ASSESSMENT OF THE SEVERITY OF METEOROLOGICAL DROUGHT IN THE REGION OF AL HOCEIMA, MOROCCO, USING PRECIPITATION TRENDS AND THE SPI

Ahmed ZIAN[1,*], Lahcen BENAABIDATE[2], Khadija HABOUBI[3], Mohammed Mouad MLIYEH[4], & Adam MILEWSKI[5]

[1]*Department of Civil Engineering, Energy and Environment (GCEE), National School of Applied Sciences of Al Hoceima (ENSAH), Abdelmalek Essaadi University, Po Box 03, Ajdir, AL hoceima, Morocco. E-mail: a.zian@uae.ac.ma*
[2]*Department of Environment, Faculty of Sciences and Techniques, LFGE, Po Box 2202 – Route d'Imouzzer, University of Sidi Mohammed Ben Abdellah, Fez, Morocco. E-mail: lahcen.benaabidate@usmba ac.ma*
[3]*Department of Civil Engineering, Energy and Environment (GCEE), National School of Applied Sciences of Al Hoceima (ENSAH), Abdelmalek Essaadi University, Po Box 03, Ajdir, AL hoceima, Morocco. E-mail: k.haboubi@uae.ac.ma*
[4]*Department of Environment, Faculty of Sciences and Techniques, LFGE, Po Box 2202 – Route d'Imouzzer, University of Sidi Mohammed Ben Abdellah, Fez, Morocco. E-mail: Mohammedmouad.mliyeh@usmba ac.ma*
[5]*Department of Geology, University of Georgia, Athens, GA, 30602. E-mail:milewski@uga.edu*
Correspondence: a.zian@uae.ac.ma https://orcid.org/0000-0002-0748-0751

Abstract: The meteorological drought is a devastating phenomenon with far reaching social and economic effects. The study of drought is important for the sustainable management of water resources which are becoming depleted. This study looks at drought in Al Hoceima province of northern Morocco, using analysis of precipitation trends and the Standardized Precipitation Index (SPI) with a simple linear regression followed by an assessment of severity. Meteorological information from five stations in the Al Hoceima region from 1975-2016 were used. According to the results, the 80s are the most affected by the drought. The occasional examination of precipitation has shown that trends in all seasons, precipitation series are expanding. More than 74% of the observation years considered experienced a severe meteorological drought. The southern part of the province has been relatively less dry compared to the central and northern. The maximum severity of the drought was seven consecutive years recorded at the Al Hoceima station, at 74% from October 1978 to November 1985. This drought trend requires intervention to minimize the impact as the earth continues to experience climate change.

Keywords: drought analysis; precipitation; Standardized Precipitation Index; linear regression; parametric analysis; Al Hoceima province, climate change.

1. INTRODUCTION

Drought is recognized by its high intensity in terms of severity and duration. This distinction occurs gradually, but significantly impacts the economic, environmental, and societal aspects of a region for a long period of time. Experts have classified drought into several types, including meteorological, hydrological, and agricultural (Mezősi, et al., 2016). In the field of climatology, meteorological or climatological drought is primarily caused by a lack of precipitation and increasing temperature (or evaporation and transpiration). If it persists, it will lead to hydrological and agricultural drought, eventually resulting in economic drought. Therefore, understanding the concept of aridity and accurate measurement are crucial for water resource projects (Yevjevich, 1967; Gavrilov et al., 2020; Ma et al., 2021). While monitoring drought is important, the most effective strategy for mitigating the damage caused by aridity is to accurately predict the duration of the dry season.

The effects of precipitation and drought changes have been analyzed by many researchers in different fields. Hydroclimatic trend assessments by Gautam et al., (2010), Potopová et al., (2019); water

quality impact by Li et al. (2018), and Murti et al., (2016); and precipitation by Wu et al., (2017), Zhang et al., (2021), and Rajić & Bezdan (2012). The extent of expected climatic consequences for the hydrologic framework of various geographic regions can be assessed by utilizing these studies. Similar research design and evaluation comparing various hydrologic factors with meteorological indices has been performed in other regions (Huang et al., 2017; Sun et al., 2019; Gu et al., 2023).

The province of Al Hoceima has faced remarkable water stress in recent years due to socio-economic and agricultural needs. According to the Provincial Directorate of Agriculture, the useful agricultural area (UAA) of the province is about 729,149 ha, of which 13.5% is used for irrigation, totaling 98,511 ha. The province consists of diverse landscapes including beaches, mountains, and forests. It also has a Mediterranean climate, with dry, hot summers and rainy, cool winters, making it an excellent tourist destination. The lack of precipitation has also affected the region's largest water table, the Rhiss-Nekor plan, which has become vulnerable to marine intrusion. Although the government has implemented water resource management strategies to meet the region's socio-economic and agricultural needs, such as the construction of dams (which face siltation issues) and the installation of a desalination plant (despite its high cost), the lack of precipitation makes water resource management challenging, and monitoring of water potential crucial.

In this study, meteorological drought was assessed. Various indices and strategies have been utilized to monitor this phenomenon on the planet. Among these, the Standardized Precipitation Index (SPI) (McKee et al., 1993) is the most useful due to its simplicity, reliance only on precipitation data, and ability to be calculated for different time periods. It was developed to serve as a moisture supply index. For instance, shorter durations of weeks or months can be used to apply the SPI for agricultural or meteorological purposes, while longer durations of years can be used for hydrological and water management purposes (Quiring, 2009). As a result, the SPI has been widely utilized by drought scientists (Tsesmelis et al., 2023; Zerouali et al., 2021) particularly in the Mediterranean region (Sabău et al., 2015). Additionally, the World Meteorological Association (WMA) uses this index to classify drought (Ojara et al., 2020). The SPI can be used for different hydrological factors including stream flow, storage supply, and reservoir overflow, using time periods of 3 months, 1 year, 2 years, and 4 years (Lorenzo-Lacruz et al., 2010). It was concluded that the SPI successfully identified water deficiencies at different time scales, and that the strongest

relationships with reservoir inflow were observed at 4-year time scales for the SPI.

The purpose of this study is to assess the spatio-temporal meteorological drought in terms of onset severity, frequency, and extent using the Standardized Precipitation Index (SPI) at a 12-month timescale in the Al Hoceima region. The study utilized five synoptic stations that were distributed homogeneously in the region. The monitoring of meteorological drought in this study employed following techniques;

Autocorrelation test to detect trends,

Characterization of the climatic regime of the region using the "Rainfall Variability Index",

Assessment of parametric trend analysis techniques: Linear regression,

Exploration of temporal monotonic trends in the time series of drought, SPI, and precipitation based on annual, monthly, and seasonal timescales in the Al Hoceima province between 1975 and 2016.

2. MATERIALS AND METHODS

2.1. Study area and data collection

The Al Hoceima province, situated in the north of Morocco along the Mediterranean coast, spans an area of 2315 km². The central and southern parts of this region are elevated with hills and mountains, whereas the northeastern side is predominantly flat, showcasing the Rhiss and Nekor plain. The river basin is divided into two big sub basins (Nekor and Rhiss) and three small basins (El Ansar, Beni Boufrah, and Feddal). A total of five synoptic stations were situated on the main tributaries of these river basins. Series of month-to-month precipitation information were gathered from 5 concise stations from Al Hoceima territory (Figure 1) for the period 1975-2016. They were obtained from the government agency that manages the water resources in the Northern Morocco region called ABHL (Agence des bassins hydrauliques de Lokouss), which controlled, collected, and compiled the precipitation data (Table 1). Note that the availability of data is acquired through the agreement between the ABHL agency and the National School of Applied Sciences of Al Hoceima. The rainfall datasets were examined to assess irregularity, homogeneity, and the lack of patterns.

2.2. The General climate of the Al Hoceima province

The climate of the province is Mediterranean type with dry and hot summers and rainy and cool winters. Nevertheless, there are three areas with very

Table 1. Characteristics of selected meteorological stations in Al Hoceima basins and those Specific local conditions.

| station	X	Y	Z	River	Years with Data	Specific Local Conditions
Tamassit	626 550	495650	220	Ghiss	1975-2016	Central Rif mountain
Tamellaht	645 050	488950	275	Nekkour	1975-2016	Nekor Alluvial Plain
Beni Boufrah	598 200	506000	130	Bni Boufrah	1975-2016	BOKOYA West Coastal Area
Targuist	605 800	477500	810	Ghiss	1975-2016	South Rif Mountain Area
Al Hoceima	634 000	516 800	35	-	1975-2016	East Coastal Area
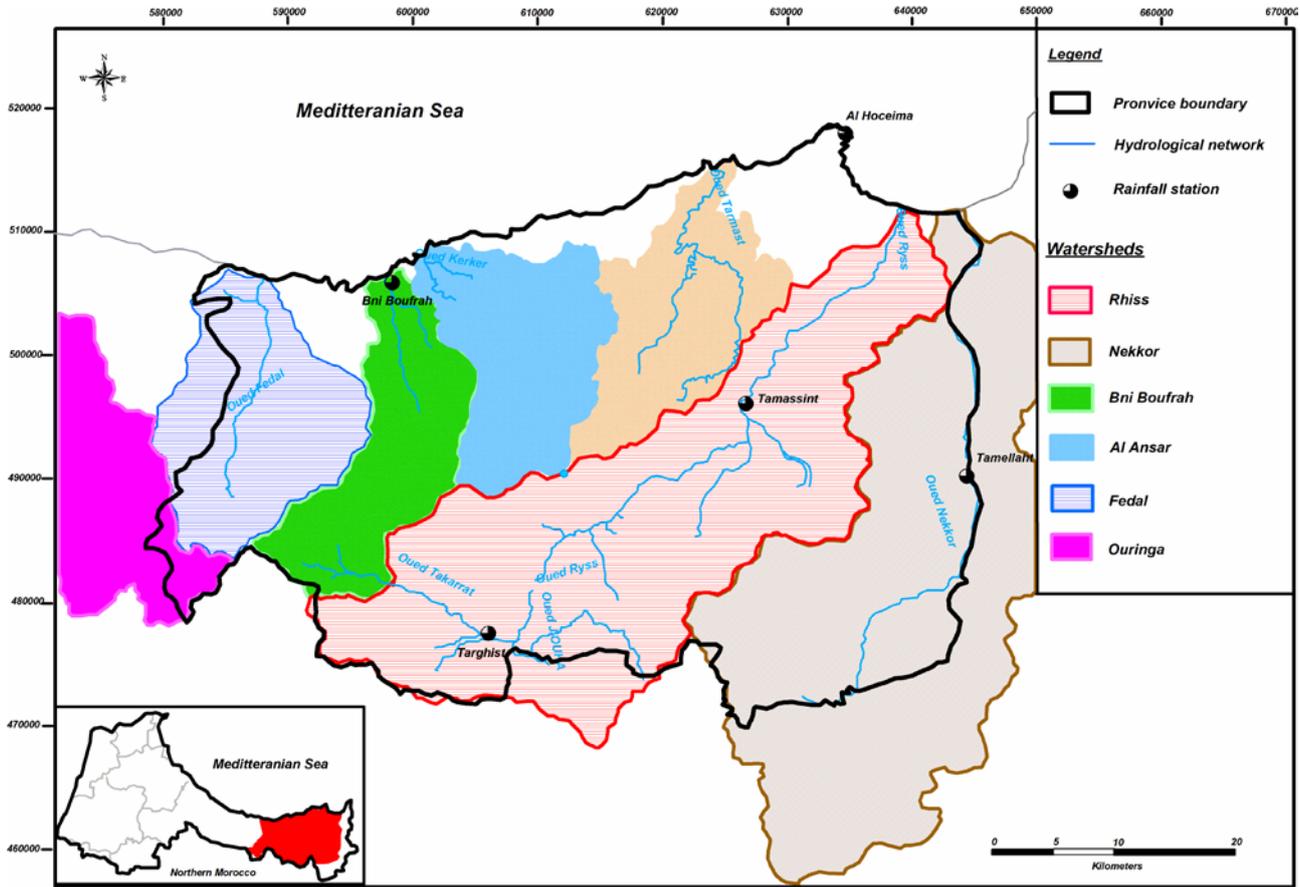
Figure 1. Location map of rainfall stations in the Al Hoceima province

different climates:

The reliefs have a Mediterranean mountain climate with high winter precipitation, often in the form of snow, and a dry and quite hot summer;

The coastal fringe has relatively high humidity but lower rainfall than in the reliefs, and temperate to warm temperatures;

The rest of the ridge and the Bokoya have a semi-arid, hot, and dry climate.

The mean annual rainfall in the Al Hoceima province ranges from 243 mm in the northern and western regions to 463 mm in the southern part of the province. The average annual rainfall is highly variable in the province, depending on altitude and proximity to the coast, but in general, it decreases from south to north. Occasional precipitation in the form of fog or mist is significant.

2.3. Statistical methods

2.3.1. Autocorrelation test

In this study the Rho Spearman and Mann Kendall tests were employed. Series pre-whitening should be performed prior to these tests to eliminate any sequential relationship between series data (Von Storch & Navarra, 1995). The lag-one serial correlation coefficient of test information xi (assigned by r_1) figures as (Salas et al., 1980).

$$r_1 = \frac{1/n-1\sum_{i=1}^{n-1}(x_i-\mu(x_i)).(x_{i+1}-\mu(x_i))}{1/n\sum_{xi=1}^{n}(x_i-\mu(x_i))^2} \quad (1)$$

$$\mu(x_i) = 1/n\sum_{i=1}^{n}x_i \quad (2)$$

Where; (x_i): Mean of station-observed precipitation data; n: sample size.

2.3.2. Rainfall variability index (δ)

Precipitation inconstancy list (δ) is determined as:

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$$\delta i = (Pi - \mu)\,\sigma \qquad (3)$$

Where δi = precipitation changeability list for year "i", Pi = yearly precipitation for specific year "i", μ and σ are the mean yearly precipitation and standard deviation for the period in the range of 1975 -2016. A negative δ indicated a dry spell year.

According to the δ index using precipitation time series, different climate systems can be defined as follows (WMO, 1975):

$$P < \mu - 2.\sigma \qquad\qquad Incredibly\ dry$$
$$\mu - 2\sigma < P < \mu - \sigma \qquad\qquad Dry$$
$$\mu - \sigma < P < \mu + \sigma \qquad\qquad Ordinary$$
$$P > \mu + \sigma \qquad\qquad Wet$$

2.3.3. Standardized Precipitation Index (SPI)

The SPI, or Standardized Precipitation Index (McKee et al., 1993), assesses the likelihood of precipitation for various time periods. Its versatility covers both short-term agricultural and long-term hydrological applications. Different time scales are used to capture drought impacts on diverse water resources. Short-term effects are evident in soil moisture conditions, while longer-term anomalies influence groundwater, sub-surface flow, and reservoir storage (Houborg et al., 2012; Felton et al., 2021). By offering early drought warnings and severity assessments, the SPI's standardized nature facilitates cross-period and cross-regional drought comparisons accommodating diverse climatic conditions (Vidal et al., 2009; Khalili et al., 2011; Wang & Ma, 2023). As a probabilistic tool, the SPI excels in drought risk analysis and finds broad applications (McKee et al., 1995; Hayes et al., 2005; Cancelliere et al., 2007; Won et al., 2020).

The precipitation record that is extended for a certain location and time period determines the SPI. To ensure a zero mean SPI for the region and time period, this record is fitted to a probability distribution, often the gamma distribution, and then converted into a normal model. Positive SPI values indicate precipitation above average, while negative values indicate precipitation below average. The standardization allows the SPI to handle both drier and wetter conditions equally, making it possible to observe rainy periods. Using bounds α and β evaluated for various time scales (3 months, 6 months, one year, 2 years, and 4 years), the calculation involves fitting a gamma probability distribution function to the precipitation frequency distribution. The unique aspect of the gamma distribution is its probability density function:

$$g(P) = \frac{1}{\beta^\alpha \Gamma(\alpha)}\, p^{\alpha-1} e^{-P/\beta}\ for\ P > 0 \qquad (4)$$

Where α and β: parameters of the function (they are both positive), P is the rainfall sum and Γ(α) is the gamma capability of α. The parameter's estimator is Maximum likelihood who is the ideal assessment (Thom 1966). M (Mean) and σ (standard deviation) of the rainfall time series can be determined considering the parameters (α and β) where M = αβ and σ = β√α, separately.

The total likelihood of rainfall $G(P)$ happening during a specified period of time is defined by:

$$G(P) = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^p p^{\alpha-1} e^{-P/\beta} dp . \qquad (5)$$

Given that this equation lacks validity when precipitation equals zero, the formulation of the comprehensive cumulative probability distribution encompassing zero is given by:

$$H(P) = q + (1 - q)G(P) \qquad (6)$$

Where q and 1 − q are the probabilities of nothing and non-zero precipitations separately. Monthly precipitation time series commonly include instances of zero precipitation. In this examination, considering bigger period scales (e.g., a year), the likelihood of invalid precipitation was null. Statistical analyses employ RDIT software, and the SPI is characterized by the accompanying condition:

$$SPI = \frac{Pi - m}{\sigma} , \qquad (7)$$

Where Pi: Rainfall of i year,

M: Mean annual precipitation according to the chronic data

σ: Standard deviation.

Note that the SPI serves as a unitless indicator with negative values signifying drought and positive values indicating wet conditions. Utilizing the SPI, one can ascertain drought intensity, magnitude, and duration, along with climatic classification, incorporating probabilities of occurrence and ΔP% (Table 2).

Table 2. Wet and drought period classification according to SPI index (McKee et al., 1993)

Class	SPI values	Drought status
1	+2 and more	Extreme wet
2	1.5 to 1.99	Very wet
3	1 to 1.49	Moderate wet
4	0.99 to -0.99	Near Normal
5	-1.49 to -1	Moderate dry
6	-1.99 to -1.5	Very dry
7	-2 and less	Extreme dry

2.3.4. Severity of drough.

The measurement of aridity in a specific location's climate, as indicated by the SPI index, is

represented by the severity of drought. This can be determined using the 'threshold of drought' index, which is a value that indicates the condition of drought. Typically, it starts from zero or a value less than zero. Therefore, when calculating the value of an SPI record, all the values falling into the drought categories indicate the severity of the drought.

3. RESULTS

3.1. Basic statistical data

The measurable precipitation data at the stations studied during the period 1975-2016 is reported in Table 3. We note that the monthly average varies between 19.4 mm and 38.2 mm, a difference of 18.8 mm. In addition, the Beni Boufrah station in the northwest of the region had the minimal mean, while the Targuist station, located in the high altitudes, recorded the highest mean. The most remarkable coefficient of variation (CV) for the estimation of precipitation was recorded in the southwest of the region at Tamassit station with a value of 1.23%, while the lowest value was found in the northeast at Al Hoceima station with 1.16%.

3.2. Precipitation values frequencies

The frequency observations selected by the values of the data series between 1975 and 2016 in all stations (Figure 2) show that the lower values

Table 3. Statistical results relating to the time series between 1975-2016 recorded at the five stations studied

Station name	Min(mm)	Max(mm)	Mean(mm)	SD(mm)	CV(%)	Cs	Ck
Tamassit	0	237	22.9	28.2	1.23	2.87	16.4
Tamellaht	0	238	23.2	27.6	1.19	2.58	13.9
Beni Boufrah	0	234	19.4	23.5	1.21	2.99	19.8
Targuist	0	309	38.2	46.5	1.22	2.44	10.8
Al Hoceima	0	204	24.6	28.7	1.16	2.21	10.2

SD: Standard deviation, CV: coefficient of variation, Cs: Skewness coefficient, Ck: Kurtosis coefficient
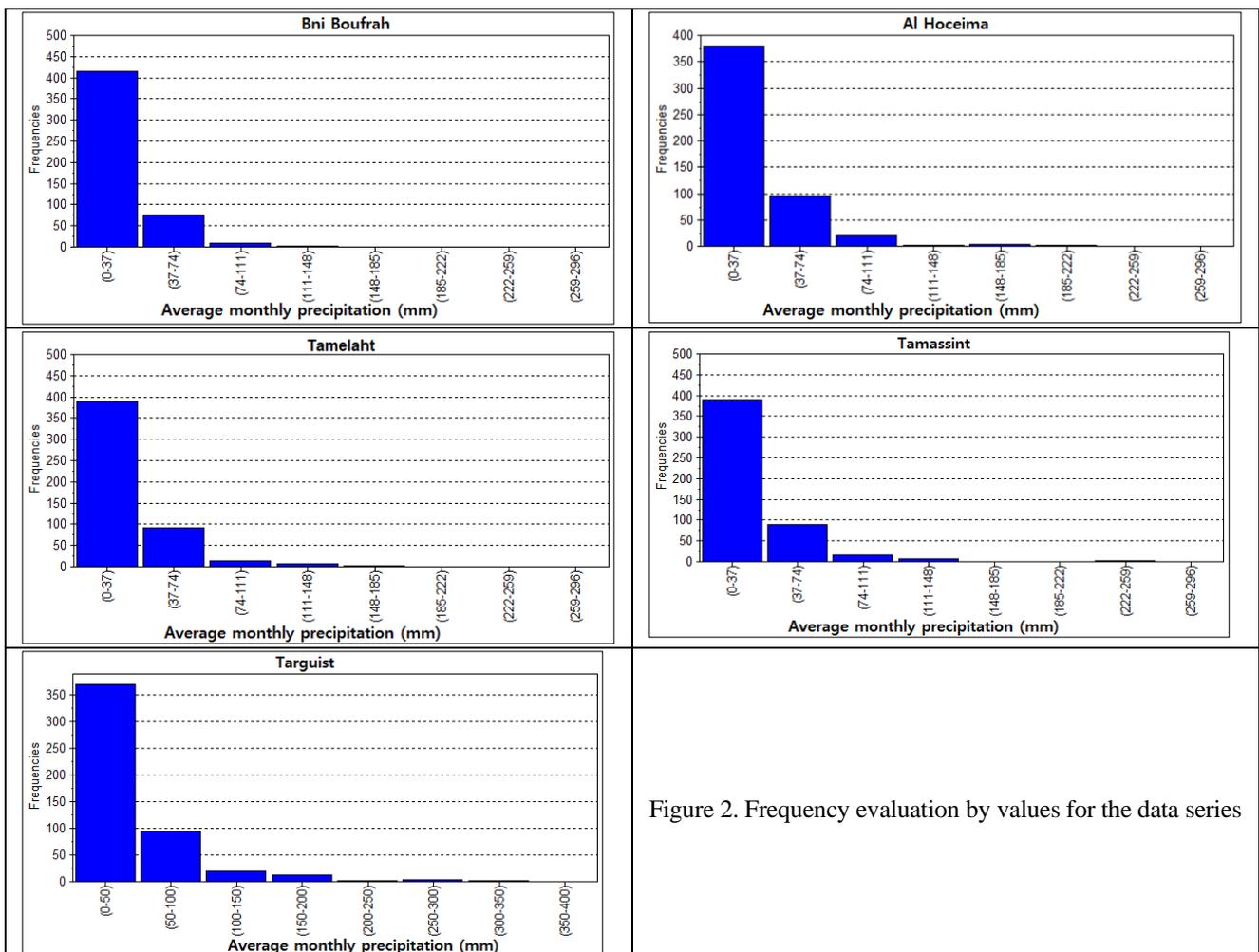

Figure 2. Frequency evaluation by values for the data series

between 0 and 37 mm have a higher frequency, exceeding 350% for all stations. The maximum frequency values were recorded at Beni Boufrah station and exceeded 400%.

3.3. Serial autocorrelation test

To verify the independence of the precipitation time series, the sequential relationship coefficient may provide a better understanding. It should be noted that for random time series the autocorrelation function will be 0 for any non-zero values. Since r_1 is less than zero, the hypothesis H_0 (r=0), which states that there is no persistence in the time series and no correlation between two successive observations, is accepted.

Figure 3 presents the results of the autocorrelation test for the precipitation data collected from the 5 selected stations. As shown, the precipitation exhibited positive sequential connections. The highest sequential connection of 0.55 was observed at the Beni Boufrah station, while the lowest sequential relationship of 0.28 was identified at the Targuist station.
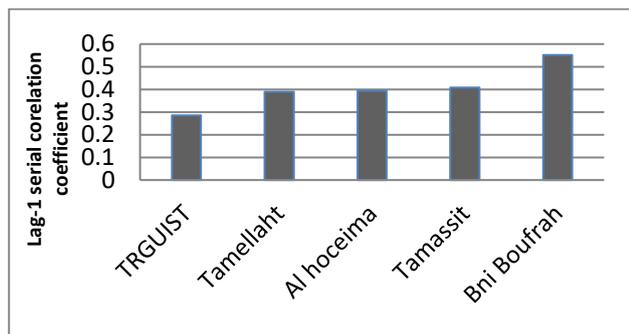

Figure 3. Auto-correlation test at the synoptic studies stations using Lag-one serial correlation coefficient.

3.4. Rainfall variability index

Yearly precipitation changeability records for the observed stations are presented in Figure 4, while Figure 5 displays the distribution of dry classification throughout the period 1975-2016, as outlined by WMO (1975). Three main periods of long droughts were identified, namely 1978-1985, 1999-2005, and the most recent period from 2010 to 2015, particularly at the Tamassit, Beni Boufrah, and Al Hoceima stations. It should be noted that Beni Boufrah, Tamellaht, and Tamassit stations recorded 29 drought years, which is more than 69% of the 42 observed years. Al Hoceima station recorded 27 drought years, Targuist station has the lowest number of drought years with only four.
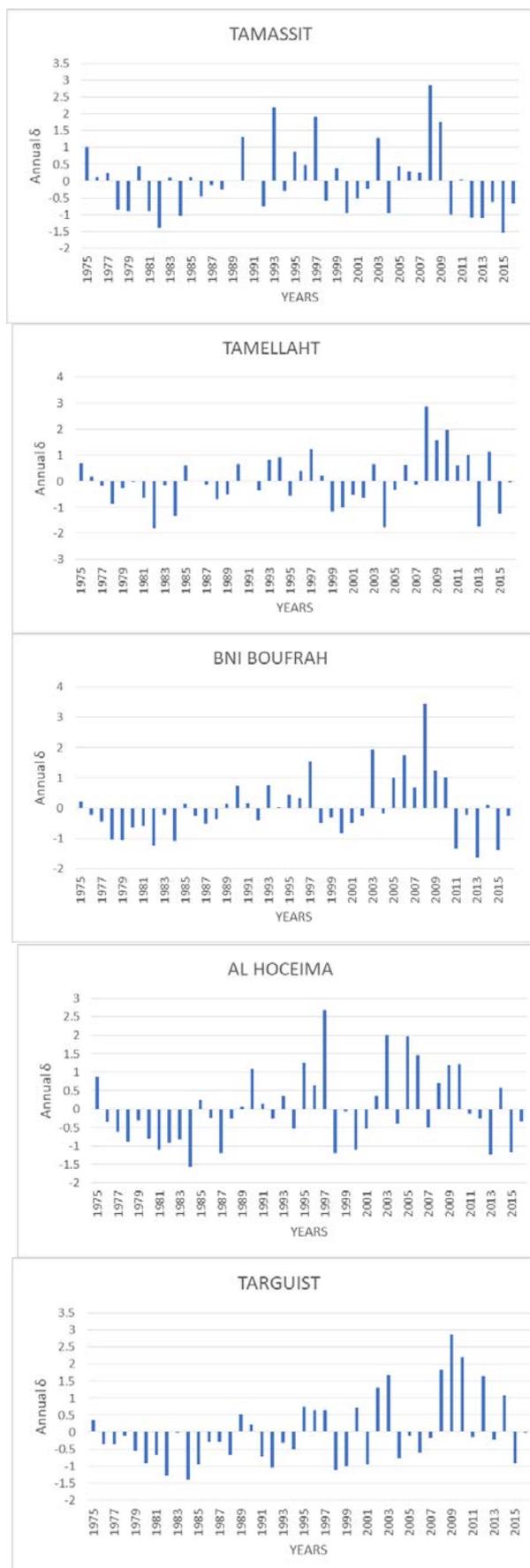

Figure 4. Rainfall variability indices for the observed time series at the studies stations (continued)
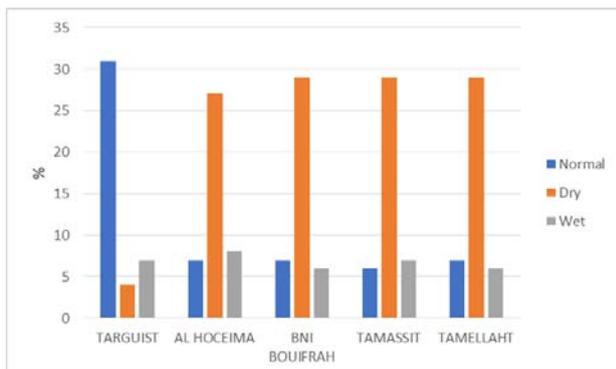
Figure 5. Rainfall variability index for the 5 synoptic stations during the period 1975–2016 according to the dry classification.

3.5. Linear regression method

The results of the linear regression method applied to annual rainfall data over the period 1975-2016 are summarized in Table 4. As shown, a significant increasing trend was detected at four stations (Tamellaht, Beni Boufrah, Targuist, and Al Hoceima). The observed period at those stations is considered a good predictor at the 95% confidence level, as the p-value for the slope of the linear regression line is lower than the chosen alpha level of 5%. The slope for the linear regression at the TAMASSIT station is still negative, indicating a decreasing trend.

3.6. Analysis of SPI-12

3.6.1. Characteristics of yearly SPI

The time series of the annual SPI index at the 5 short stations throughout the period 1975-2016 is presented in Figure 6. It is noted that the meteorological drought occurred for more than 30 of the 42 years considered. Table 5 summarizes the drought inventory at the different stations, considering the drought severity classification given in Table 2. It should be noted that between 10 and 7 years are recognized as periods of extreme drought in all stations except the Targuist station, which recorded only four years of extreme drought. The worst drought recorded at any station was during the winter of 1999 at Beni Boufrah.

Table.4. Linear regression parameters for annual precipitation over the period 1975-2016

Station	intercept	Montage interest rate (%)	P-value for montage interest rate
Tamassit	475.57	-0.1	0.9
Tamellaht	-2723.26	1.5	0.16
Bni Boufrah	-3130.13	1.68	0.1
Targuist	-13933.8	7.21	0.005
Alhoceima	-3395.2	1.85	0.1

3.6.2. Autocorrelation for SPI-12

The autocorrelation for the yearly SPI during the period 1975-2016 at the observed station is presented in Table 6. As shown, all the consecutive relationships are positive and were observed in all seasonal series of the stations.

Table 6. Autocorrelation test for seasonal rainfall data

Station name	W	Sp	Su	A
TAMASSIT	0.36	0.13	0.2	0.37
TAMELLAHT	0.52	0.19	0.12	0.24
BNI BOUFRAH	0.56	0.26	0.37	0.55
TARGUIST	0.54	0.4	0.5	0.6
AL HOCEIMA	0.43	0.17	0.28	0.48

W: *Winter; Sp: Spring; Su: Summer; A: Autumn*

Table.7. characteristics of the severity of drought according to SPI-12 index at 5 observed stations during the period between 1975-2016.

Station	Maximum severity of drought (%)	Period (year and month)	Number of drought years
Al Hoceima	74	1978. 10 - 1985. 11	7
Bni Boufrah	60	1978. 04 - 1983. 12	5
Targuist	59	1979. 01 - 1983. 11	4
Tamellaht	55	1978. 05 - 1985. 09	7
Tamassit	28	1981. 09 - 1983. 11	2

Table 5. Statistics of yearly SPI value at stations studies

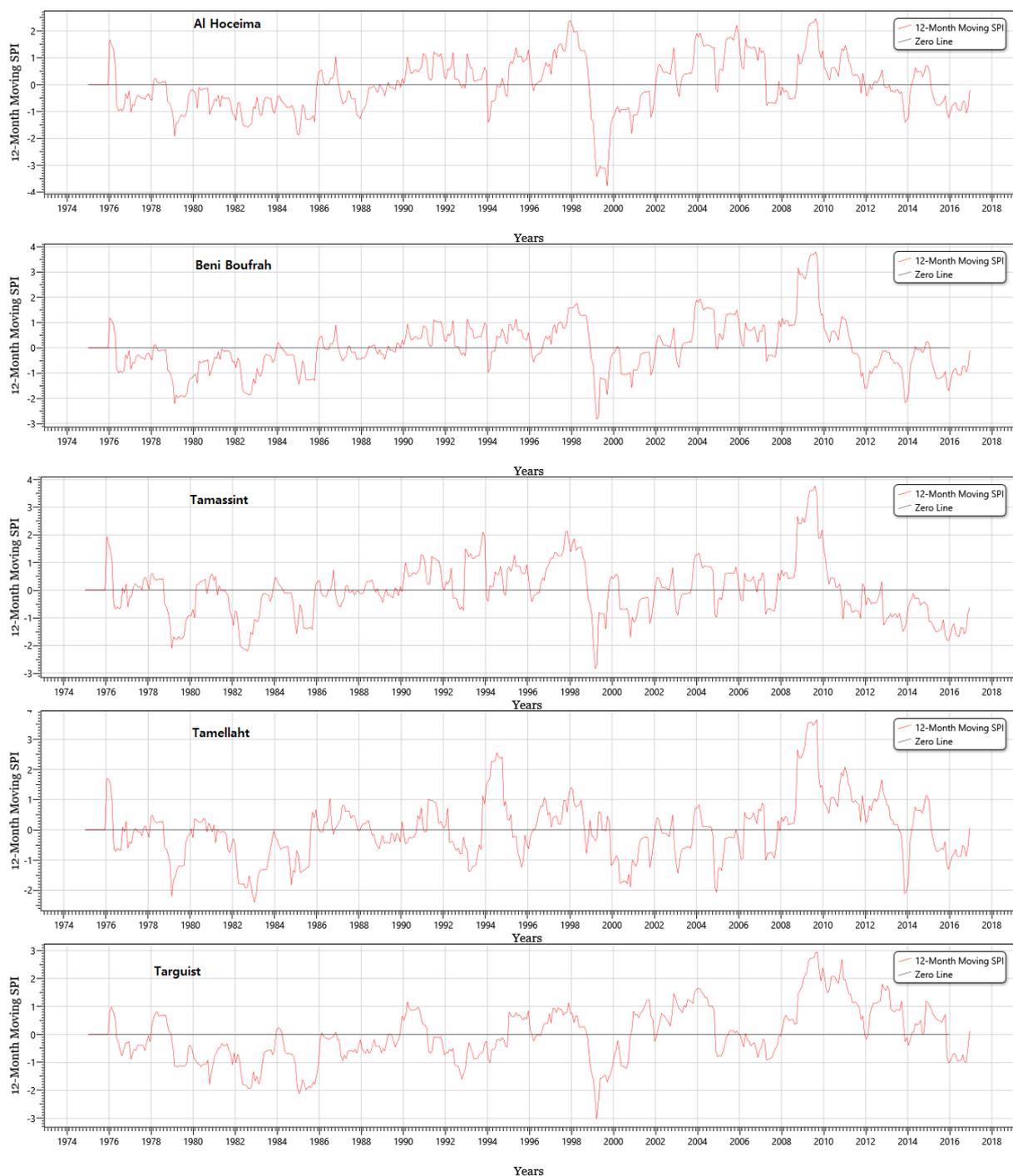|	Extreme drought			Number of drought years by class			
	SPI	YEAR	Season	Moderate drought	Severe drought	Extreme drought	Total
TAMASSIT	-3.1	1982	Winter	14	12	07	33
TAMELLAHT	-2.979	1999	Winter	16	09	10	35
BNI BOUFRAH	-3.162	1999	Winter	13	11	07	31
TARGHIST	-2.448	1999	Spring	10	18	4	32
EL HOCEIMA	-3.066	1982	Winter	13	11	9	33

Figure 6. Plots of yearly SPI at the five stations throughout the period 1975–2016

3.6.3. Severity of drought

The last important parameter of drought is severity, which characterizes the extent of dry conditions. The severity of drought is determined by the values of the Standardized Precipitation Index (SPI) that fall within the drought classes. In this case, a SPI value of zero is assigned to the threshold of drought severity. Figure 7 shows the severity of drought at the five study stations from 1975 to 2016. Table 7 provides details about the characteristics of drought severity. It is worth noting that the highest severity of drought, reaching 74%, was recorded at the Al Hoceima station between October 1978 and November 1985, which occurred during a seven year period of drought. The Beni Boufrah station experienced five years of drought between March 1978 and December 1983, with a severity of 60%. Targuist and Tamellaht stations experienced drought severities of 59% and 55%, respectively, during the periods of May 1981 to September 1985, and September 1985 to March 1991. However, Tamassit station had the lowest severity of drought, with only 28% over a two-year period.
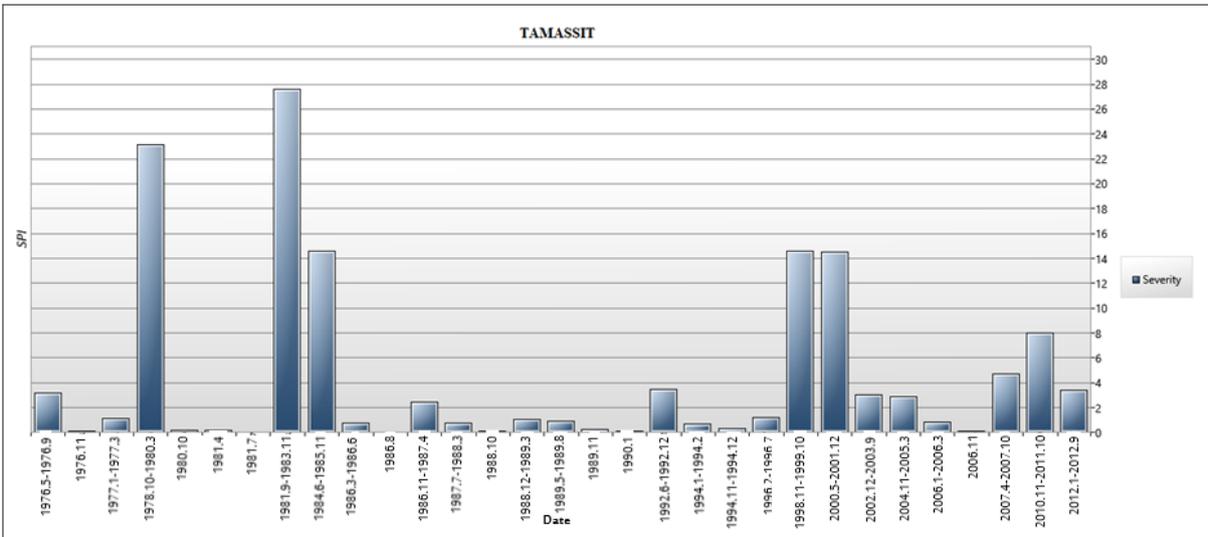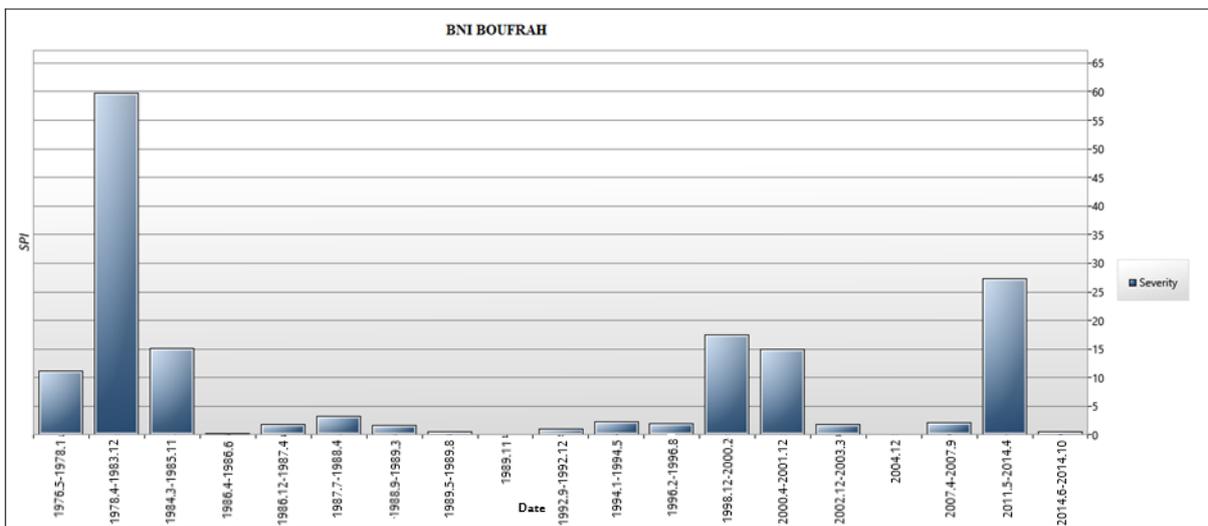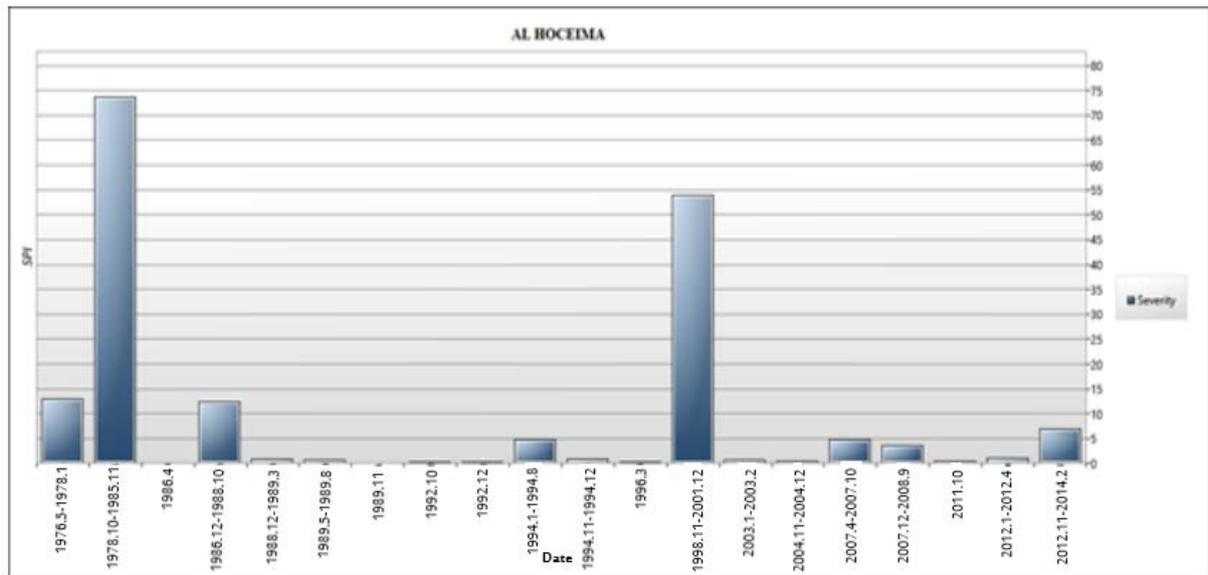
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Figure 7. Severity of drought at 5 provincial stations (period 1975-2016)

4. DISCUSSION

According to the basic statistical results, there is significant spatial variation in monthly average precipitation across the region, with high-altitude areas (Targuist) receiving more precipitation compared to lower-altitude areas (Beni Boufrah). The coefficient of variation indicates that
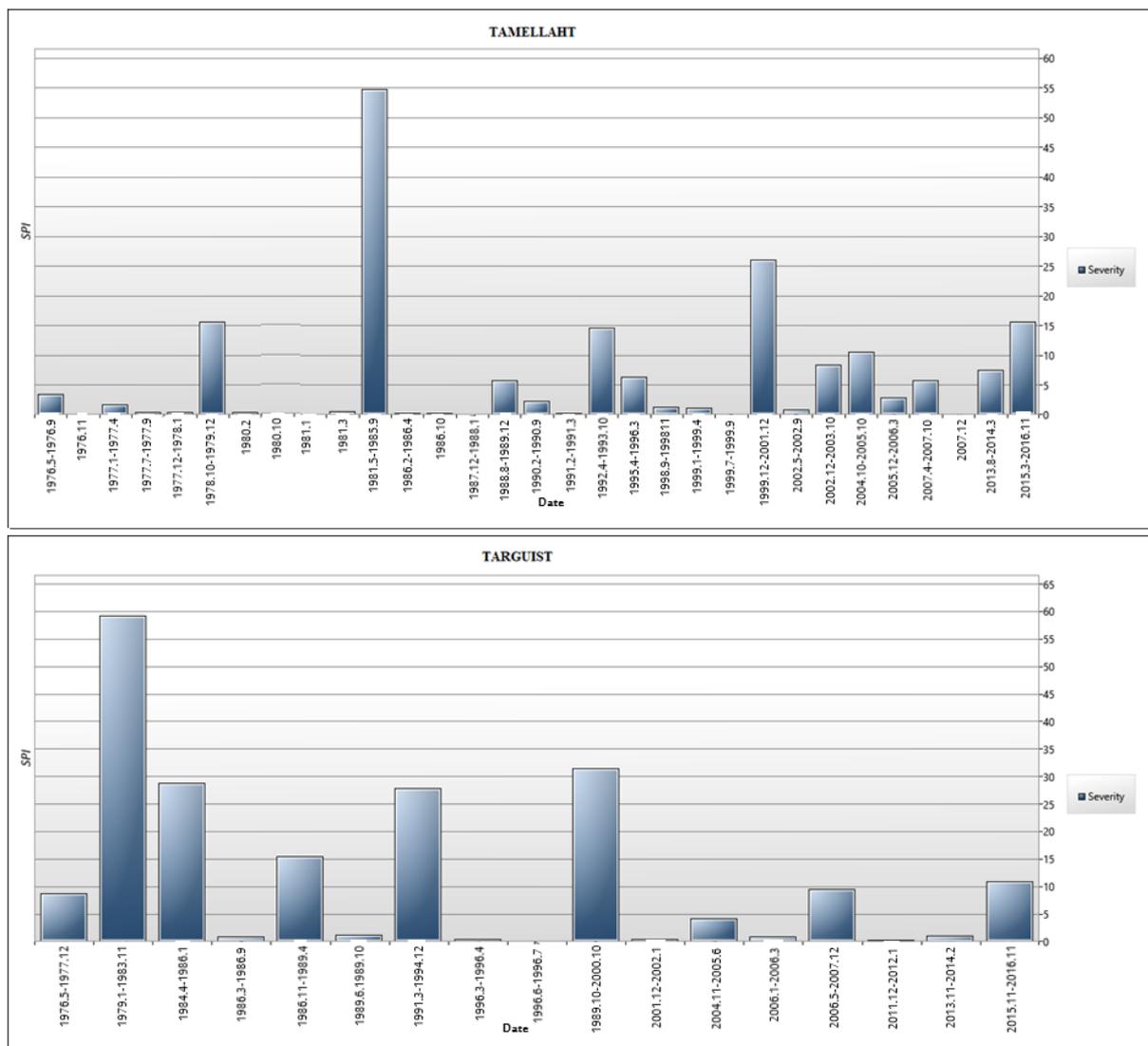
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Figure 7. Severity of drought at 5 provincial stations (period 1975-2016) (continued)

precipitation is slightly more variable at Tamassit Station compared to Al Hoceima Station, suggesting differences in precipitation consistency within the region.

The frequency evaluation by values, for the data series (Figure 2), show that the North-west region records the highest frequency (about 420%) of the lowest precipitation (interval 0-37 mm). In this situation, we note that there is no difference between the province's mountainous inland and coastal sections. This indicates a significant lack of precipitation that cannot be explained by the mountain's higher humidity or the proximity to the sea, which, on the contrary, produces abundant precipitation.

The auto-correlation test (Figure 3) reveals that the sequential connection increases progressively when going from the south to the northwest via the northeast. This variation can be explained by the diversity of microclimates that exist in the region (see

section 2.1). Despite this, the results provided by the rainfall variability index (Figure 5) were able to show that periods of drought were detected in the northern regions (Tamassit, Al Hoceima, and Beni Boufrah stations). The south (Targuist Station) remains protected from the phenomenon of drought since it is located inside the Rifain belts which are characterized by a wet climate. However, this does not apply to Tamassint station, which is also located in the mountain region.

All the statistical studies show that most precipitation occurs in the southwestern area of the region, which is characterized by high mountains such as Targuist, Sidi Boutmim, and Zarkt. However, the coastal area (Beni Boufrah and Al Hoceima Stations) received minimal precipitation, likely due to the fact that most of the incoming precipitation originates from the Atlantic Ocean, with northerly winds during cold North Atlantic events (Bout-Roumazeilles et al., 2007), and is blocked by the Rif

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mountain. The study on rainfall variability in this region (Salhi et al., 2019) confirms this. In fact, the study revealed that heavy cloud masses are primarily released within the mountain range, acting as an atmospheric barrier or enhancing convection. When these cloud masses are lighter, they move towards the plains where they release less precipitation. As a result, rainfall varies from the central region to the coast, as well as from west to east. The amount of rainfall gradually decreases until it reaches a point where the average monthly rainfall is less than 50 mm (Salhi et al., 2019). As we move further south, the mountains become higher, and precipitation becomes more abundant. This likely explains the consistent occurrence of drought in the Targuist station (Rainfall variability index – Figure 5). However, it is expected that humid conditions occur only in 7 of 42 years of observation. This situation can only be attributed to the prevailing drought trend in the region, which will undoubtedly have an impact on the agricultural and economic sectors.

The results of the SPI index (Figure 6 and table 5) show that the Al Hoceima province exhibits a high severity of drought, ranging from 83.3% to 73.8%, according to the classification of McKee et al, 1993 (Table 2). Specifically, it should be noted that the northern region (Al Hoceima city) and the southeast region (Tamellaht) recorded 9-10 years of extreme drought, while the central zone (Tamassit) and the northwest region (Beni Boufrah) experienced 7 years of extreme drought. Furthermore, it is interesting to observe that the periods of maximum extreme droughts all occurred in the autumn, which is typically considered a season with higher rainfall, except for the resort of Targuist located in the heart of the Rif Mountains. The autocorrelation test results for the yearly SPI (Table 6) indicate that significant sequential correlation, with values greater than 0.5, were found in the winter series. Normally, the winter season is characterized by substantial rainfall, which contributes to the increased severity of drought. Lower serial correlation values were detected in spring and summer for all the stations, except for Targuist, which exhibited good correlation throughout each season except spring. The severity of the drought (Figure 7) demonstrated a maximum succession of meteorological drought, although the Tamassit station showed the lowest severity among the stations. However, it recorded the greatest number of years of drought, indicating that this area is not exempt from the phenomenon.

Finally, the current weather situation is extremely alarming. The irregularity of precipitation, both in terms of location and timing, serves as a clear indicator of climate change in this region (Meseguer-Ruiz et al., 2019). What makes this situation even more concerning is that despite being located between the mountain ranges of the Mediterranean coast which should provide moisture, the area continues to suffer from drought.

5. CONCLUSION

The comprehensive analysis of precipitation data from 1975 to 2016 across five synoptic stations in Northern Morocco reveals significant spatial and temporal variations in rainfall, with notable implications for water resource management, agriculture, and regional climate understanding. The spatial variation lies in high-altitude areas, such as Targuist, which receives more precipitation compared to lower-altitude areas, such as Beni Boufrah, but remains insufficient. The coastal area experiences minimal precipitation, likely due to the blocking effect of the Rif Mountains on incoming Atlantic winds. The spatial distribution of rainfall varies from the center to the coast, and from the west to the east, declining steadily towards the coast. Precipitation variability is highest at the Tamassit Station (south-west) and lowest at the Al Hoceima Station (north-east), indicating differences consistent within the region. The Northwest region records the highest frequency of low precipitation (0-37 mm), suggesting a significant lack of rainfall irrespective of proximity to the mountains or the sea. The autocorrelation test reveals a progressive increase in sequential connection from the south to the northwest, likely influenced by ocean proximity. Despite this, periods of drought are detected in northern regions (Tamassit, Al Hoceima, Beni Boufrah), while the southern Targuist station remains relatively protected due to its wet climate. The Al Hoceima province shows the highest severity of drought, with a significant percentage of years experiencing extreme drought conditions. The central zone (Tamassit) and north-west (Beni Boufrah) record fewer extreme drought years but still experience considerable drought conditions. A significant sequential correlation for yearly SPI is found in the winter, indicating increased drought severity during a season typically characterized by important rainfall. Lower serial correlation values are detected in spring and summer for allo stations, but Targuist, which shows good correlation except in spring.

The spatial and temporal anomalies in precipitation that were discovered in this study can indicate that the meteorological situation is critical and may be an indicator of climate change impacts on the region. One recent study in the Al Hoceima region (Ghis–Nekor watershed) confirmed the increasing

trends of precipitation (Benyoussef et al., 2024). The findings can help anticipate periods of water quality deterioration associated with drought and reduced precipitation. Overall, the analysis emphasizes the importance of continuous monitoring and analysis of precipitation data to manage and adapt to the challenges posed by climate variability and change in Northern Morocco.

Despite the occurrence of dry spells and droughts, there is an overall increasing trend in rainfall at most stations, suggesting changes in precipitation patterns over time. The high frequency and severity of droughts emphasize the need for improved drought preparedness and mitigation strategies. On the other hand, ongoing monitoring of precipitation data is crucial for understanding long-term trends and for effective water resource management. To do this, the following recommendations should be introduced to expand the monitoring:

- Use ofclimate models to predict future precipitation trends and assess potential impacts of climate change on water resources.

- Perform multivariate analysis to consider other factors affecting precipitation, such as temperature, humidity, and atmospheric pressure.

- Conduct studies on the impact of identified precipitation trends on specific sectors like agriculture, hydropower, and water quality.

- Investigate the socio-economic implications of changing precipitation patterns and droughts on local communities and economies.

- Develop and test strategies for mitigating the impacts of droughts and managing increasing rainfall to prevent flooding and waterlogging.

- Incorporate more synoptic stations and gather current data across Northern Morocco to gain a comprehensive understanding of regional variations. The comprehensive examination of patterns and variability in precipitation series over the Al Hoceima territory presented here is still lacking. Therefore, only the local people in Al Hoceima province will find this geographical distribution important.

To ensure sustainable development and resilience to climate variability, the Al Hoceima region should better manage its water resources to lessen the effects of droughts, and adjust to shifting precipitation patterns by conducting more research.

Examinations of the precipitation data from five synoptic stations in Northern Morocco from 1975 to 2016 demonstrate significant temporal and geographical variations in rainfall. These findings have significant implications for managing water resources and our understanding of the local diverse climate.

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