IMPACT OF DROUGHT IN NORTHEASTERN ALGERIA: COMPARATIVE STUDY OF THE SPI AND SPEI INDICES

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ABSTRACT

Purpose: The study aimed to evaluate drought trends in Annaba, Algeria, considering global warming and extreme weather, using quantitative indices for improved drought comprehension and prediction.

Theoretical Framework: The study assesses changes in drought frequency and severity in the Annaba region of Algeria due to global warming and extreme weather conditions. It employs quantitative indices to enhance drought understanding and prediction.

Methodology: The study analyzes temperature and precipitation data (1981-2021) from an Annaba weather station to assess drought characteristics. Standardized indices (SPI, SPEI) and extreme value analysis (Generalized Pareto Distribution) are used to quantify drought intensity, duration, and temperature impacts.

Findings: Our analyses reveal a critical divergence in drought assessment tools. While stable monthly temperatures suggest a constant influence on evapotranspiration, the SPEI index (including temperature) indicates increasing drought compared to the precipitation-only SPI. This highlights the importance of considering temperature alongside precipitation for accurate drought assessment.

Research Practical and Social Implication: This study emphasizes the significance of considering the interplay among temperature, precipitation, and evapotranspiration for better understanding and predicting drought changes in the Annaba region, Algeria. These insights are crucial for sustainable water resource management and climate change adaptation in the region.

Originality/Value: This study distinguishes itself by its comprehensive analysis of long-term climate data to examine drought trends in a specific region (Annaba, Algeria) severely impacted by climate change. By comparing the effectiveness of two drought indices (SPEI and SPI), it offers valuable insights into how to improve drought assessments by considering the role of temperature in evapotranspiration. This research enriches the existing literature on drought management and climate change adaptation, providing a valuable case study for similar arid and semi-arid regions worldwide.

Keywords: Drought Characteristics, Northeast Algeria, Pareto General Distribution, SPI-SPEI.

IMPACTO DA SECA NO NORDESTE DA ARGÉLIA: ESTUDO COMPARATIVO DOS ÍNDICES SPI E SPEI

RESUMO

Objetivo: O estudo teve como objetivo avaliar as tendências da seca em Annaba, Argélia, considerando o aquecimento global e o clima extremo, utilizando índices quantitativos para melhor compreensão e previsão da seca.

Quadro teórico: O estudo avalia as mudanças na frequência e gravidade da seca na região de Annaba, na Argélia, devido ao aquecimento global e às condições climáticas extremas. Emprega índices quantitativos para melhorar a compreensão e previsão da seca.

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² University of Sciences and Technology Houari Boumediene Algeriers, Algeria. E-mail: a.medjerab@gmail.com Orcid: https://orcid.org/0009-0002-9751-8617
Metodologia: O estudo analisa os dados de temperatura e precipitação (1981-2021) de uma estação meteorológica de Annaba para avaliar as características da seca. Índices padronizados (SPI, SPEI) e análise de valor extremo (Distribuição de Pareto Generalizada) são utilizados para quantificar os impactos de intensidade, duração e temperatura da seca.

Constatações: Nossas análises revelam uma divergência crítica em ferramentas de avaliação da seca. Enquanto temperaturas mensais estáveis sugerem uma influência constante na evapotranspiração, o índice SPEI (incluindo a temperatura) indica um aumento da seca em comparação com o SPI apenas de precipitação. Isso destaca a importância de considerar a temperatura ao lado da precipitação para uma avaliação precisa da seca.

Pesquisa Implicação Prática e Social: Este estudo enfatiza a importância de considerar a interação entre temperatura, precipitação e evapotranspiração para melhor compreensão e previsão de mudanças na seca na região de Annaba, Argélia. Essas percepções são cruciais para a gestão sustentável dos recursos hídricos e a adaptação às mudanças climáticas na região.

Originalidade/valor: Este estudo se distingue por sua análise abrangente de dados climáticos de longo prazo para examinar as tendências da seca em uma região específica (Annaba, Argélia) severamente impactada pelas mudanças climáticas. Ao comparar a eficácia de dois índices de seca (SPEI e SPI), oferece informações valiosas sobre como melhorar as avaliações de seca, considerando o papel da temperatura na evapotranspiração. Esta pesquisa enriquece a literatura existente sobre gestão de secas e adaptação às mudanças climáticas, fornecendo um estudo de caso valioso para regiões áridas e semiáridas semelhantes em todo o mundo.

Palavras-chave: Características da Seca, Nordeste da Argélia, Distribuição Geral de Pareto, SPI-SPEI.

IMPACTO DE LA SEQUÍA EN EL NORESTE DE ARGELIA: ESTUDIO COMPARATIVO DE LOS ÍNDICES SPI Y SPEI

RESUMEN

Propósito: El estudio tuvo como objetivo evaluar las tendencias de sequía en Annaba, Argelia, considerando el calentamiento global y el clima extremo, utilizando índices cuantitativos para mejorar la comprensión y predicción de la sequía.

Marco teórico: El estudio evalúa los cambios en la frecuencia y gravedad de la sequía en la región de Annaba, en Argelia, debido al calentamiento global y a las condiciones climáticas extremas. Emplea índices cuantitativos para mejorar la comprensión y predicción de la sequía.

Metodología: El estudio analiza los datos de temperatura y precipitación (1981-2021) de una estación meteorológica de Annaba para evaluar las características de la sequía. Se utilizan índices estandarizados (SPI, SPEI) y análisis de valores extremos (Distribución Generalizada de Pareto) para cuantificar la intensidad, la duración y los impactos de la sequía.

Hallazgos: Nuestros análisis revelan una divergencia crítica en las herramientas de evaluación de la sequía. Si bien las temperaturas mensuales estábles sugieren una influencia constante en la evapotranspiración, el índice SPEI (incluida la temperatura) indica una sequía creciente en comparación con el SPI de solo precipitación. Esto destaca la importancia de considerar la temperatura junto con la precipitación para una evaluación precisa de la sequía.

Investigación Implicación práctica y social: Este estudio enfatiza la importancia de considerar la interacción entre la temperatura, la precipitación y la evapotranspiración para comprender mejor y predecir los cambios de sequía en la región de Annaba, Argelia. Estos conocimientos son cruciales para la gestión sostenible de los recursos hídricos y la adaptación al cambio climático en la región.

Originalidad/Valor: Este estudio se distingue por su análisis exhaustivo de los datos climáticos a largo plazo para examinar las tendencias de sequía en una región específica (Annaba, Argelia) gravemente afectada por el cambio climático. Al comparar la efectividad de dos índices de sequía (SPEI y SPI), ofrece información valiosa sobre cómo mejorar las evaluaciones de la sequía al considerar el papel de la temperatura en la evapotranspiración. Esta investigación enriquece la literatura existente sobre el manejo de la sequía y la adaptación al cambio climático, proporcionando un valioso estudio de caso para regiones áridas y semiáridas similares en todo el mundo.
1 INTRODUCTION

Drought is a scourge that endangers both people’s lives and industrial and agricultural production (GIEC 2022; Watson et al. 1998). Desertification, ecological degradation, and the impact on human society and the natural environment have all received significant attention from the international community. When the phenomenon lasts for an entire season or an extended period, precipitation levels fall below normal. Precipitation is insufficient to meet the demands of the environment and human activity. Weather droughts are typically characterised by below-average precipitation and above-average temperatures. (Bin et al. 2015; Faye et al. 2017).

The Drought Index is currently used in drought monitoring and analysis research on a global and regional scale. Drought is generally thought to form and develop as a result of a slow accumulation of surface water deficit, with the degree of drought determined by the amount and duration of the deficit. The Standardised Precipitation Index (SPI) is a drought index that is widely used in meteorology. Temperature, wind, and relative humidity are also important factors in determining drought. Drought has appeared in most Mediterranean countries since the early 1980s (Kadi 1995). According to some research, the impact of droughts is expected to grow in the coming years (Watson et al. 1998; Bourque 2000) while temperatures will rise, favouring strong increases in precipitation (GIEC 2022).

In the context of global warming, the ongoing rise in temperature has resulted in a rapid increase in surface evaporation, causing further changes in the equilibrium of the surface water balance. Previously, using precipitation change as a single factor index to describe drought severity, such as the percentage of precipitation anomaly, SPI, and Z, could not fully reflect this new change. Several indices have been developed to study this phenomenon, such as the Anomaly Index of Rainfall (AIR) (Kouame et al. 2014), the Palmer Severity Index (PDSI) (Palmer 1965; Alley 1984), and the Standardised Precipitation Index (SPI) (McKee et al. 1993), the latter is recommended by many organisations such as the World Meteorological Organisation (WMO) and many others for its simplicity, robustness, and flexibility for drought analysis because it can be used at different.
The literature results showed that SPEI based on precipitation and evapotranspiration can more flexibly reflect drought variation characteristics, whereas the SPI index does not affect temperature changes in evapotranspiration. This does not facilitate the identification of drought variation characteristics. The number and timing of drought events are identical; however, both indices showed differences in the 12-month time trend. SPEI showed a drying trend, while SPI showed a humidification trend. The first climate research in Algeria was conducted in 1946, thanks to Seltzer’s rainfall study. The work done in northern Algeria using a comparative method of averages revealed that the magnitude of the rainfall deficit between 1974 and 1992 increased from east to west. They highlight a drought trend similar to that of 1913–1940. Farmer and Wigly (Kadi 1995) describe the evolution of a drought severity index across the same region and predict the occurrence of severe drought. Other drought studies have found that a rainfall deficit began in 1970 and has persisted (Meddi and Humbert, 2000). This deficit leads to serious economic and social problems. As a result, the water supply situation has become more difficult to manage.

Nowadays, these predictions have been confirmed throughout the territory. We are particularly interested in this work in Algeria’s north-east, where rainfall has decreased significantly in recent decades while temperature, evaporation, and rainfall intensity have increased (Khoualdia et al. 2014; Mostafa-Kara 2013; Denidina et al. 2020; Bentchakal 2021). The purpose of this study is to investigate drought in this region using temperature and precipitation data collected at the selected stations between 1981 and 2021. The 12-month SPI and SPEI sequences were constructed using mean values. The SPI and SPEI indices were used to investigate the temporal variation characteristics of drought and moisture, providing a foundation for the optimal allocation of water resources and the development of disaster prevention and mitigation strategies in the region. To support the findings, we estimated the model by maximising the probability of the data collected. In this case, we found that using the likelihood method to estimate the parameters of a temperature probability distribution, specifically the distribution of maximum or minimum temperatures, was the best approach. Given the nature of the data, the Gumbel distribution was chosen (Nagode et al., 2023; Gumbel, 1958).
2 MATERIAL AND METHODS

2.1 STUDY AREA

Algeria’s climate is predominantly Mediterranean, with hot and dry summers and rainy winters. This climate presents a wide variety of regional climates, determined by the country’s geographical location, which is subdivided into seven climate zones (Fig. 1).

**Figure 1**  
*Algeria’s essential climate regions*

In the north, there are three climate zones and a sub-zone, while in the south, there is only one climate zone. Zone A extends along the coastline and part of the northern slope of the coastal chains (maritime Mediterranean climate). Zone B covers the plains and valleys between the coastal chains and the Atlas Tellien (continental Mediterranean climate). Zone C encompasses the high plateaus between the Tellian Atlas and the Saharan Atlas, with altitudes greater than 500m (Mediterranean mountain climate). Zone D covers the Sahara beyond the Saharan Atlas up to latitude. It includes the Chief Valley, located between the Ouarsenis Mountains and the Dahra and Braz Mountains (Köppen and Geiger 1936; Peel et al. 2007).
study area is located in northeastern Algeria (Fig. 2). It covers 36°30’ to 37°10’ North latitude and 7°15’ to 7°50’ East longitude. This region and its municipalities are prone to heavy flooding.

Figure 2

Geographic location of study area

2.2 DATA COLLECTION AND INDICES

Drought is one of the most devastating hazards, with severe consequences. It necessitates extremely stringent monitoring and surveillance, for which climatologists employ more or less reliable calculation techniques. The most widely used method is the Standardised Precipitation Index (SPI) (McKee et al. 1993; Berhail et al. 2021). Geostatistical assessment of meteorological drought in light of climate change. This index is powerful and adaptable (WMO 2013). We used it to monitor the drought, see the effects of the rainfall deficit on the studied region, and prevent or mitigate damage using data from the Annaba meteorological station. The SPI index has the advantage of covering a relatively short period, allowing for the early detection of drought situations. The best time to calculate this is after 20 to 30 years of monthly surveys (Guttman 1994; Faye et al. 2017; Xing 2015).
The primary limitation of SPI is that it can only quantify precipitation deficit because the data is based on monthly precipitation readings. Vicente Serrano et al. (2010) solved this constraint or limit of the SPI by incorporating temperature into the calculations of a new index they call the standardised precipitation and evapotranspiration index (SPEI). Mathematically, SPEI is similar to SPI, but it uses temperature data to calculate potential evapotranspiration. As a result, it combines the sensitivity to changes in evapotranspiration demand (caused by variations and trends in air temperature) with the multi-temporal nature of SPI (Pita 2001; Potop et al. 2014). These severe droughts are caused by below-average precipitation, and rising temperatures can exacerbate droughts in general. To monitor and quantify drought, the drought index must be combined with temperature data.

Our first goal in this study is to provide a comprehensive analysis of drought conditions in the Annaba region from 1981 to 2021, using the SPEI series for various time lags, multi-scale models, the trend, and the spatial-temporal extent of the drought. The second goal is to provide reliable data on SPEI’s performance. In this case, a correlation analysis between SPEI and SPI is carried out without taking temperature into account. Precipitation and temperature data were provided by the National Agency of Hydraulic Resources (NAHR), the National Office of Meteorology (NOM), and the NASA website (NASA 2023).

2.3 CALCULATION METHODS

**SPEI Calculation:** SPEI is based on a climate water balance, which is determined by the difference between Precipitation (P) and potential evapotranspiration (ETP) for a month (Vicente-Serrano 2010).

\[
D_i = P_i - ETP_i
\]  

\( D_i \): provides a simple measure of the water surplus or deficit for the month analysed.

The ETP is calculated according to the Thornthwaite equation (Abramowitz and Stegun 1965). The calculated values \( D_i \) are aggregated at different time scales, following the same procedure as for the SPI. The difference, \( D_{k,i,j} \) in a given month \( j \) and year \( i \) depends on the time scale chosen, \( k \). For example, the difference accumulated in a month of a given year, with a time scale of 12 months, is calculated according to the following formula:
where:  

\[ X_{i,j}^K = \sum_{l=13-k}^{12} D_{i-l,j} + \sum_{l=1}^{j} D_{i,j}, \quad si j < k, et \]  \hspace{1cm} (2)  

\[ X_{i,j}^K = \sum_{l=j-k}^{j} D_{i,l}, \quad si j \geq k \]  \hspace{1cm} (3)  

\[ D_{ij} \] is the difference of P-ETP of the i month of the year, in mm. Then, the log-logistic distribution is selected to normalise the D series to obtain the SPEI. The probability density function of the distributed log-logistic variable is expressed as follows:  

\[ f(x) = \frac{\beta}{\alpha} \left( \frac{x - \gamma}{\alpha} \right)^{\beta-1} \left[ 1 + \left( \frac{x - \gamma}{\alpha} \right)\beta \right]^{-2} \]  \hspace{1cm} (4)  

Where:  

\[ \alpha, \beta, \text{ and } \gamma \] are the scale, shape, and origin parameters, respectively, for the D values in the range (\( \gamma > D < \infty \)). Thus, the probability distribution function of the D series is given by:  

\[ F(x) = \left[ 1 + \left( \frac{x - \gamma}{\alpha} \right)\beta \right]^{-1} \]  \hspace{1cm} (5)  

with, \( F(x) \), SPEI can easily be obtained as normalised values of \( F(x) \). For example, after the classical approximation of Abramowitz and Stegun (Thornthwaite 1948):  

\[ SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \]  \hspace{1cm} (6)  

Where:  

\[ W = \sqrt{2 \ln(p)} \] for \( p \leq 0.5 \) and \( p \) is the probability of exceeding a given D value, \( p = 1 - F(x) \). If \( p > 0.5 \), \( p \) is replaced by \( 1 - p \), and the resulting SPEI sign is reversed.  

The constants are: \( C_0 = 2.515517; \ C_1 = 0.802853; \ C_2 = 0.010328; \ d_1 = 1.432788; \ d_2 = 0.189269 \) and \( d_3 = 0.001308 \). Positive SPEI values indicate above-average moisture conditions, while negative values indicate drought conditions. A drought event is defined when the SPEI
value is \(-1\) over a period. The drought categories based on SPEI values are presented in Table 1.

### Table 1

*Classification of drought by SPI (OMM)*

<table>
<thead>
<tr>
<th>SPI values</th>
<th>Drought categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0 and more</td>
<td>Extremely humid</td>
</tr>
<tr>
<td>1.50 to 1.99</td>
<td>Very humid</td>
</tr>
<tr>
<td>1.0 to 1.49</td>
<td>Humid</td>
</tr>
<tr>
<td>-0.99 to 0.99</td>
<td>Normal</td>
</tr>
<tr>
<td>-1.0 to -1.49</td>
<td>Moderately dry</td>
</tr>
<tr>
<td>-1.50 to -1.99</td>
<td>Severely dry</td>
</tr>
<tr>
<td>-2.0 and less</td>
<td>Extremely dry</td>
</tr>
</tbody>
</table>

*Source: Prepared by Authors (2024)*

### 2.4 SPI CALCULATION

R core software was used to calculate the SPEI indices based on monthly precipitation and temperature data from 1981 to 2021. McKee et al. (1993) of Colorado State University developed the Standardised Precipitation Index (SPI) to calculate rainfall deficits over a given period. It is a powerful, adaptable, and simple index to calculate (Guttman 1998, 1999). Only precipitation data is required. Furthermore, the SPI works equally well for analysing wet or dry periods or cycles. The SPI can be expressed as follows:

\[
SPI = \frac{P_i - P_m}{S} \tag{7}
\]

with, \(P_i\): the rain of the month or year \(i\); \(P_m\): the average rain of the series on the time scale considered; \(S\): the standard deviation of the series on the relevant time scale.

Positive SPI values indicate precipitation above the median, while negative values show precipitation below the median. Because the index is normalised, wet and dry climates can be represented similarly. Table 3 shows the World Meteorological Organization’s classification, which distinguishes seven drought classes ranging from extremely dry to extremely wet.
2.5 STATISTICAL ANALYSIS

The approach used to detect a change in the SPEI database follows the following steps:
- The Statistical Standardized Variable Test was selected.
- The Mann-Kendall statistical test was used to understand long-term data trends.
- The magnitude of the trends was detected by calculating the slope of the line.

Mann-Kendall and Pettit’s tests were run on the XLSTAT computer program (Kundzewicz and Robson 2000). The non-parametric Mann-Kendall test (Mann 1945; Kendall 1975) was used to detect a desiccation or wetting trend in the study area based on the SPEI. Sen’s slope method, which can be found in the Mann-Kendall test on XLSTAT, was used to calculate the magnitude of the change. Pettit’s t-test identified the SPEI data change t-point.

3 RESULTS AND DISCUSSION

3.1 STANDARDISED PRECIPITATION INDEX (SPI)

Table 2 and Figs. 3 and 4 depict the magnitude of the SPI trend and change point models derived from the Mann-Kendall test, Sen’s slope estimator, and Pettit’s test. The trend of data at four-time scales is increasing, as evidenced by the positive Sen and Kendall slope estimators. Positive trends were found to be statistically significant at a 95% confidence level on all four-time scales (SPI 1 month, SPI 3 months, SPI 6 months, and SPI 9 months). The absolute value of the trend gradually increases as the SPI is calculated with more staggered months (0.179 per year for one month, 0.317 per year for three months, 0.390 per year for six months, and 0.428 per year for nine months).

<table>
<thead>
<tr>
<th>Variable</th>
<th>SPI 1 month</th>
<th>SPI 3 months</th>
<th>SPI 6 months</th>
<th>SPI 9 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann Kendall test and Sen’s slope</td>
<td>p Value</td>
<td>0.030</td>
<td>0.023</td>
<td>0.025</td>
</tr>
<tr>
<td></td>
<td>Kendall’s tau</td>
<td>0.179</td>
<td>0.317</td>
<td>0.390</td>
</tr>
<tr>
<td></td>
<td>Sen’s slope</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Trend</td>
<td>Increase</td>
<td>Increase</td>
<td>Increase</td>
</tr>
<tr>
<td>Pettitt test</td>
<td>p Value</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td></td>
<td>Date of rupture</td>
<td>June-02</td>
<td>June-02</td>
<td>Aug-02</td>
</tr>
<tr>
<td></td>
<td>Mean before rupture</td>
<td>-0.128</td>
<td>-0.459</td>
<td>-0.587</td>
</tr>
<tr>
<td></td>
<td>Mean after rupture</td>
<td>0.421</td>
<td>0.527</td>
<td>0.657</td>
</tr>
</tbody>
</table>
Figure 3

*SPI trend models obtained from the Mann-Kendall test of the Sen’s slope estimator*

Source: Prepared by Authors (2024)
3.2 STANDARDISED PRECIPITATION AND EVAPOTRANSPIRATION INDEX (SPEI)

SPEI also showed significant drying trends, with statistically significant downward trends at a 95% confidence level. At the same level, the increase was statistically significant
As a result of the rising temperature, SPEI decreased more than SPI. The magnitudes of the trends, as measured by Sen’s slope estimator, were very small (less than 0.001) and positive at all time scales. The Pettit’s t-test on the series revealed that June, August, October, and December of 2002 were primarily breaking points for four-time scales (SPEI 3, SPEI 6, SPEI 9, and SPEI 12). For the SPI, the months of June, August, and October of 2002 were the breaking points for all time scales (Table 3, Fig. 6). From these breaking points, the SPEI and SPI values on various time scales increased slightly.

**Table 3**

*Trend and year of change of SPEI series on time scales of 3, 6, 9, and 12 months from 1981 to 2021 in the Annaba region*

<table>
<thead>
<tr>
<th>Variable</th>
<th>SPEI 3 months</th>
<th>SPEI 6 months</th>
<th>SPEI 9 months</th>
<th>SPEI 12 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann Kendall test and Sen’s slope</td>
<td>p Value</td>
<td>0.030</td>
<td>0.035</td>
<td>0.034</td>
</tr>
<tr>
<td>Kendall’s tau</td>
<td>0.208</td>
<td>0.264</td>
<td>0.314</td>
<td>0.357</td>
</tr>
<tr>
<td>Sen’s slope</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Trend</td>
<td>Increase</td>
<td>Increase</td>
<td>Increase</td>
<td>Increase</td>
</tr>
<tr>
<td>Pettit test</td>
<td>Date of rupture</td>
<td>juin-02</td>
<td>août-02</td>
<td>oct-02</td>
</tr>
<tr>
<td></td>
<td>Mean before rupture</td>
<td>-0.353</td>
<td>-0.463</td>
<td>-0.537</td>
</tr>
<tr>
<td></td>
<td>Mean after rupture</td>
<td>0.395</td>
<td>0.518</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Variation rate</td>
<td>26340</td>
<td>34106</td>
<td>39058</td>
</tr>
</tbody>
</table>

Source: Prepared by Authors (2024)
Figure 5

SPEI trend models obtained from the Mann-Kendall test of the Sen’s slope estimator

Source: Prepared by Authors (2024)
Figure 6

SPEI break models obtained from Pettit’s t-test

Source: Prepared by Authors (2024)
3.3 CORRELATION ANALYSIS

Pearson’s correlation analysis was performed between the monthly SPI and SPEI over a 12-month accumulation period (Freedman et al. 2007) (Table 4). SPEI and SPI correlations over 12 months were generally medium to low. According to the data, the highest values were obtained between 1991-2001, 2001-2011, and 2011-2021, at 0.706, 0.773, and 0.708, respectively. The data indicate that the region is experiencing a significant drought. The SPI’s time evolution over 12 months was calculated using the average rainfall. Its graphical representation alongside the SPEI enables us to confirm the similarities and temporal differences between them.

Table 4

Mean correlations between SPI and SPEI on the 12-month time scale by 1981-2021 sub-period on the Annaba region

<table>
<thead>
<tr>
<th></th>
<th>SPEI_81-91</th>
<th>SPEI_91-2001</th>
<th>SPEI_2001-2011</th>
<th>SPEI_2011-2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPI_81-91</td>
<td>Pearson Correlation</td>
<td>.680**</td>
<td>0.028</td>
<td>-0.248**</td>
</tr>
<tr>
<td>p Value</td>
<td>0.000</td>
<td>0.765</td>
<td>0.006</td>
<td>0.667</td>
</tr>
<tr>
<td>N</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>SPI_91-2001</td>
<td>Pearson Correlation</td>
<td>0.039</td>
<td>.706**</td>
<td>-0.236**</td>
</tr>
<tr>
<td>p Value</td>
<td>0.670</td>
<td>0.000</td>
<td>0.010</td>
<td>0.704</td>
</tr>
<tr>
<td>N</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>SPI_2001-2011</td>
<td>Pearson Correlation</td>
<td>-0.170</td>
<td>-0.150</td>
<td>.773**</td>
</tr>
<tr>
<td>p Value</td>
<td>0.063</td>
<td>0.102</td>
<td>0.000</td>
<td>0.386</td>
</tr>
<tr>
<td>N</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>SPI_2011-2021</td>
<td>Pearson Correlation</td>
<td>.225*</td>
<td>-0.015</td>
<td>-.226*</td>
</tr>
<tr>
<td>p Value</td>
<td>0.013</td>
<td>0.870</td>
<td>0.013</td>
<td>0.000</td>
</tr>
<tr>
<td>N</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
</tbody>
</table>

Source: Prepared by Authors (2024)

Fig. 7 shows that the SPI was lower than the SPEI and that the difference decreased until 2002, when the SPI became positive and remained higher than the SPI through 2021. The positive SPI values observed between 2002 and 2018 were most likely due to climate change-induced temperature increases, which exacerbated water deficits and resulted in SPEI reductions (IPCC 2013). According to the World Meteorological Organisation (WMO 2013), this situation would most likely result in an intensification of the hydrological cycle, resulting in water scarcity and drought intensity.
3.4 TEMPORAL EXTENT OF DROUGHT AND STATISTICAL SURVEY

a- Temporal extent

This study analysed the duration of drought events for each year (SPEI ≤ −1). Fig. 8 shows the average number of dry months per year from 1981 to 2021. Each year, the various SPEI time scales were taken into account. The various SPEI time scales can represent drought conditions in different ways. SPEI with one month translates the meteorological drought. Agricultural occurs on time scales of 3 to 6 months, whereas hydrological drought indexes of 6 to 12 months are useful for monitoring surface water resources (McKee et al. 1993; Lloyd-Hughes and Saunders 2002; Potop et al. 2014). As shown in Fig. 8, the number of dry months has increased significantly over the study period, with drought conditions occurring more frequently on some time scales. For example, on some time scales, a month has been affected every two years. The maximum number of dry months was -1.5 for SPEI 24 and -1 for SPEI 6, while the average was -1.25 for SPEI 3. The results in Table 4 confirm the presence of a severe drought in the Annaba region.
Figure 8

The annual average number of dry months (SPEI ≤ -1) over time scales of 1, 2, 3, 12, and 24 months from 1981 to 2021

Source: Prepared by Authors (2024)

b- Statistical survey

We chose the Generalised Pareto Distribution (GPD) for modelling. In addition, we identified an optimal threshold for this distribution based on Resnick’s work (1987). This study aims to identify the parameters required for statistical analysis of extreme temperature values (Fig. 09), as discussed in the works of (Christian 2016, Desvina 2019). The temperature data used in this article is based on the average monthly temperatures recorded at the Annaba meteorological station from 1981 to 2021.
3.5 PARAMETER ESTIMATION AND MODEL VALIDATION

This data can be used to estimate the GPD parameters. The parameters are made up of a shape parameter that defines the shape of the extreme value distribution and a scale parameter that quantifies the extreme values’ deviation from the selected threshold. The parameters were estimated using machine learning maximum likelihood. Assuming that our sample of excesses is $X = (X_1, \ldots, X_N)$, it follows the GPD distribution:

$$GPD_u(x) = 1 - \left[1 - \frac{x-u}{\sigma}\right]^{-\frac{1}{\xi}} \quad \xi \neq 0$$ (8)

If, $x = y - u$, the density function $g$ of $GPD_u(x)$ is then for:

$$\frac{d}{dx} GPD_u(x) = g(x)$$ (9)

$$g(x) = \frac{1}{\sigma} \left(1 + \frac{x}{\sigma}\right)^{-\frac{1}{\xi}-1}$$ (10)

The likelihood is given by:

$$\mathcal{L} (\xi, \mu, \sigma, X) = \prod_{i=1}^{n} g(X_i)$$ (11)
The log-likelihood is given by:

$$ t(\xi, \sigma, X) = \ln L(\xi, \sigma, X) $$ (10)

$$ t(\xi, \delta; X) = -N_u \ln \sigma - \left(\frac{1}{\delta} + 1\right) \sum_{i=1}^{N_u} \ln \left(1 + \frac{\xi}{\sigma} X_i\right) $$ (12)

Deriving this function gives:

$$ \frac{\partial t(\xi, \sigma; X)}{\partial \xi} = 0 $$ (13)

$$ \frac{\partial t(\xi, \sigma; X)}{\partial \sigma} = 0 $$ (14)

We obtain a system with two equations and two unknowns, the solution being the Maximum Likelihood estimators \((\hat{\xi}_{N_u}, \hat{\sigma}_{N_u})\).

and, for \(\delta=0\), we have:

$$ g(\chi) = \frac{1}{\sigma} \exp\left(-\frac{\chi}{\sigma}\right) $$ (15)

$$ l(0, \sigma; X) = -N_u \ln \sigma - \frac{1}{\sigma} \sum_{i=1}^{N_u} X_i $$ (16)

We then obtain the estimator, which is none other than the empirical mean of the excesses:

$$ \delta N_u = \frac{\sum_{i=1}^{N_u} X_i}{N_u} $$ (17)

Table 5 displays the estimated scale and shape parameters, as well as the 95% confidence intervals and covariance matrices. Furthermore, Table 5 shows that the shape parameter is negative, indicating that the GP distribution is the Pareto II type. The value is nearly zero, indicating that the exponential distribution is not considered. Confidence intervals are used to help support this conclusion. The QQ plot technique was used to validate the chosen models. The QQ plot for the station shows a nearly linear relationship. This finding indicates
that the GPD type II model (Table 6) is suitable for analysing the highest monthly temperature recorded at the Annaba weather station.

**Table 5**

*GPD model fitted for maximum monthly temperature*

<table>
<thead>
<tr>
<th>Location</th>
<th>Scale</th>
<th>shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated parameters</td>
<td>30.80</td>
<td>2.36</td>
</tr>
</tbody>
</table>

| Standard Error Estimates | 0.37 | 0.25 | 0.06 |

**Table 6**

*Estimated parameter covariance matrix*

<table>
<thead>
<tr>
<th>Location</th>
<th>Scale</th>
<th>shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>0.14</td>
<td>-0.03</td>
</tr>
</tbody>
</table>

| Scale | 0.003 | 0.06 | -0.009 |
| Shape | -0.007 | -0.009 | 0.004 |

AIC = 199.0672  
BIC = 204.4872

Source: Prepared by Authors (2024)

3.6 MODEL VALIDATION

The purpose of the two graphs (Fig. 10) is to examine Henry’s trend line and the discrepancies in the observations. All of the points shown are in alignment, resulting in a linear-shaped cluster. As a result, the Generalised Pareto Distribution (GPD) accurately models the Annaba station’s annual maximum temperatures.
Figure 10

QQ plot for Annaba station

Source: Prepared by Authors (2024)

3.7 GPD ESTIMATED YIELD

Table 7 shows the return rates computed using the Maximum Likelihood (Abdellaoui et al., 2005) method for various monthly maximum temperature return periods, as well as 95% confidence intervals (CI) based on profile probability. The return level represents the distribution’s highest quantile. These values represent the expected number of occurrences that will exceed a certain threshold on average once every “n” years. The value of “n” represents the reciprocal of the probability of exceeding the threshold. For example, a yield level of 100 years indicates that you can expect to exceed this value once every 100 years. This observation will help to assess and manage the risks associated with rising temperatures. Expect temperatures to exceed 31.34°C every two years, 39.99°C every twenty years, and 45.40°C every hundred years.

Table 7

<table>
<thead>
<tr>
<th>Return period</th>
<th>Estimated return level (in °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 years</td>
<td>31.34481</td>
</tr>
<tr>
<td>20 years</td>
<td>39.99167</td>
</tr>
<tr>
<td>100 years</td>
<td>45.40476</td>
</tr>
</tbody>
</table>

Source: Prepared by Authors (2024)
4 CONCLUSION

In this study, the SPEI, calculated using temperatures and precipitation, was used to test drought evolution. This study aims to analyse drought evolution and trends in the Annaba region using the SPEI, which includes temperature and precipitation data, and to compare its performance to the widely used SPI. This study employs and analyses multi-scale models to determine the extent and spatiotemporal characteristics of the SPEI. These various approaches gave us the following results: SPEI multi-scale analysis revealed a drying trend across the majority of the region. Several light to moderate droughts have been recorded since the 1980s, with a few severe episodes in recent years. The Man Kendall test shows that SPEI mean values on four-time scales (1, 3, 6, and 12) have decreased significantly since June 2002. When the SPEI was calculated several months later, the absolute value of the downward trend gradually increased. The spatial-temporal extent of the drought-causing condition was investigated to determine its severity. The number of dry months increased significantly, as did the percentage of years with more than six weeks.

The analysis of the correlations between the SPEI and the SPI over 12 months revealed that the overall correlation between the SPEI and SPI was medium to low. The highest values were obtained during the 1991-2001, 2001-2011, and 2011-2021 sub-periods, at 0.706, 0.773, and 0.708, respectively. Given the significant temperature increase over each month, SPEI outperformed SPI in this case. SPEI has demonstrated its ability to monitor droughts in the Annaba region effectively. As temperatures rise, vegetation growth becomes more sensitive to precipitation (Wu et al., 2020). As a result, future studies should improve the SPEI index to better characterise the drought in the studied region as well as some other regions in Algeria. In this study, we used the SPEI to monitor drought because it is an improved index that considers both precipitation and temperature, as well as its multivariable nature. Drought types could be analysed at different time scales. In future research, we intend to conduct comprehensive performance analyses of various in situ drought indices, including the widely used Palmer Drought Index (PDSI) and its improved variants. To understand temperature maxima in the region over a 100-year period, we used the generalised Pareto distribution (GPD). The goal was to analyse and predict the patterns of maximum temperature variations.

Using the maximum likelihood (Abdellaoui et al., 2005) method to estimate the parameters, it is determined that the Pareto II type (with a confined tail) is better suited for the Annaba weather station. The estimated return rates are calculated over multiple return periods, and temperatures stabilise at around 31.5°C within two years. For example, the model predicts...
that average monthly temperatures will stabilise after approximately 100 years. The temperature reaches 45.5 degrees Celsius. This finding suggests that, regardless of the time of return, the average monthly temperature is expected to exceed 31.5°C, confirming the region’s ongoing drought.

DECLARATION OF DATA AVAILABILITY

Data sets and/or analyses in the course of the present study are available from the corresponding author upon request.

ACKNOWLEDGMENTS

The authors gratefully acknowledged the National Office of Meteorology and the National Water Resources Agency for providing climate data for free. We would also like to thank (power.larc.nasa.gov) for making the data available

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