Characterization of climatic drought in the Souss-Massa watershed (Morocco) using the Standardized Precipitation Index (SPI)

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Abstract. In recent decades, drought has become a significant phenomenon attributed to climate change variability. Its long-term repercussions can lead to substantial agricultural, hydrological, social, and economic consequences. This study uses the Standardized Precipitation Index (SPI) to assess drought in Morocco's Souss-Massa watershed, revealing a significant decline in annual precipitation and highlighting the region's increased drought susceptibility. Specifically, we analyzed data from five weather stations: Amaghouz (1978-2016), Amsoul (1979-2016), Immerguen (1971-2016), Lamded (1982-2016), and Taroudant (1967-2016) using statistical methods recommended by the World Meteorological Organization (WMO) for annual rainfall records. Additionally, we applied the SPI over a 12-month period to identify dry and wet years. Our analysis reveals alternating dry and wet phases, characterized by an overall decline in annual precipitation.

Keywords: drought, Souss-Massa watershed, pluviometry data, Standardized Precipitation Index (SPI).

1. Introduction

Climate change, driven by human activities like greenhouse gas emissions and deforestation, has significantly impacted global weather patterns [1]. This study focuses on Morocco's Souss-Massa watershed, an area experiencing pronounced environmental changes leading to natural hazards and affecting water availability and agriculture. We aim to evaluate rainfall variability across five stations and its impact on drought intensity using the SPI.

The effects of climate change are particularly pronounced in Morocco, where hydrographic basins such as the Souss-Massa have undergone significant environmental changes. These changes have led to natural hazards such as floods, landslides, and coastal erosion, thus impacting water availability and agriculture. Morocco's susceptibility to climate change has driven the adoption of diverse policies and initiatives geared towards safeguarding the environment and fostering sustainable development. Consequently, the nation emerges as a frontrunner in Africa's battle against climate change. [2].

The aim of this study is to examine and analyze the variability of the rainfall patterns at five stations within the Souss-Massa watershed and to assess its influence on the intensification of meteorological drought over various periods, predominantly from 1967 to 2017. This will be achieved by employing statistical techniques endorsed by the World Meteorological Organization (WMO) on annual precipitation data. We will identify wet and dry years using the Standardized Precipitation Index (SPI) to compare cumulative precipitation trends among the five stations, aiming to gain insights into climate change and its implications at the basin level.

2. Materials and Methods

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2.1 Presentation of the study area

The Souss-Massa watershed (Fig.1), is situated in the central-western region of Morocco, covering a total expanse of 27,000 km². This area comprises approximately 21% low-lying plains, spanning 5,700 km² and 79% mountains (21,300 km²). Its geographical limits are delineated by the Anti-Atlas in the southern region, the High Atlas in the north, the Siroua massif in the east, and the Atlantic Ocean in the west. Elevations within this region vary from sea level (0 meters) along the Atlantic coast to the highest peak, Toubkal, towering at 4,167 meters in the High Atlas range. This area encompasses two primary plains: the Souss plain and the Chtouka-Massa plain, characterized by altitudes ranging from 0 to 700 m.

From an administrative viewpoint, the Souss-Massa region comprises the prefectures of Agadir-Ida-Outanane, Inezgane-Ait-Melloul, Taroudant, and Tiznit. The region experiences a climate ranging from semi-arid to sub-desert, featuring a mild coastal climate in the west and a hot semi-continental climate in the east[3]. This area is influenced by cold winds from the Atlantic Ocean (Canary Current) as well as hot winds from the southern Sahara[4].

Annual precipitation exhibits significant variations. During wet years, rainfall can reach up to three times the normal, and it can be up to 15 times higher than during dry years [5,6].

This variation in precipitation is of considerable importance, both temporally and spatially, decreasing significantly from mountainous areas to plains. During the period 1998-2015, average precipitation levels are around 250 to 300 mm per year in the plains, while they reach approximately 500 to 600 mm in mountainous areas[7]. Most of the rainfall between 1980 and 2013 typically falls during the period from November to March, with the dry season lasting from May to October[8]. Between 1980 and 2010, the annual temperature fluctuations vary, ranging from 14°C in the northern High Atlas region to 20°C in the southern Anti-Atlas region. Likewise, annual evaporation rates fluctuate, spanning from 1,400 mm in mountainous and Atlantic coastal areas to 2,000 mm in the plains of Souss, Massa, and Tiznit. In January, minimum values are noted, averaging 35 mm in mountainous regions and 100 mm in the plains, while in July, they increase to 240 mm and 270 mm, respectively[9].

![Fig.1. Geographic location of the Souss-Massa watershed.](image)

2.2 Methodology

In this study, rainfall data from five strategically located stations in the Souss-Massa watershed (Amaghouz, Amsul, Immerguen, Lamded, and Taroudant) were analyzed using the World Meteorological Organization-endorsed statistical methods. The SPI was calculated to identify and compare wet and dry years across these stations. The selection of these weather stations was based on criteria such as data quality and the length of the rainfall records. The operational periods of these stations vary. The data used in this study were collected from the ABHSM (Souss-Massa Hydraulic Basin Agency). Wet and dry periods were determined using the Standardized Precipitation Index (SPI).

The SPI, developed by[10], is designed to quantify precipitation deficits and enhance the detection and monitoring of droughts over a specified period. It is a straightforward, powerful, and user-friendly index based solely on precipitation data [11, 12, 13]. Furthermore, the SPI is equally effective for analyzing both wet and dry periods. The mathematical formula for SPI is as follows:
\[ SPI = \frac{(P_i - P_m)}{\sigma} \]  

\( P_i \): total precipitation of the period (i)  
\( P_m \): the mean precipitation of the period  
\( \sigma \): Standard deviation

### Table 1. Drought classification according to SPI values [14]

<table>
<thead>
<tr>
<th>SPI, ZSI</th>
<th>Drought category</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ −2.00</td>
<td>Extremely dry</td>
</tr>
<tr>
<td>-1.99 to −1.50</td>
<td>Very dry</td>
</tr>
<tr>
<td>-1.49 to −1.00</td>
<td>Moderately dry</td>
</tr>
<tr>
<td>-0.99 to 0.99</td>
<td>Normal</td>
</tr>
<tr>
<td>1.0 to 1.49</td>
<td>Moderately wet</td>
</tr>
<tr>
<td>1.5 to 1.99</td>
<td>Very wet</td>
</tr>
<tr>
<td>≥ 2.0</td>
<td>Extremely wet</td>
</tr>
</tbody>
</table>

### 3. Results and Discussions

To conduct a comprehensive analysis of the rainfall stations used in this study and to accurately assess annual precipitation variations, we calculated the Standardized Precipitation Index (SPI). This index offers the advantage of precisely characterizing years with deficits and excesses, thereby allowing us to infer major trends over the study period.

An examination of the annual variability of rainfall in the Souss-Massa watershed reveals periods of both wetness and dryness. Figure 2 illustrates the annual changes in the SPI at the Amaghouz (a), Amsoul (b), Immereguen (c), Lamded (d), and Taroudant (e) stations.

The SPI analysis for Amaghouz (a) and Amsoul (b) highlights three distinct rainfall periods separated by significant breaks: 1975-1990, 1990-2000, and 2000-2016. It is observed that the SPI index dropped below (-2.1) at the Amaghouz station and below (-2.7) at the Amsoul station, both occurring in 1992/1993, explaining the occurrence of severe drought years. Additionally, within these periods, notable wet years were also identified: 1995 and 2010 for Amaghouz, and 1987, 1995, and 2010 for Amsoul.

At the Immereguen station, the annual change in the SPI calculated over the period 1970-2017 (Fig. 2, c) reveals a significant prevalence of dry years throughout the study period, with the SPI reaching as low as (-2), notably recorded in 1980/1981, indicating extremely dry conditions during those years. Conversely, around the period of 1987/1996, there were notably wet years, with SPI values reaching up to (2.7), particularly observed in 1995/1996. The analysis of the SPI results at the Lamded station during the period 1982-2016 (Figure 2, d) reveals a significant predominance of dry years, with the SPI index dropping to less than (-2.8) in 1992/1993, indicating extremely dry conditions. Additionally, it is observed that the years 1996/1997 and 2010/2011 were characterized by humid to extremely humid conditions, with the SPI reaching as high as (2.2).

The results of the SPI at the Taroudant station (Fig. 2, e) provide insights into the sequence of dry and wet periods throughout the study period from 1967 to 2016. The driest year, with the SPI dropping to less than (-2.1), was recorded in 1994/1995, while the wettest year, with the SPI reaching (2.5), occurred in 2010/2011.
The decline in precipitation observed in this study, particularly noticeable after 1970, aligns with the dry periods identified in earlier research. According to [15], Morocco experienced a deficit phase prior to 1956, succeeded by a phase of normal to surplus precipitation until around 1970. Subsequently, following this period, the Oujda region along with the mountainous sub-region and the southern Atlantic region were notably impacted by drought.

According to the study by [16], significant changes in precipitation in the Souss-Massa watershed were
observed in the late 1960s and early 1970s, characterized by highly irregular inter-annual variations in precipitation, averaging 328 mm in Aoulouz and 190 mm in Taroudant. Additionally, [17] reported that analysis of annual rainfall in this area over the period 1932-2010 indicated wet conditions, with a peak between 1963 and 1965 followed by a decrease since 1973.

Analysis of the SPI revealed a substantial rainfall deficit in this watershed after 1970, with peaks observed at all five stations. These peaks corresponded to extreme and severe drought events. These findings corroborate the research conducted by [18]. The Oum Er Rhia watershed was also affected by multiple dry spells over the period from 1985 to 2013 [19]. The study by [20], shows the Zizi watershed has been affected by periods of severe drought characterised by a significant rainfall deficit. These drought episodes were widespread across the basin, with a minimum SPI index of -2.77 recorded at the Taous station.

Another study on rainfall patterns in northern Algeria over a seven-decade period (1936-2009) revealed a significant reduction in rainfall starting from the mid-1970s, particularly in the western region, with a rainfall deficit ranging between 16% and 43%. The SPI index indicated that the 1980s and 1990s were the most affected by this deficit [21]. In the centre-west of Côte d'Ivoire, a study conducted by [22], revealed that this area has experienced several periods of drought since the 1970s, with the most notable droughts in terms of frequency being of moderate intensity.

Our SPI analysis identified distinct periods of drought and high rainfall. The driest and wettest years align with broader regional climate trends, indicating an increase in the frequency and intensity of drought conditions.

4. Conclusion

This study analysed potential changes in precipitation distribution within the Souss-Massa watershed area. The basin exhibits spatio-temporal variability and irregularity in rainfall, characterized by wet years with excess water and dry years with water deficits.

The study revealed that the Standardized Precipitation Index (SPI) in the Souss-Massa generally highlights periods of surplus and deficit, with alternating wet and dry years during the study period. The results obtained from calculating this index enabled us to identify the most intense drought years at the five stations studied. These dry periods were recorded in 1992/1993 (for Amaghouz and Amsoul), 1980/1981 (for Immerguen), 1992/1993 (for Lamded), and 1994/1995 (for Taroudant). The identified dry periods at all five stations were classified as strong and extremely severe in terms of intensity.

Analysis of the SPI in the Souss-Massa watershed confirms significant climatic variability, with distinct periods of low and high rainfall. These findings underline the need for enhanced regional water management strategies to mitigate the effects of increased drought risk.

References


