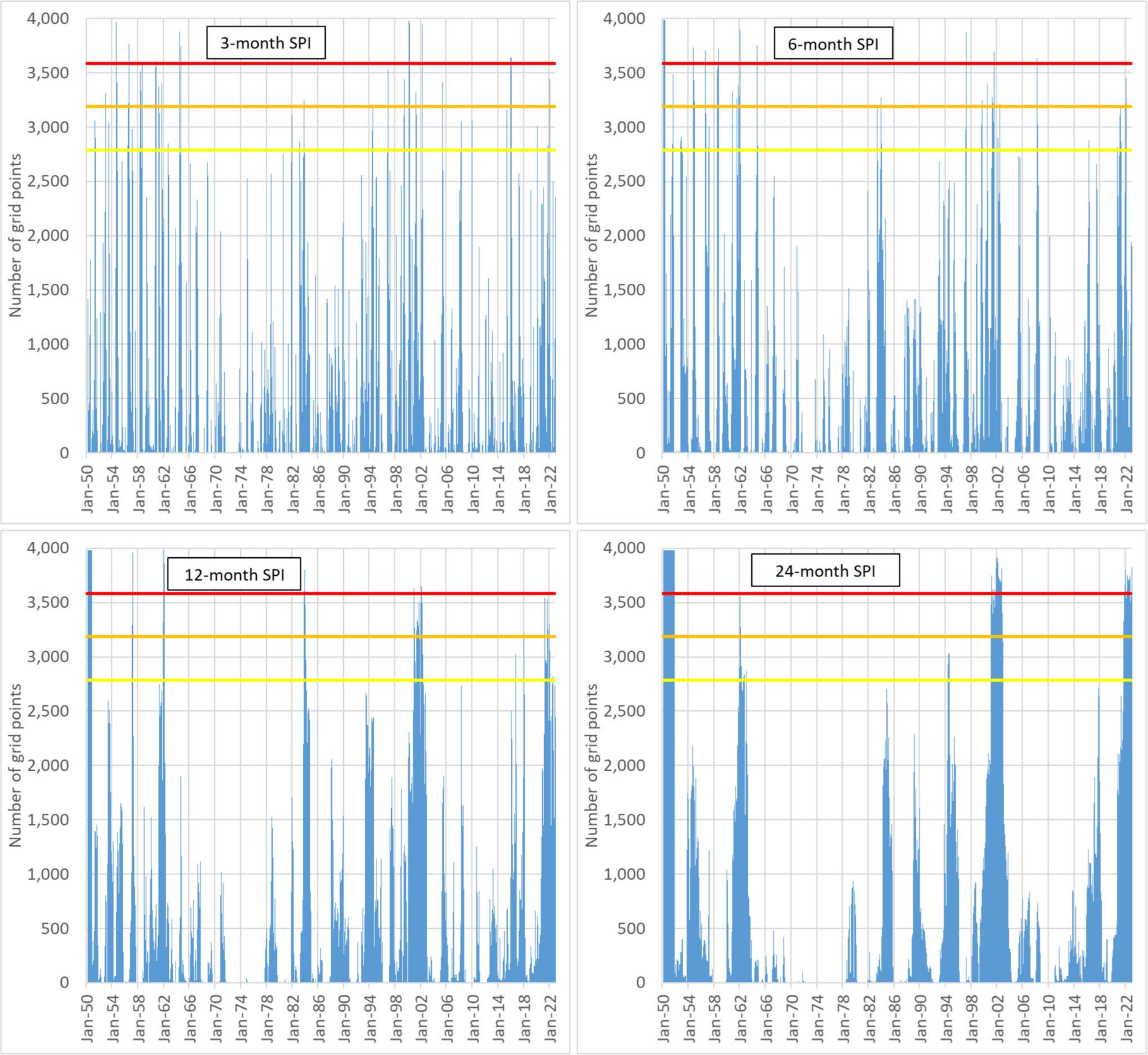


**Fig. 3** Number of grid points showing drought conditions. The yellow, orange and red lines represent the thresholds corresponding to the 70%, 80% and 90% of the grid points, respectively

be seen at a glance by displaying the median, interquartile range, and potential outliers in each zone. This is especially important when dealing with data derived from ERA5-Land, which offers detailed spatial and temporal information. A simple average might obscure local extremes, whereas a box plot reveals the full range of variability. Moreover, to highlight the areas most frequently affected by drought, the drought characteristics were spatially distributed across the basins of Northern Algeria (Figs. 5, 6, 7, and 8). The maps facilitate the identification of patterns and anomalies in the data. For example, if a particular region consistently exhibits longer drought durations or larger deficit volumes, this may indicate greater vulnerability or increased climate sensitivity. Such insights are essential for regional water management strategies, as they assist decision makers in prioritizing areas for targeted intervention or infrastructure development.

The mean DF values do not reveal significant variances among the various time scales (from about 16.2% to about 15.4%, for the 3- and the 24-month SPI, respectively); however, different ranges are apparent among the various scales. In effect, DF values range between 13.1% and 18.4% are present for the 3-month SPI; on the other hand, DF values range between 10 and 20% for 24-month SPI (Fig. 4).

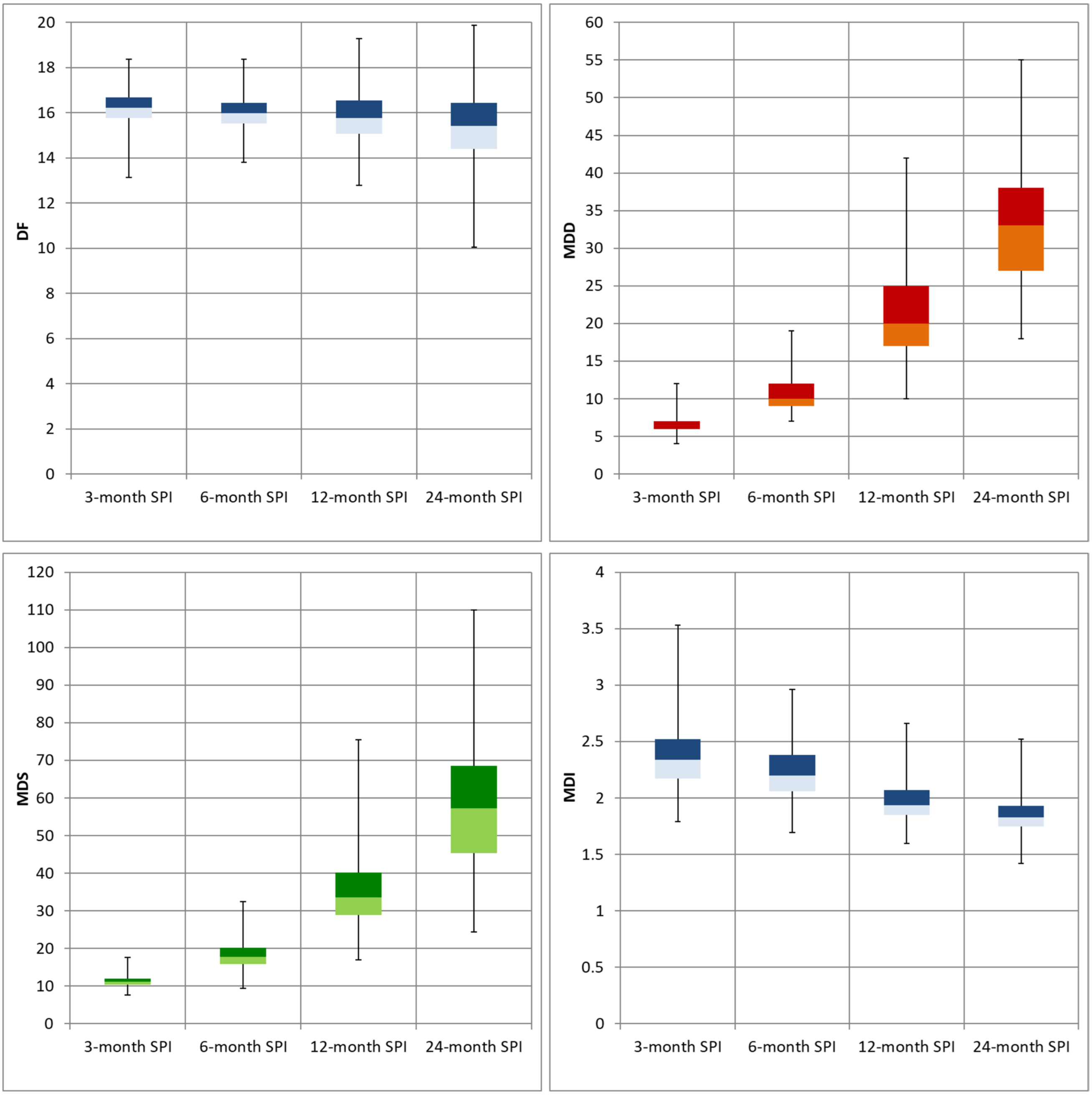


**Fig. 4** Boxplots characterization of DF, MDD, MDS, and MDI representing the minimum, the second quartile, the median, the third quartiles and the maximum values

Spatially, the drought frequency significantly differs across the basins and for the different time scales considered (Fig. 5). In fact, for the 3-month SPI the highest DF values have been identified in the eastern side of the investigated area, in particular in the Melrhir Chott (ID 06) and the El Hodna (ID 05) basins, but also in the Cheliff basin (ID 01). As regards the 6-month SPI, the highest frequencies have been detected in the Seybous (ID 14) and the Ech Chergui Chott (ID 08) basins, placed in the northeastern and in the southwestern sides of the study area, respectively. The 12-month SPI displayed an analogous behavior than the 6-month SPI, with the western side of the region featuring the highest drought events frequency of drought events involving especially the Macta (ID 11) and the Ech Chergui Chott (ID 08) basins. The 24-month SPI presented both the highest and the lowest DF values, with the first ones involving the mountain areas of the Melrhir Chott basin (ID 06) and the latter the southern area of the same basin and the Cheliff (ID 01), the Oran coastal (ID 04) and the Tafna (ID 16) basins (Fig. 5).

MDD statistics evidence that the 3-month SPI has the lowest values, while 24-month SPI has the highest. The analysis revealed a mean and maximum MDD of 6 and 12 months, respectively, in Northern Algeria in the 3-month SPI observation period, whereas 18 and 55 months, respectively, have been observed for the 24-month SPI (Fig. 4).

The spatial analysis showed that for the 3- and 6-month SPI the MDD did not reveal any particular behaviour (Fig. 6). In contrast, the 12- and 24-month SPI spatial distribution of the MDD allowed us to identify the areas in which the longest drought events occur. In fact, the MDD maximum values have been detected in the south–west of Northern Algeria, and specifically in the Ech Chergui Chott basin (ID8) for the 12-month SPI, and in the whole western side for the 24-month SPI. In particular, this latter outcome mainly involved the Ech Chergui Chott (ID8), the Macta (ID 11) and the Cheliff (ID 01) basins (Fig. 6).

MDS displayed a similar behaviour to MDD at different time scales, with average values spanning between 11.1 (3-month SPI) and more than 57 (24-month SPI). Furthermore, in the case of the MDS the larger the time span the wider the spread, minimum and the maximum values in the range between more than 7 and about 17.5 for the 3-month SPI, and between more than 24 and about 110 for the 24-month SPI (Fig. 4).

The similar behaviour between MDD and MDS has been also identified by performing the spatial analysis of the MDS values. In fact, the short-time SPI did not show any particular behaviour of the MDS, while the western side of the region has been identified as the one with the highest severity values for the long-time SPI (Fig. 7). Specifically, the Ech Chergui Chott basin (ID8), showed the highest MDS values for both the 12- and the 24-month SPI, while the Macta (ID 11) and the Cheliff (ID 01) catchments presented the highest severity for the 24-month SPI (Fig. 7).

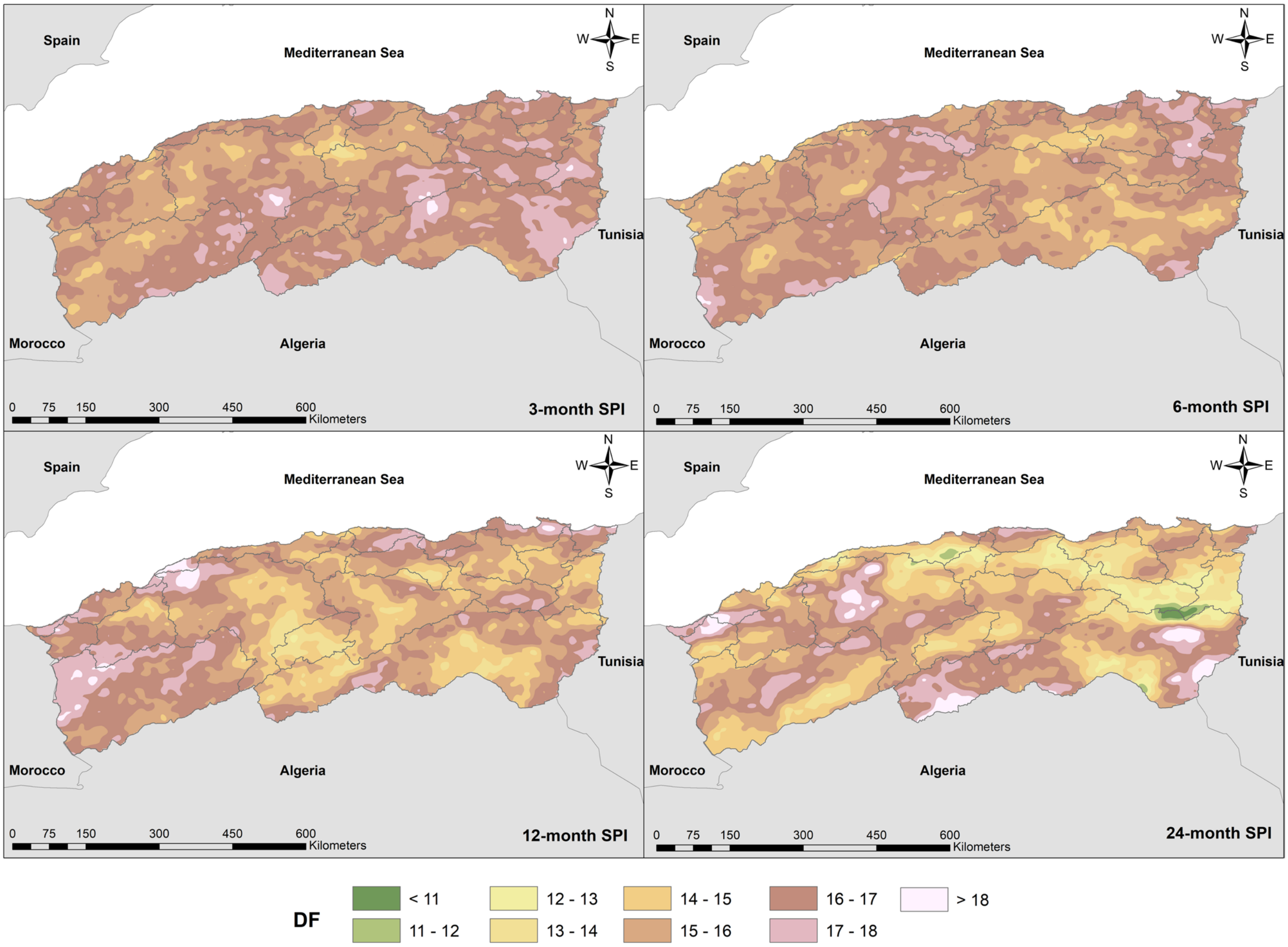


**Fig. 5** Spatial distribution of DF over Northern Algeria

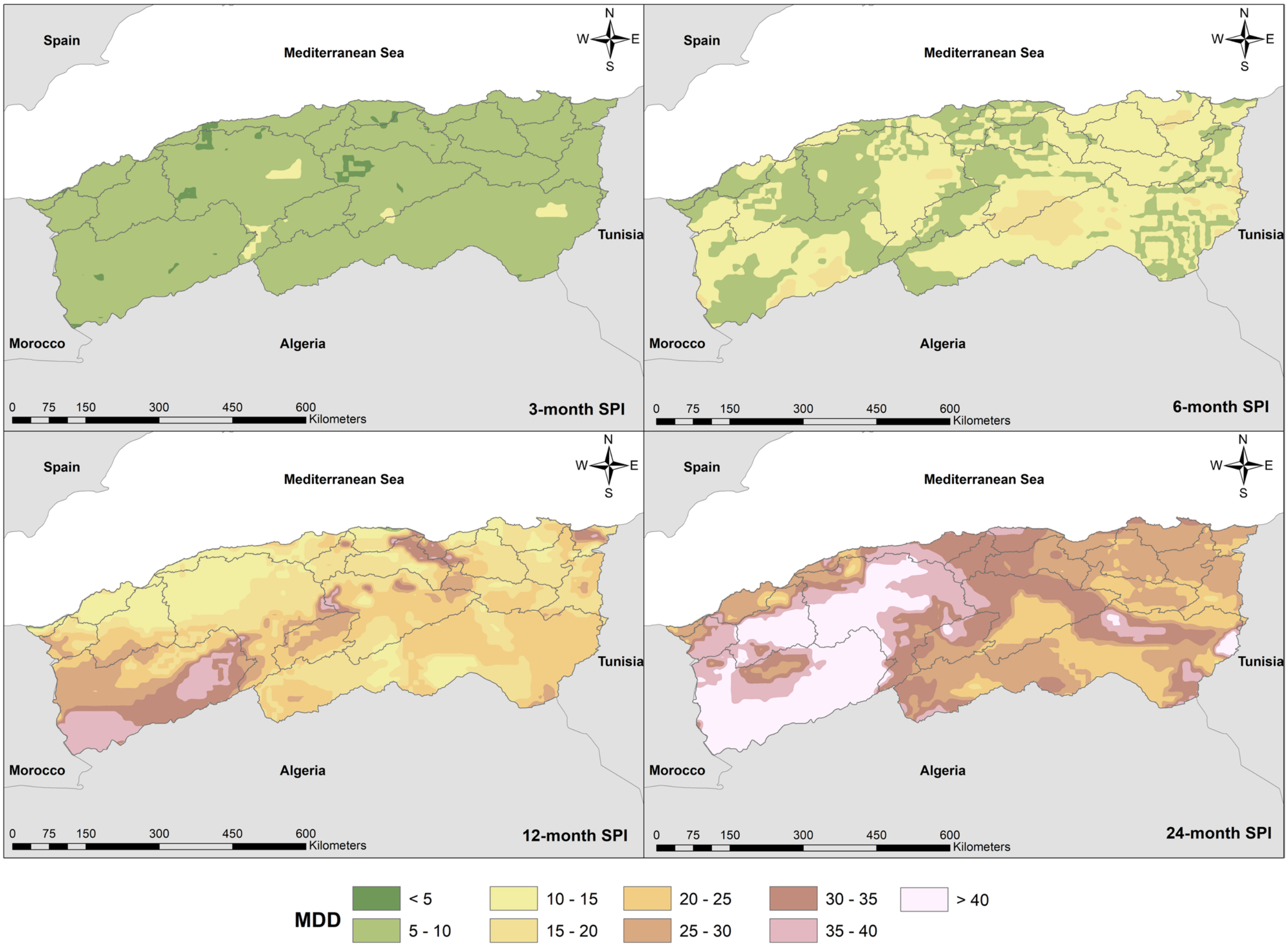


**Fig. 6** Spatial distribution of MDD over Northern Algeria

Finally, the various time scale revealed a slight decrease in the MDI values, whose mean values are between 1.83 and 2.33 for the 24- and the 3-month SPI, respectively (Fig. 4).

Spatially, both the short- and the long-time SPI did not show any particular behaviour of the MDI, with only the Zahrez basin (ID 17) showed relevant results for the 3-month SPI (Fig. 8).

Figures 9 and 10 show the main findings of the MK test applied to the 6- and 12-month SPI values. Specifically, for the 6-month SPI, two distinct periods were analysed: the dry season (spring and summer) and the wet season (autumn and winter).

As a result, a decrease in the SPI values, meaning more severity droughts, has been identified in the northwestern side of the study area for both the 6- and the 12-month SPI. A further decrease has also been identified in the southeastern part of the watershed but only for the 6-month SPI during the wet period. These results are particularly important, because these areas are not interested by the highest values of the drought characteristics. This means that in the future drought may hit the areas that have not suffered from it until the present day.

## Discussion

One reason why the SPI remains highly suitable for this kind of investigation is that, despite its simplicity, it is statistically robust. It turns rainfall data into a normalized distribution, enabling the comparison of drought severity across different climates, from arid to humid zones, without requiring complex calibration. This makes it especially useful in regions with varying climatic conditions, such as Northern Algeria, where temporal and spatial precipitation variability is significant. Moreover, its ability to be computed over different timescales (e.g., 3, 6, 12, and 24 months) enhances its analytical power. Short timescales capture meteorological and agricultural drought, while hydrological or socio-economic impacts are best evaluated through longer timescales. This multi-scale capability

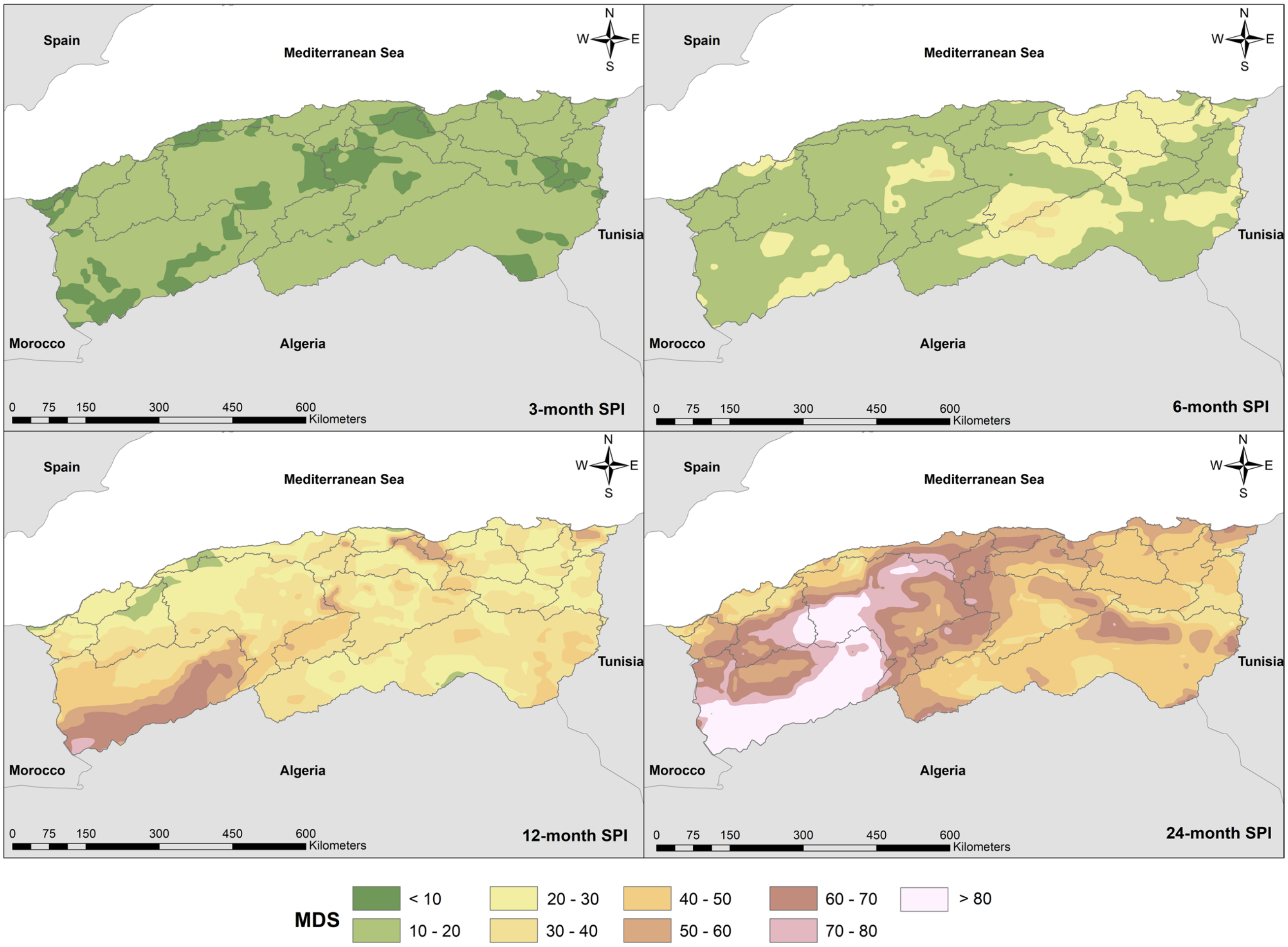


**Fig. 7** Spatial distribution of MDS over Northern Algeria

allows SPI to reflect the duration and cumulative effects of rainfall deficits, giving it a broader scope than the simplicity of its formula might suggest. Critically, the SPI is also data efficient. In regions where comprehensive hydrological or soil moisture data is lacking, which is often the case in developing countries or areas with sparse station networks, the SPI can still be reliably computed using only precipitation records. When used with gridded data sets like ERA5-Land, it provides even more comprehensive spatial coverage.

Recent research on meteorological drought in Algeria has primarily employed the SPI (Berhail et al. 2022; Fellag et al. 2021; Haied et al. 2023). However, these studies have been limited to basin-level analyses, lacking a broader perspective (e.g. Achite et al. 2024b). Vice versa, this study examines drought across the entire northern part of Algeria, utilizing the SPI over various aggregation periods. ERA5-Land precipitation data, from 1950 to 2022, were used for this analysis. This gridded data set proved invaluable tool due to the lack and inconsistency of land-based rainfall observations in the area, a critical consideration given the region's limited and unevenly distributed natural water resources.

The time trends examination in terms of grid points with SPI values below −1 percentage highlights the most important drought events that have gradually affected this area, especially since approximately 1980. This escalation aligns with a marked rainfall reduction observed from the late 1970s, as noted in literature (e.g., Meddi et al. 2014), and during the early 2000s, reflecting broader Mediterranean patterns (Hoerling et al. 2012). These drought conditions have significantly affected farming and water resources, resulting in worse crop output and heightened pressure on water supplies.

Findings from the run method highlighted the western region of the study area as Northern Algeria's most drought-vulnerable zone, considering the different drought characteristics and the different SPI time scales. These results agree with past studies such as the ones by Taibi and Souag (2011) and by Derdous et al. (2021) that identified the northwestern

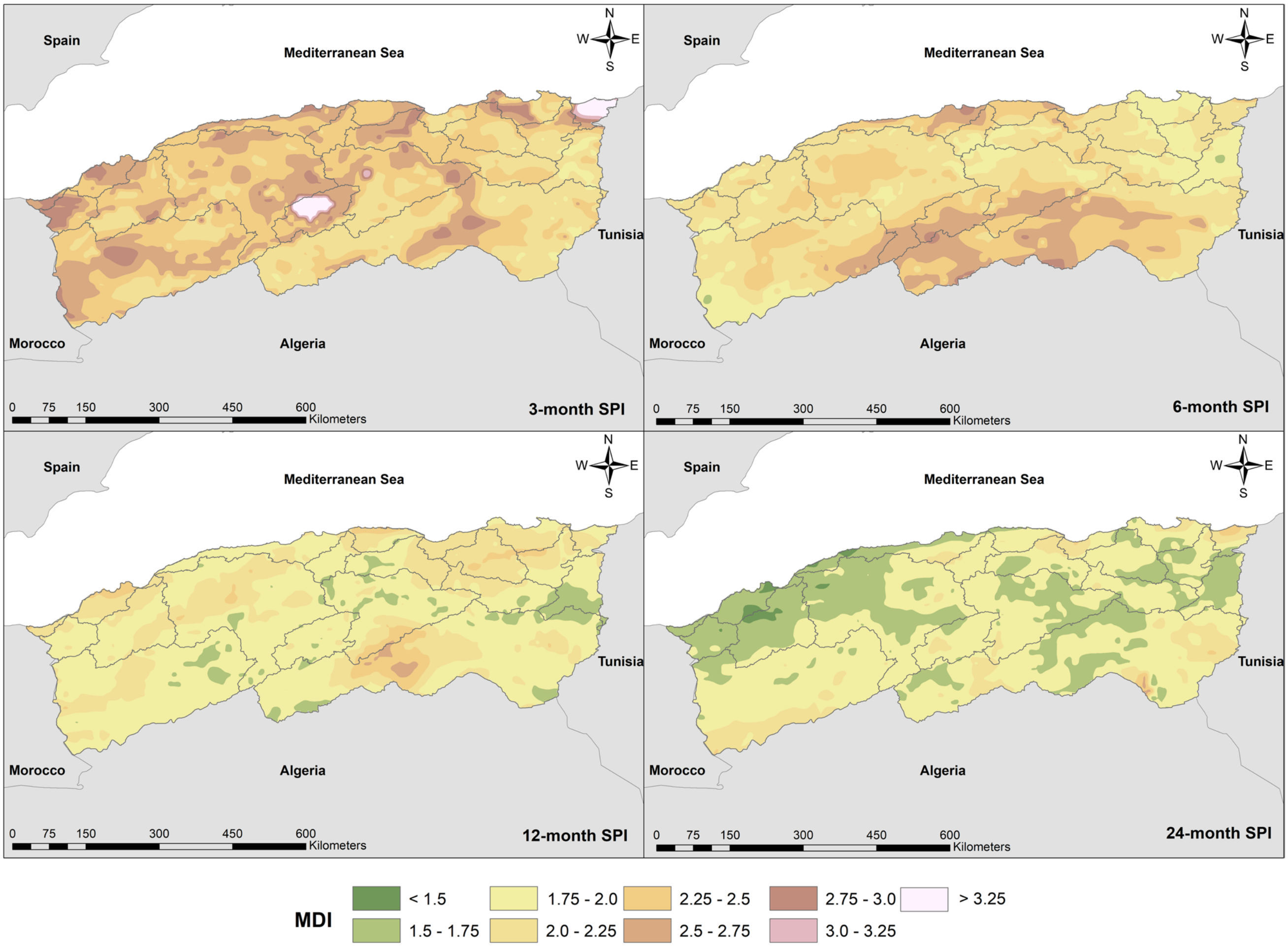


**Fig. 8** Spatial distribution of MDI over Northern Algeria

and central highland regions of Algeria as the ones affected by severe droughts.

Finally, it should be noted that numerous studies have sought to identify the climatic factors associated with droughts. Research by Derdous et al. (2020), Zeroual et al. (2017), Taibi et al. (2017), Hallouz et al. (2020), and Caloiero and Veltri (2019) has shown that rainfall and drought in Mediterranean regions are closely influenced by large-scale atmospheric circulation patterns. These include the Western Mediterranean Oscillation (WeMO), the Mediterranean Oscillation (MO), the El Niño Southern Oscillation (ENSO), and in particular the North Atlantic Oscillation (NAO) (Caloiero et al. 2018). In Algeria, these indices, particularly the NAO, exhibit a negative correlation with precipitation (Meddi et al. 2014).

As regards the comparison with studies using alternative drought indices rather than SPI, the results of this study highlight a considerable increase in drought frequency and extent from the 1980s onward across Northern Algeria. These results are in line with those obtained using other drought indices including the Palmer Drought Severity Index (PDSI) and the Standardized Precipitation Evapotranspiration Index (SPEI), though some key differences emerge due to the presence of temperature and evapotranspiration in those indices. For instance, Safi et al. (2020) applied the SPEI across Northern Algeria. As a result, they also observed a significant rise in drought severity and frequency post-1980, particularly in the western and southwestern regions. These areas correspond to those identified in this SPI-based analysis as those experiencing long and severe droughts (e.g., Ech Chergui Chott and Macta basins). The SPEI results attributed these patterns not only to precipitation deficits but also to increased evapotranspiration linked to rising temperatures. Similarly, Vicente-Serrano et al. (2014) conducted a multi-scalar drought assessment using both SPI and SPEI across the Mediterranean Basin and found that, while SPI effectively captures meteorological droughts, SPEI detects more severe droughts in recent decades due to temperature-driven increases in evaporative demand. This supports

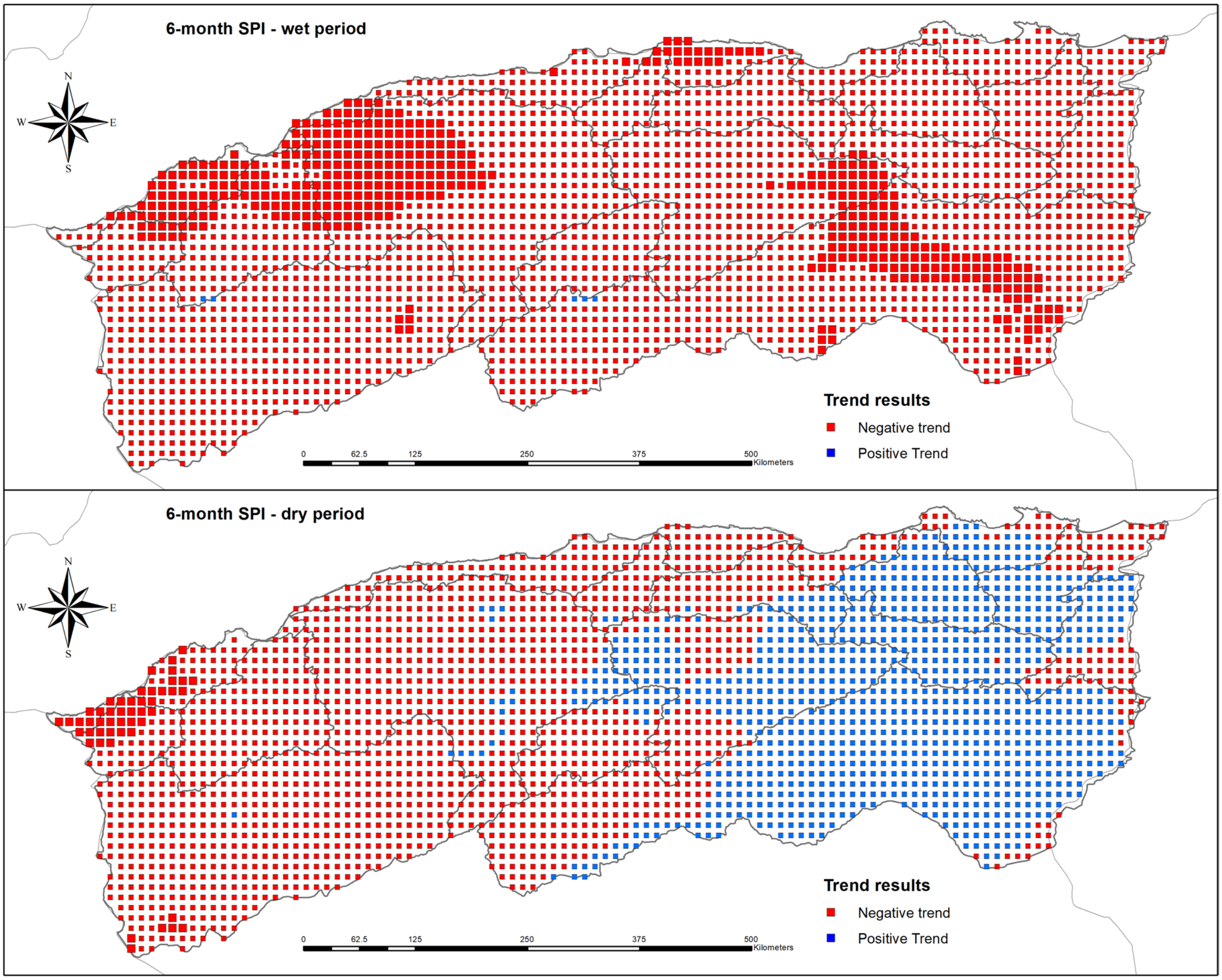


**Fig. 9** Trend analysis based on 6-month SPI data. Square dimensions reflect statistical significance: large squares correspond to $p < 0.05$, smaller ones to non-significant results

the higher severity seen in recent years (e.g., 2000–2002, 2021–2022) in both the SPI and the SPEI studies, though SPEI typically registers slightly greater intensity. In addition, Touchan et al. (2011) used tree-ring data and the PDSI to reconstruct historical droughts in North Africa and reported significant multi-annual droughts in the mid-twentieth century, consistent with the 1954, 1956, and 1964 events highlighted by the 3- and 6-month SPI in this study. While the PDSI is more sensitive to soil moisture and long-term droughts, its patterns of prolonged drought phases support the temporal persistence captured by the 24-month SPI.

## Conclusions

This paper aimed to explore some of the principal features (frequency, and maximum values of duration, severity, and intensity) of the drought events in the northern part of Algeria. Here, periods of severe drought have occurred, affecting the environment and farming, as well as depleting water supplies, especially since the 1980s. Specifically, in this paper the period 1950 –2022 was analysed through the use of the SPI evaluated from the ERA5-Land data set at different timescales. Results clearly indicated that considering the 3- and the 6-month SPI, which refer to how drought affects plant life and farming, it is likely that various short and low severity drought events may occur. By contrast, when considering the 12- and 24-month SPI (which provide significant insights for water resource management), the Algerian territory may experience few yet more severe drought events, in particular the western part of Northern Algeria. These outcomes highlight the critical need for comprehensive adaptation strategies, paired with reliable drought forecasting and monitoring tools.

This study offer valuable understanding of the spatial and temporal behaviour of drought in Northern Algeria, a region

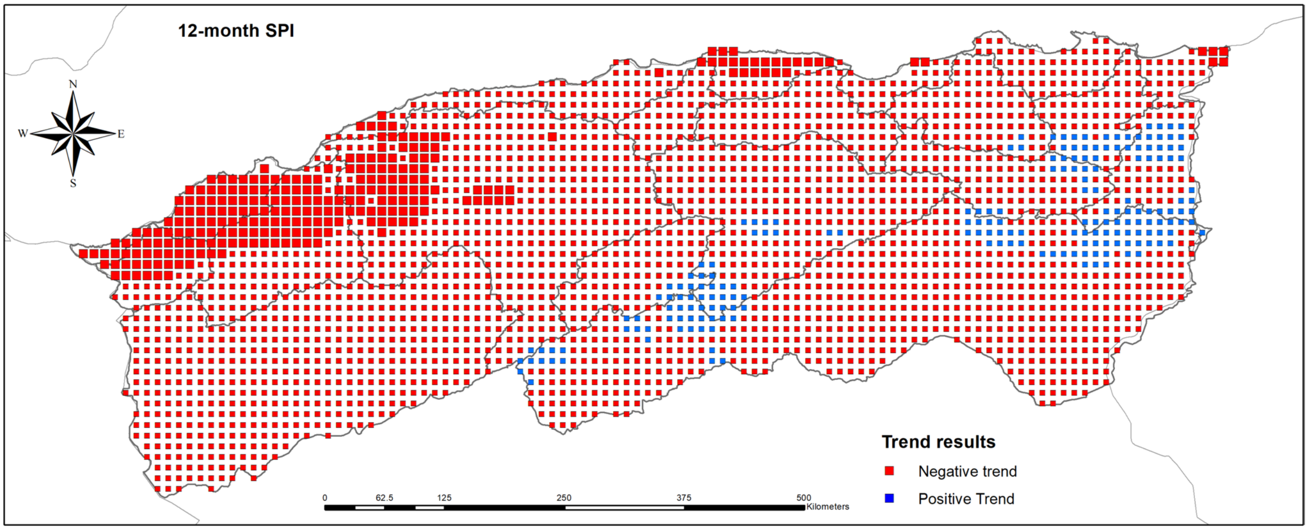


**Fig. 10** Trend analysis based on 12-month SPI data. Square dimensions reflect statistical significance: large squares correspond to $p < 0.05$, smaller ones to non-significant results

increasingly susceptible to climate extremes. By analysing long-term trends using the SPI derived from the ERA5-Land data set, the study not only enhances the understanding of drought behavior at multiple timescales but also underscores the growing need for scale-specific adaptation strategies. The findings contribute to scientific knowledge by illustrating how drought characteristics differ between agricultural and hydrological contexts, offering a framework that can be applied in other semi-arid and Mediterranean regions worldwide. Globally, this work aligns with international efforts to improve drought resilience when facing climate challenges, particularly in regions dependent on rain-fed agriculture and limited water resources. By bridging data-driven analysis with practical implications for drought monitoring and risk management, the study supports broader objectives under frameworks, such as the UN Sustainable Development Goals (SDGs), especially those related to climate action, food security, and sustainable water use.

**Supplementary Information** The online version contains supplementary material available at https://doi.org/10.1007/s41207-025-00848-5.

**Data availability** Data sets generated during the current study are available from the corresponding author on reasonable request.

## Declarations

**Conflict of interest** All authors have no conflicts of interest.

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