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Drought Variability in Agadir's Region (Southern Morocco) – Recent and Future Trends

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ABSTRACT

The area of Agadir, which is situated on Morocco's southern Atlantic coast, is characterized by an arid climate, and has been strongly impacted by climate change. The purpose of this research is to assess observed and modeled drought variability in time, on the basis of rainfall time series for the periods 1973–2020, and 2022–2099 by use of SPI, short for Standardized Precipitation Index. Findings from the SPI analysis show that the years from 1981 to 1986 were the driest as per the instrumental record. Future SPI projections indicate that the area under study will face several prolonged drought and wet periods between 2022 and 2099. The longest drought will take place from 2090 to 2093. Analysis of the relationship between rainfall in Agadir and North Atlantic Oscillation (NAO), is also studied especially for the winter months. The results of the study will provide a basis for drought surveillance and hydro-meteorological studies, in addition to initiating the desired managment of environment in this area.

Keywords: Agadir, Morocco, drought, SPI, NAO.

INTRODUCTION

Drought is a natural phenomenon that affects vast regions all over the world every year [Safari and Dashti., 2013]. It may be described as a period when the amount of water available at a certain area is below a certain threshold, and it practically occurs in all climatic regimes [Mishra, and Singh., 2010]. This natural hazard poses a major menace to the world's agricultural land and corps [Lesk et al., 2016; lamesol et al., 2022]. The increasing frequencies and intensities have been noticed in Southern Europe, including the Mediterranean region [Spinoni et al., 2015]. Given that the trends in precipitations greatly vary in some regions, such as in Morocco [Driouech et al., 2020], it is necessary to investigate the key determining factors in regions exposed to higher drought intensities. In Morocco, the drought trends have been investigated in several studies whose results showed spatial heterogeneity due to the involved diverse meteorological variables [Driouech et al., 2020]. As a result of global warming, it is anticipated to experience a wide range of effects, including extreme precipitation (dry and wet events). This region is also affected by some heavy precipitation episodes that cause local floods, which can result in significant economic losses.Thus, understanding precipitation patterns will help in effectively developing more mitigation strategies. Moreover, drought characterization and monitoring are essential in aride and semi-arid regions in the face of climate change [Dafouf et al., 2022].

The study's goal is to:

- assess the temporal variability of droughts over 48-year period (1973–2020), in South of Morocco (Agadir Region) using the Standardised Precipitation Index tool (SPI);
- contribute to a better understanding of the precipitation pattern by investigating past and future trends in temporal structure;
- contribute to the management of environmental sustainability;

- explore the relationship between drought and the Nord Atlantic large-scale circulation (NAO), with the purpose of predicting short-term precipitation.

MATERIAL AND METHODS

Description of the studied site

The city of Agadir is situated in Morocco's southwest, on the Atlantic coast (Fig. 1). The climate of the city of Agadir is arid according to the Martonne aridity index over the period from 1980 to 2015 [El Ajhar et al., 2018]. Average annual precipitation is marked by temporal variability. It averages 224 mm per year at the Agadir station. The rainy season extends from October to March. Average temperatures are around 13°C at their maximum in January and 33 °C in July and August [Stour, Agoumi, 2008; Aroui, 2016]. During the last ten years, the climate has been marked by important periods of drought. The average monthly wind speed fluctuates between 4.30 km/h in January and 9.64 km/h in May ((NOAA) Global Historical Climatology Network (GHCN)). The station of Agadir is located at a longitude of 09-24-00W, a latitude of 30-19-01N, and an altitude of 23 m [Tairi et al, 2018].

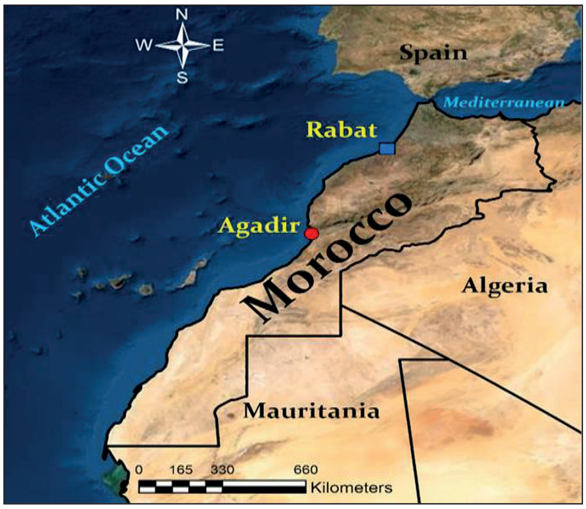

Figure 1. Location of the city of Agadir in southern of Morocco (Rabat: capital city of Morocco) in Africa's North-West

Research design

The standardized precipitation index (SPI) is used to study the evolution of recent and future droughts in the Agadir region over several time series with scales of 1, 3, 6, 9, or 12 months. The valuation of the correlations was established from the data of the NAO index and the different values of the SPI during the data period 1973–2020. The interval of the correlation index extracted from the correlation maps.

Dataset

The precipitation observation data utilized in this analysis are from the Global Historical Climatological Network (GHCN) for the years 1973 to 2020 (NOAA). To solve the statistical analysis challenges caused by the large regional heterogeneity of precipitation sums, the standardized precipitation index is explored instead of precipitation sums for the investigation of precipitation variability. The station under consideration has a few missing data points. The NAO data, and correlation maps are extracted from the website of the Division of the National Center for Atmospheric Research (NOAA: GHCN).

Normalized precipitation index (SPI)

Precipitation is considered the most important component of the complex hydrologic cycle because of its impacts on our daily lives and on society, economic activities such as agriculture, and water resources [Elkharrim and Bahi, 2015]. Therefore, precipitation is often taken as a starting point towards understanding changes in the governing climate [Elkharrim and Bahi, 2015]. Thus, precipitation is very relevant. However, in climate research, it is still difficult to get accurate estimates of localized variations in precipitation. For this reason, we use SPI. It is an entirely precipitation-based probabilistic indicator [Elkharrim and Bahi, 2015]. The SPI was developed by McKee et al. (1993) as a specific probability-related indicator of the precipitation deficiency. The World Meteorological Organization (WMO, 2012) has identified the SPI as a crucial indicator for monitoring drought, and it has been widely used as an operational [Wilhite et al, 2000; McRoberts and Nielsen-Gammon, 2011], and analytical tool. It may be computed for any accumulation time scale and is often represented as SPI-n, where n is the number of accumulation months. It is typically calculated by accumulating monthly precipitation. The long-term precipitation record for the required time period provides the foundation for the SPI calculation for any site. Positive SPI numbers shows the amount of precipitation over the median, while negative numbers show recipitation below the median. Because the SPI is normalized. A definition of the SPI_i is by the follow mathematical formula:

$$SPI_i = \frac{Xi - \bar{X}}{Sd} \quad (1)$$

where: SPI_i – the standardised precipitation index for total duration *I*; *Xi* – the cumulative precipitation for period *i*; $\bar{X}$ – the historical series' mean precipitation for the cumulative time; *Sd* – the standard deviation of the mean precipitation over the entire time *I*.

It is more simple and used to measure the precipitation deficit over a range of time scales and represent how it affects the availability of different water sources. Using SPI values as a basis for classification, the criteria for droughts are illustrated in Table 1 [WMO 2012; Xue et al., 2013; Jain et al., 2015]. A drought episode is considered to have occurred once the SPI is persistently negative and has a -1.0 intensity or below. When the SPI becomes positive, [Elkharrim and Bahi, 2015]. As a result, each drought event has a beginning and a finish, as well as an intensity for each month that it lasts [Elkharrim and Bahi, 2015]. The drought "magnitude" may be defined as the SPI's positive sum for all months of a drought incidence [Elkharrim and Bahi, 2015]. The system of classicification reported in Table 1 of the SPI values is used to describe the severity of droughts caused by the calculation of the SPI [McKee, 1993].

Table 1. Class of drought related to SPI values according to the CDCC Centre's classification and the WMO's SPI user guide [WMO 2012; Xue et al, 2013; Jain et al, 2015]

SPI values	Class
SPI≥2.00	Extemely wet
1.5 ≤SPI≤ 1.99	Very wet
1 ≤SPI≤ 1.49	Moderatly wet
-0.99 ≤SPI≤ 0.99	Near normal
-1.49 ≤SPI≤ -1.00	Moderatly dry
-2 ≤SPI≤ -1.5	Severatly dry
SPI ≤ -2	Exceptionally dry

Correlations of the SPI indicator with the North Atlantic Oscillation (NAO) mode at the seasonal and annual scales

Some studies have associated precipitation on the Moroccan Atlantic and Mediterranean coasts with Phases of the North Atlantic Oscillation [Driouech et al., 2013]. The strength and position of the Icelandic Depression and the Azores Anticyclone change on a regular basis. Climate variability is related to atmospheric or oceanic circulation and is often explained by the atmosphere-ocean coupling that generates teleconnections.

As a result, analyses combining this atmosphere-ocean coupling are critical for understanding cyclicity and precipitation periodicity models. Their variation can influence the weather in southern Morocco by modifying the location of the Azores anticyclone, which affects the temperature and precipitation regimes over Morocco [Driouech et al., 2020]. The NAO has two phases: a positive phase related to the strengthening of the Icelandic depression and the Azores anticyclone, and a negative phase connected with the weakening of the Icelandic depression and the anticyclone of the Azores [Xue et al, 2013; Elkharrim and Bahi, 2015; Amouch et al, 2020]. In the positive phase, droughts pervade in the Mediterranean while storms are more numerous in Europe, but in the negative phase, the Mediterranean benefits from wet weather, although the weather in Europe remains less humid [Driouech et al., 2010].

RESULTS AND DISCUSION

Observed SPI analysis (1973–2020)

In this work, the SPI is used to investigate the properties of precipitation variability in Agadir, over a period of 48 years using monthly precipitation (1973–2020). SPI applied to various time series is mainly used to investigate the temporal variability of precipitation (1, 3, 6, 9, and 12 months).

SPI_1 month (Fig. 2a)

Because the distribution has been adjusted, this time scale provides a more accurate indication of monthly precipitation. Its application can be closely related to meteorological classification of drought. It varies between -1.38 in six years (1977, 1979, 1988, 1999, 2006, and 2012),

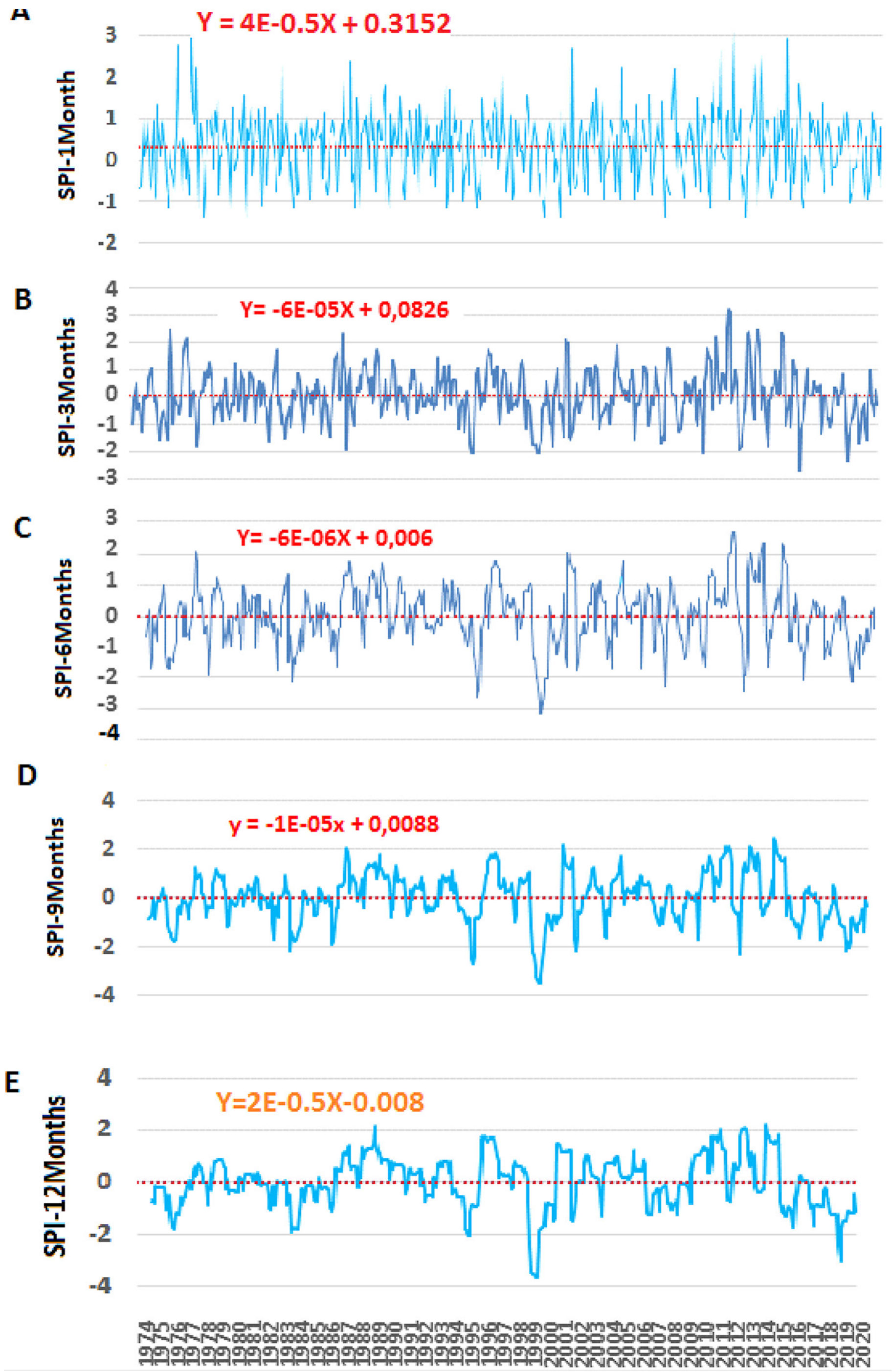

Figure 2. SPI time series for Agadir at A – 1 month, B – 3 months,C – 6 months, D – 9 months, and E – 12 months time steps for the period 1973–2020 (Data sources: OGIMET)

and 3.12 in the month of May 2011. The trend curve is almost stable in the value of SPI=0.3 and 31% of the cases studied were dry (SPI<0) with the longest duration of dryness of six months during 2007 (Table 3).

The quarterly SPI (Fig. 2b)

This time scale compares precipitation totals from a certain 3-month period to precipitation totals from the same 3-month period for all years in the record. It represents the weather drought and offers seasonal precipitation estimates. It varies between -2.91 in the first trimester of 2016, and 3.28 in the second trimester of 2011, and shows seven peaks of dry periods, and ten peaks of wet periods (where the SPI value exceeds 2 (extremely wet)). The trend curve is almost stable at the value of SPI=0. Similarly,

Table 2. Severatly and extremely drought years frequency in the Agadir Station during the period 1973–2020

Drought years	Intensity (SPI)	Classement
1994	-1.88	Severatly dry / extremely dry
1995	-2.04	Severatly dry / extremely dry
1999	-3.61	Severatly dry / extremely dry
2000	-1.75	Severatly dry / extremely dry
2002	-1.52	Severatly dry / extremely dry
2016	-1.74	Severatly dry / extremely dry
2018	-1.68	Severatly dry / extremely dry
2019	-3.07	Severatly dry / extremely dry
2020	-1.5	Severatly dry / extremely dry

there were periods of drought where the SPI value were less than -1.5 (severe/extreme drought), and 48% of the cases studied were dry (SPI < 0) with the longest duration of dryness of twelve months during 1974–1975 (Table 3).

The half-yearly SPI (Fig. 2c)

It can be useful in displaying precipitation throughout different seasons. Information obtained from this record depending on the circumstances, abnormal streamflows and reservoir levels may also be connected with the region as well as the season. It varies between -3.2 in the first semester of 1999 and 2.86 in the second trimester 2011, with seven dry peaks and six wet peaks with a slight moisture tendency. The trend curve is almost stable at the value of SPI = 0. About 47% of the cases studied were dry(SPI<0) with the longest duration of dryness of twelve months during 1982/1983 (Table 3).

The nine-month SPI (Fig. 2d)

In fact of the drought takes at least a season to develop, the SPI 9-month indicate the inter-seasonal precipitation patterns. Visual inspection of the nine-month SPI showed that the dry and wet period's cycle frequently occurs every 4 years. SPI values less than -1.5 for these durations are typically a solid indicator that dryness is wreaking havoc on agriculture and may be harming other sectors as well. It varies between -3.26 in 1999, and 2.45 in 2014, showing seven peaks of dry periods and eight peaks of wet periods. The trend curve is almost stable in the value of SPI=0. 47%. About of the cases studied were dry (negative value of SPI) with the longest duration of dryness of nineteen months during 1974–1976. (Table 3).

The annual SPI (Fig. 2E)

This time scale reflects long-term precipitation patterns, which we can assign to hydrological dryness. Visual inspection of annual SPI showed that the dry and wet period's cycle frequently occurs every 3 years. It varies between -3.61 in 1999 and 2.2 in 2014, with two peaks of dry periods and three peaks of wet periods. The trend curve is almost stable at the value of SPI=0. About 49% of the cases studied are dry (SPI<0) (Table 3). Among the 48 years studied, the following episodes were identified as extremely severe or extreme drought: 1994, 1995, 1999, 2000, 2002, 2016, 2018, 2019 and 2020 (Table 2). The period from 1981 to 1986 (278 months) constitutes the longest duration of observed and recorded drought. And 1995–1998 (55 months) the longest duration of observed wetness (Table 3).

Table 3. Stats retrieved from the observed and modeled SPI chronological series at Agadir

Time scale (Months)	1	3	6	9	12	1	3	6	9	12
Period and result nature	Observed (1973–2020)					Modeled (2022–2099)				
Number of cases With SPI<0	179	274	272	270	12	326	441	467	473	444
The longest duration of drought	6	12	12	18	278	8	10	19	34	48
Period of longest duration	2007	1974/1975	1982/1983	1974/1976	1981/1986	2071/2072	2091/2092	2091/2093	2090/2093	2092/2093
Number of cases With SPI>0	397	300	302	298	287	610	493	464	455	481
The longest duration Of Wet	11	12	26	25	55	20	27	25	61	61
Period of the longest duration	2018	2007 and 1987/1988	2010/2012	2010/2012	1995/1998	2056/2057	2023/2025	2023/2025	2056/2061	2056/2061

Future SPI projections (2022–2099) using the HadGEM2 model

The upcoming drought prediction conditions were assessed utilizing the SPI while taking emission scenario RCP 4.5 into account, because it represents the average of the predictions. SPI time series at calculated scales of 3, 6, 9, and 12 months from monthly simulated precipitations are represented in Figure 3. It is noted that the trend line has a weak negative trend towards drought for the four periods. For the period 2022–2099 under RCP 4.5 baseline:

- For the future SPI (SPI – 1 months RCP 4.5 Figure 3a):
  - the SPI will vary between -1.27 in the months of May 2078, 2098, and 2099, and 3.56 in the month of October 2051;
  - the SPI will decrease by 0.2 between 2022 and 2099 according to the simulation;
  - the trend curve decreases slightly toward drought. and 35% of the cases studied will be dry (SPI<0) with the longest duration of dryness of eight months during 2071/2072 (Table 3).
- For the future SPI (SPI – 3 months RCP 4.5 Figure 3b):
  - the SPI will vary between -2.23 in the fourth trimester of 2095 and 3.60 in the third trimester of 2042;
  - the SPI will decrease by 0.4 between 2022 and 2099 according to the simulation since the trend curve will have a tendency toward drought;
  - about 47% of the cases studied will be dry (SPI<0) with the longest duration of dryness of ten months during 2091/2092 (Table 3).
- For the future SPI (SPI – 6 months RCP 4.5 Figure 3c):
  - visual inspection of the sex-month SPI showed that the dry and wet period's cycle frequently will occur every 2 years;
  - the SPI will vary between -3.09 in both 2062 and 2096 in the first semester and 3.52 in the first semester of 2051;
  - the SPI will decrease by 0.6 between 2022 and 2099 according to the simulation since the trend curve will have a tendency toward drought;
  - about 50% of the cases studied will be dry (SPI<0) with the longest duration of dryness of ninteen months during 2091/2093 (Table 3).
- For the future SPI (SPI – 9 months RCP 4.5 Figure 3d):
  - the SPI will vary between -3.28 in 2062 and 3.25 in 2051;
  - the SPI will decrease by 0.55 between 2022 and 2099 according to the simulation since the trend curve will have a tendency toward drought;
  - about 51% of the cases studied will be dry (SPI<0) with the longest duration of dryness of thirty months during 2090–2093 (Table 3).
- For the future SPI (SPI – 12 months RCP 4.5 Figure 3e):
  - visual inspection of SPI showed that the seasonal dry and wet period's cycle frequently will occur in every 4 years;
  - the SPI will vary between -3.36 in 2096 and 3.10 in 2099;
  - the SPI will decrease by 0.8 between 2022 and 2099 according to the simulation since the trend curve will have a tendency toward drought;
  - about 48% of the cases studied will be dry (SPI<0) with the longest duration of dryness of fourty eight months during 2092–2093 (the longest duration of drought in the future record) (Table 3).

Table 3 contains all SPI timescales (observed and modeled), the number of dry and wet months, and the length of drought or wet period for the study period. The monthly SPI data series showed departures from long-term cumulative precipitation were minimized as the time scale grew and the drought increased. The longest recorded period of wet weather will be from 2056 to 2061 (61 months), and the longest recorded period of drought will be from 2092 to 2093 (48 months) (Table 3).

Correlations of the SPI indicator with the NAO mode (North Atlantic Oscillation) at the seasonal and annual scales

Table 4 provides linear correlation coefficients between the SPI series and the NAO index for the relevant period in order to quantify the link between the SPI in Agadir and the fluctuation of the NAO at different time scales (monthly and seasonal). The correlations are illustrated

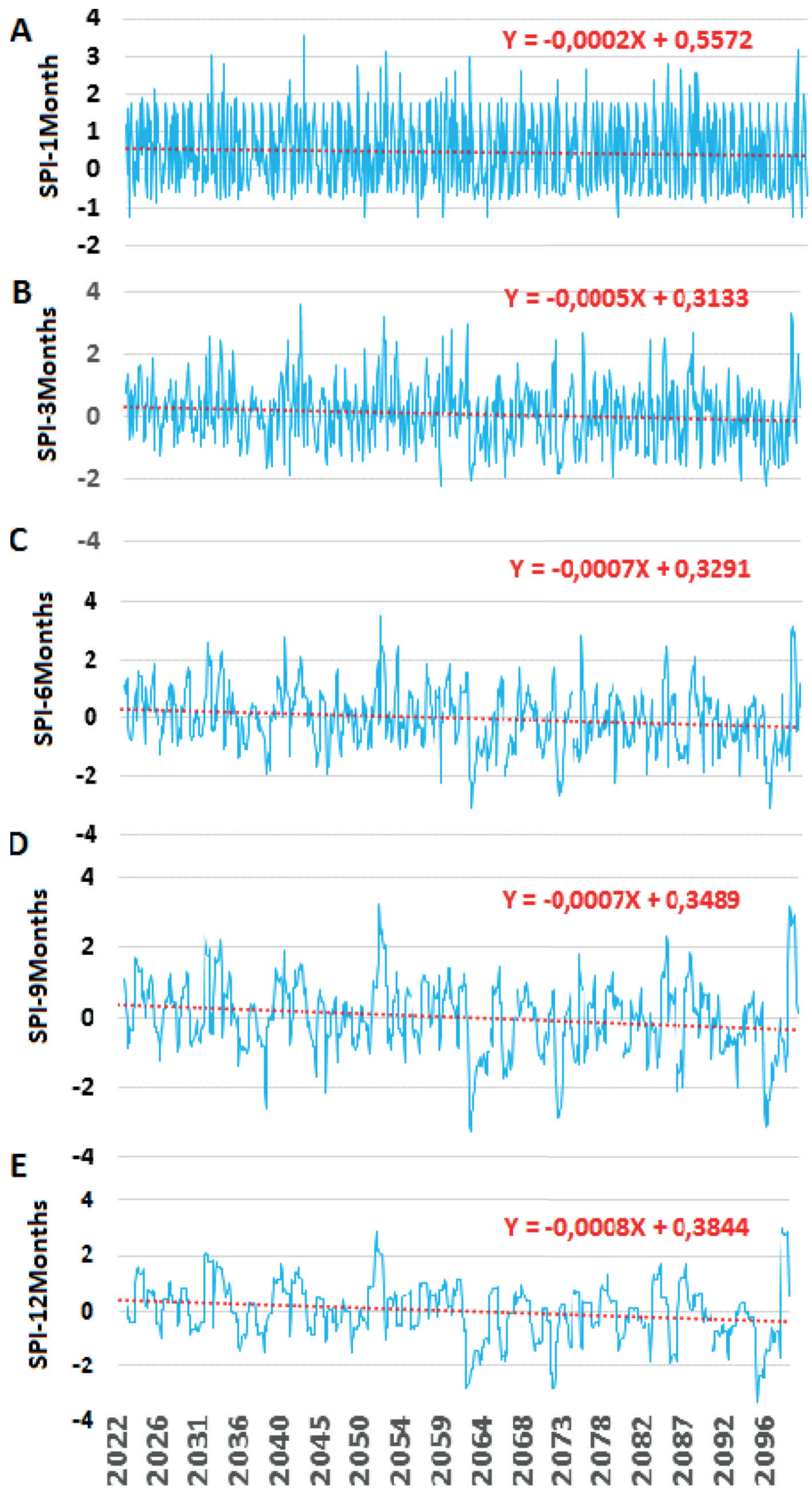

Figure 3. Modeled SPI time series for Agadir at A – 1 month, B – 3 months,C – 6 months, D – 9 months and E – 12 months for the periods 2022 to 2099, for RCP4.5 scenario (Data sources: OGIMET)

in Figure 4, we can extract the table of correlations between precipitation and the NOA index (Table 4).

The correlation between SPI from 1973 to 2020 and the NAO index is negative and strong for November, December, January and February (between -0.4 and -0.6). but it is weak for September and March (between -0.2 and 0.2) Table 4, the correlation is generally negative, indicating that winter rainfall in the Agadir region is related to NAO^-. It is clear that precipitation in this region follows the negative NAO phase. The monthly

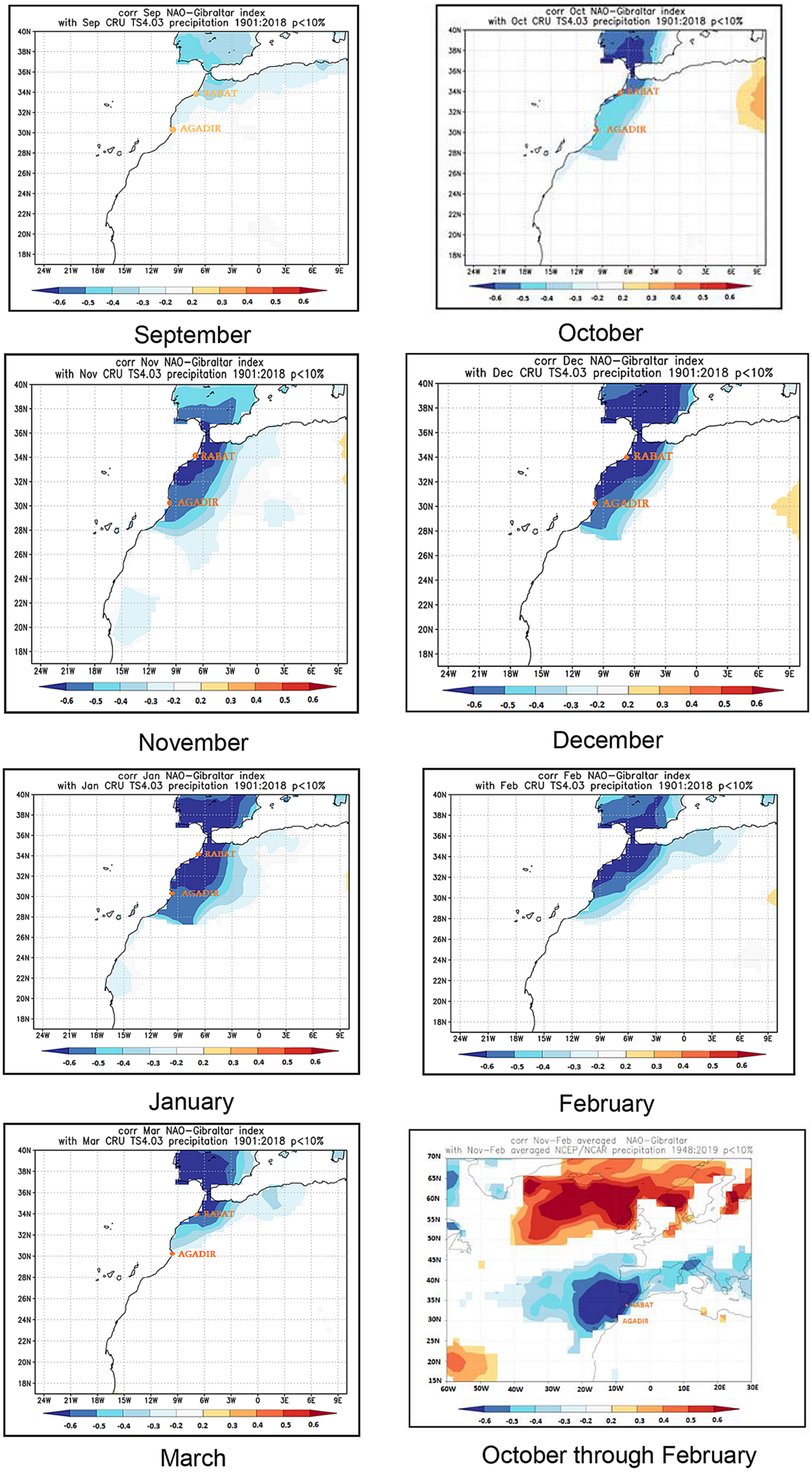

Figure 4. Maps shows the Correlation between precipitation 1973–2020 and the wintertime North Atlantic Oscillation Index (NAO) and for all the winter season during the period 1948–2019 (sources of data: NCEP/NCAR)

Table 4. The monthly correlation value from September to March and for the winter season between precipitation and the NCEP/NCAR Atlantic Oscillation Index (NAO) during the period 1973–2020

Period	Correlation Precipitation/NOA
September	Between -0.2 and 0.2
November	Between -0.4 and -0.5
December	Between -0.5 and -0.6
January	Between -0.5 and -0.6
February	Between -0.5 and -0.6
March	Between -0.3 and -0.2
Winter period Nov-Fev	Between -0.2 and 0.2

trends of the SPI index for Agadir during the period 1973–2020 show a negative correlation and are equal to -0.37, meaning an average negative correlation. Then the NAO influence is significant on a monthly scale, which is compatible with the results of a previous study [Driouech et al, 2020]. The quarterly trend of the SPI index for Agadir during the period 1973–2020 shows a negative correlation equal to -0.18, meaning a weak negative correlation. Then the NAO influence is medium on a quarterly scale. The half-yearly trends of the SPI index for Agadir during the period 1973–2020 show a negative correlation equal to -0.10, meaning a weak negative correlation. Then the NAO influence is low on a half-yearly scale. The ninth-month trends of the SPI index for Agadir during the period 1973–2020 shows a negative correlation equal to -0.06, meaning a weak negative correlation. The annual trends of the SPI index for Agadir during the period 1973–2020 shows an insignificant negative correlation and equal to -0.05, meaning an approximatively null correlation. Then the NAO influence is low on a annual scale, which is compatible with the results of previous studies [Driouech et al., 2013; Amouch et al, 2020].

CONCLUSIONS

The study of the recent and future climate of the region of Agadir is carried out using the SPI index which uses only precipitation. The trend line for SPI (1, 3, 6, 9 and 12 months) is nearly steady between 1973 and 2020. The driest years were 1999 and 2019, with SPI peaks of -3.61 and -3.07, respectively. For future projections, we relied on the future scenario 4.5, as it represents the average of the three scenarios (2.5, 4.5, and 8.5). Future (2022–2099) SPI projections using the HadGEM2 model show a general trend toward drought for the 2022–2099 period under scenario RCP4.5. We observe that the large amounts of winter precipitation are correlated with the NAO^-, and the monthly trend gives a good negative correlation with the NAO. The teleconnection patterns of the Northern Hemisphere, especially the NAO explain most of the total differences in seasonal precipitation.

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