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Analysis of meteorological and hydrological drought based in SPI and SDI index in the Inaouen Basin (Northern Morocco)

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Abstract
Drought is a normal climatic feature, which affects almost all regions. It has become in recent years more intense and frequent, which has a very negative impact on the socio-economic balance of the countries. Among droughts receiving particular interest are meteorological and hydrological droughts. This paper focuses on the analysis of the characteristics of these two types of droughts in the Inaouen region of northern Morocco for different time scales (3, 6 and 12 months). Analysis of the characteristics of meteorological and hydrological drought was assessed using the Standardized Precipitation Index (SPI) and the StreamflowDrought Index (SDI), respectively. The analysis of the trend was based on the test of Mann-Kendall (MK) and regression quantile method. The relationship between SPI and SDI has been apprehended through to the coefficients of correlation of Pearson and Spearman. The results showed that the frequency of episodes of drought varied according the time scale considered. The quantile regression reveals, compared to Mk test, a positive trend at higher quantiles and negative trend at the lower quantiles. Correlation results showed that for the 12-month scale, there is a strong positive correlation between SPI and SDI at different periods. These results provide an overview of drought trends in the region and therefore would be very useful in applying drought adaptation policies by water resource managers.

1. Introduction
Drought is a terrible risk for the economy, mainly on rainfed agriculture. The analysis of recurrence and persistence of this phenomenon by scientific methods seeks to establish an estimate of probabilities that could be contributes to the planning of strategies for the mobilization and management of water resources.
Morocco, whose climate varies from saharian in south to sub-humid in north, had many droughts of varying magnitude during its history; some had sometimes dramatic impact on the living conditions of the population, especially the rural ones (famine, pestilence, epidemics and crises) [1].
Drought is a recurring extreme climate event overland characterized by below-normal precipitation over a period of months to years[2].
The complexity of the phenomenon is also demonstrated by the difficulty to determine with precision the beginning and the end as well as the severity of the drought. Thus, this phenomenon can be characterized by three factors: the intensity, duration and spatial coverage [3].
Drought can be generated by various weather phenomena, with adverse consequences at many levels, and the concept of drought depends on the perspective of the water resource user. According to different types of drought impacts in different areas, drought can generally be classified into four types: meteorological, agricultural, hydrological and socio-economic.
Meteorological drought is an extended period with precipitation below normal, and usually appears before other types of drought [4].
Hydrological drought describes a deficiency in the volume of the water supply, which includes streamflow, reservoir storage, and/or groundwater heights [3].Hydrological drought can be affected by meteorological drought and the relationship between them is important for management approaches [5].

Analysis of historical droughts gives better information for effective monitoring of future drought events. Several procedures have been adopted by researchers to characterize droughts. A technique widely used in the study of droughts is the use of drought indices. In our case we opted for two very simple and effective indices: Standardized Precipitation Index (SPI) developed by McKee *et al.*[6] to characterize meteorological droughts and StreamflowDrought Index (SDI) developed by Nalbantis and Tsakiris[7] to characterize the hydrological droughts.
The main objective of this study is a comparative analysis of the meteorological (SPI) and hydrological (SDI) drought based on data from the selected hydrometeorological stations in the Inaouen basin. The SPI and SDI were calculated for time scales of 3, 6 and 12 months for each hydrological year during the period 1971-1972 to 2010-2011. The present research adopts a non-parametric approach to detect trends in meteorological and hydrological drought and their relationships over the last decades.

2. Material and Methods

2.1. Study region

This study focuses on the basin of Inaouen (figure 1) located inNorth of Morocco between latitudes 34°35’24’’N and 33°50’24’’N, and longitudes 4°49’48’’W and 3°48’36’’W and covering an area of 3648 km^2 with an average altitude of 694 m. Located in the eastern part of the basin of Sebu, the Inaouen region profits from a Mediterranean climate with oceanic influences[8]. This climate is characterized by strong seasonal contrasts and very irregular rainfall [9]. Geological domain of Inaouen basin is divided into two main areas: the northern part of the basin belongs to the Pre-Rif area and the southern part of the basin is related to the Atlas area.

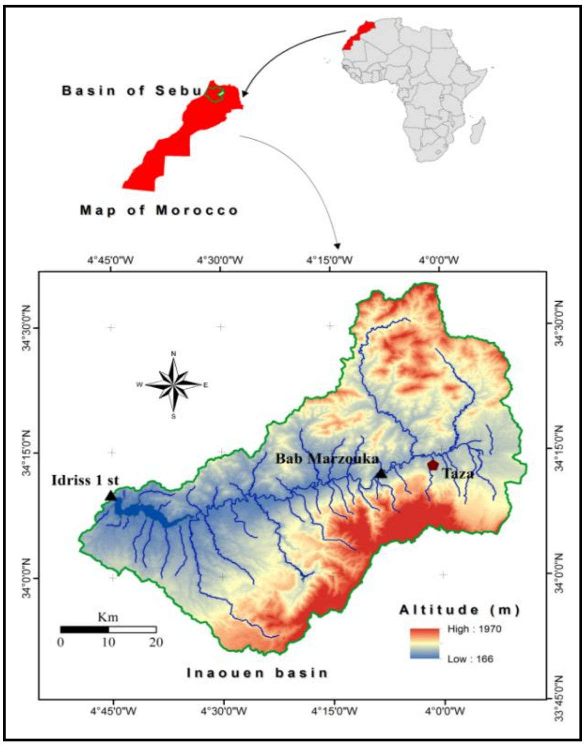

Figure 1:Location of the basin of Inaouen and the hydrometeorologicalstations.

Data sets used in this paper are monthly precipitation and streamflow data collected at the Bab Marzouka station located upstream of the basin and Idriss 1st station located at the downstream. These values were used to calculate the SPI and SDI index.

2.2. Methods

2.2.1. Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) was developed by McKee *et al.*[6] as a way to define and monitor drought events. It is a simple index, based solely on rainfall data, and allows equally checking the wet periods / cycles and the dry periods / cycles. The SPI compares precipitation over a certain period (normally 1-24 months) to the average long-term precipitation observed at the same site [10].
The SPI can be computed for different time scales. These time scales reflect the impact of drought on the availability of different types of water resources. Soil moisture reacts relatively quickly to rainfall anomalies in

the short term, while groundwater, streamflow and reservoir storage are sensitive to rainfall anomalies in the longer term.
Mathematically, the computation of SPI for any site is based on the long-term precipitation record (longer than 30 years) for any time scale. This long-term record is fitted to a probability distribution (Gamma distribution has been widely used), which is then transformed into a normal distribution [10].

2.2.2.Streamflow Drought Index (SDI)

The Streamflow Drought Index (SDI) developed by Nalbantis and Tsakiris[7], was used to characterize the hydrological drought. Its calculation is similar to SPI, and therefore has the same characteristics of simplicity and efficiency. The SDI is based on monthly observed streamflow volumes at different time scales and thus offers the advantage of controlling hydrological drought and/or the supply of water in the short, medium and long-term.

2.2.3. Identification of drought events

Once the meteorological and hydrological drought indices based on data series of precipitation and streamflow are calculated, it is necessary to take certain criteria to detect drought events. For this, severity, duration and intensity are three important characteristics of drought (figure 2). The duration of the drought (Dd) is the period between the time of occurrence of drought and time of completion. The severity of the drought (DS) is defined by the accumulated drought index during a drought event. The intensity of the drought (DI) is measured as the severity of the drought divided by the duration.

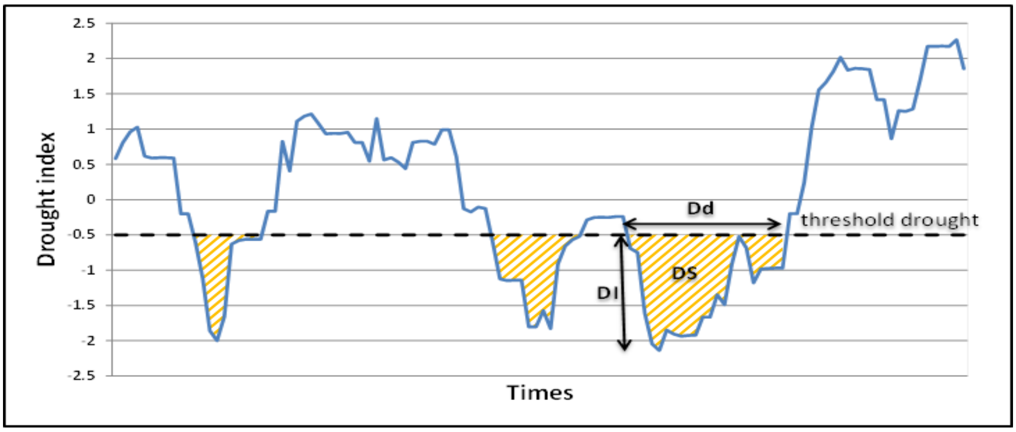

Figure 2: The three components of a drought event. DS denotes the severity of a drought event, DI intensity and Dd is the duration[11].

According to Tigkas[12], we use as a level of drought a threshold equal to -0.5. The table 1 details a classification system that defines the intensity of drought (or humidity) depending on the value of the drought index for any time scale.

Table 1: Classification of drought according to the SPI and SDI values[12].

Index values of drought (SPI or SDI)	Class Description
+2.0 and more	Extremely wet
+1.5 to +1.99	Very wet
+1.00 to +1.49	Moderately wet
+0.5 to +0.99	Mild wet
-0.49 to +0.49	Normal
-0.5 to -0.99	Mild drought
-1.0 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
-2.0 and less	Extreme drought

2.2.4. Trend and correlation test analysis

In order to describe the evolution of values of SPI and SDI at different temporal scales, we first use the test Mann-Kendall (MK) [13] often used in environmental sciences. And then when significant trends have been obtained from MK tests, the rates of variation of the variables are estimated by their slope of a simple linear regression.

In a second step, method of quantile regression introduced in econometrics by Koenker and Basset [14] is used. This is a regression statistical technique well defined on the quantiles rather than regression on the average. Indeed, the estimation of the average effect given by the simple linear regression contains only a small part of the information. Also, this regression is not suitable for data with heterogeneous variance because the rate of change is not constant in the data set [15]. At the opposite, the quantile regression allows extending the techniques of linear regressions to quantiles, and which therefore gives, more complete information on the distribution, often very useful.
To investigate the relationship between the meteorological and hydrological drought, we have calculated, in the first step, the correlation coefficients of Pearson and Spearman for all series. In the second step and to clearly visualize this relationship, the Pearson coefficient was calculated between each period of SPI and SDI at different time scales (for 1, 3, 6 and 12 months) and the results have been presented in the form of correlogram.

3. Results and discussion

3.1. SPI and SDI temporal evolution results

In a first step, the annual change of the indices SPI and SDIhas been analysed. The graphs below show the results (figure 3).

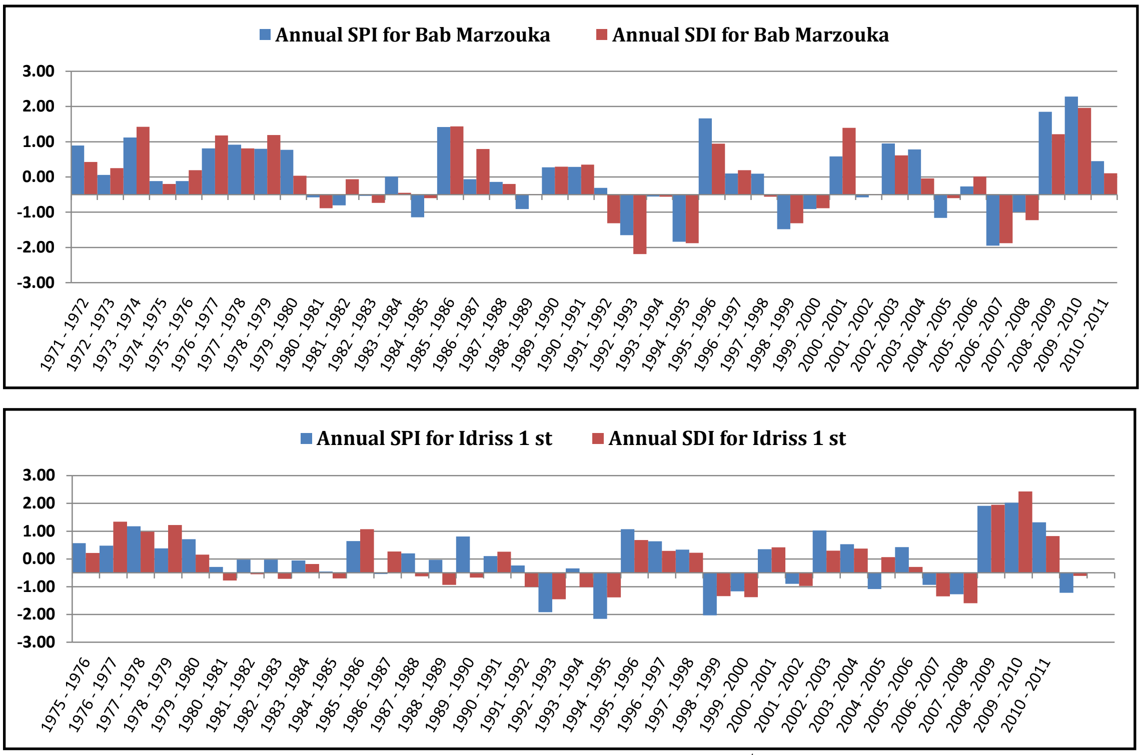

Figure 3: Change of annual SPI and SDI index for Idriss 1st and Bab Marzouka stations.

These results show that drought events identified by the SDI annual index are almost all identified by the annual SPI. The most exceptional event is the drought which began at the year 1992-1993 of severity of more than 4 and which lasted of 3 years. This gives an idea of the existence of a relationship between hydrological and meteorological drought.
In the second step, the analysis of the indices SPI and SDI at multiple time scales (3, 6 and 12 months) has been executed. The scale of 3 months is used to represent the short-term drought, the scale of 6 months for the drought in the medium term, and the scale of 12 months is used for the long-term drought. The results of Bab Marzouka station are showed in figures 4 and 5 and the characteristics of drought events of both stations Bab Marzouka and Idriss 1st in table 2.
In the graphs below (figure 4), the orange color indicates periods where the values of the indices SPI and SDI are below the limit of - 0.5. It is thus possible to identify the probability of encountering dry sequences and to determine the date of their beginning and their end and therefore their duration.
In the short term (3 months), the values of SPI and SDI vary widely and are sometimes positive, sometimes negative. But in these conditions, each new rain or flow measured affects significantly the quarterly totals. In the medium and long terms (6 and 12 months), it is obvious that each new event has less impact on cumulative totals and therefore the values of SPI and SDI are less fluctuating.

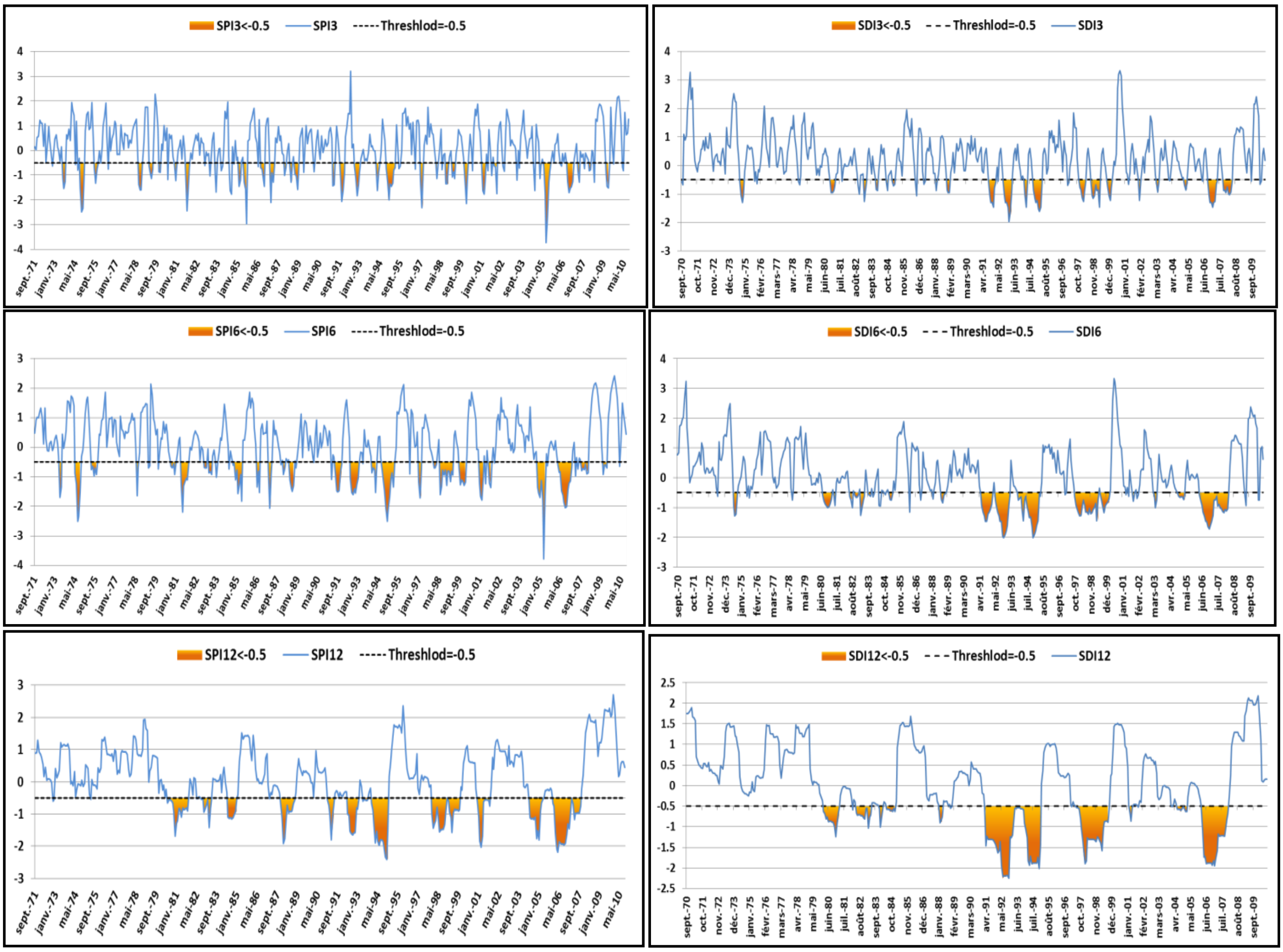

Figure 4: Evolution of the SPI and SDI for time scales of 3, 6 and 12 months for Bab Marzouka station.

Table 2: Characterization of drought events from monthly SPI and SDI index

Time scale	Parameters observed	SPI		SDI	
		Bab Marzouka (1971-2011)	Idriss 1st (1975-2012)	Bab Marzouka (1970-2011)	Idriss 1st (1970-2012)
3 months	Frequency	63	54	35	40
	Average duration (months)	2.38	2.29	3.46	4.97
	% of the time under drought	31.38	28.05	24.49	35.46
	Extreme value of the SPI or SDI (date of occurrence)	-3.73 (Apr 2005)	-3.02 (Aug 1984)	-1.97 (Feb 1993)	-2.38 (Aug 2007)
6 months	Frequency	44	37	34	26
	Average duration (months)	3.56	3.46	4.83	6.97
	% of the time under drought	33.26	29.15	33.88	36.47
	Extreme value of the SPI or SDI (date of occurrence)	-3.78 (Apr 2005)	-3.33 (Apr 2005)	-2.01 (Dec 92 and Dec 94)	-1.72 (July 1992)
12 months	Frequency	16	19	15	10
	Average duration (months)	9.75	6.68	10.46	18.6
	% of the time under drought	33.26	29.33	32.64	38.54
	Extreme value of the SPI or SDI (date of occurrence)	-2.41 (Dec 1994)	-2.75 (Nov 1994)	-2.25 (Nov 1992)	-1.72 (Dec 94 and Apr 99)

It is also important to note that at short term the number of drought events increases but with periods of drought, which are very short (on average 2-3 months). With the increase of the time scales (6 or 12 months), the number of occurrences of drought is reduced, but drought lasts longer (3 to 10 months on average). Thus, with the increase of time scales, the values of the indices SPI and SDI stabilize and better reflect the times of water deficit.

3.2. Trend analysis

The trends of indices SPI and SDI are analyzed. Two methods, Mann-Kendall test and quantile regression have been applied for the meteorological and hydrological drought over the period of 1971–1972 to 2010–2011.

The outputs of the Mann-Kendall test for the different time scales of the series of SPI and SDI for both stations Idriss 1st and Bab Marzouka are presented in table 3. If the p value is less than the level of significance α (alpha) = 0.05, H0 is rejected indicating that there is a tendency in the time series, and if H0 was accepted, it indicates no trend was detected. Thus, the result is considered statistically significant when the null hypothesis is rejected. The table 3 indicates that there is almost no tendency for SPI values especially for the Idriss 1st station. By contrast, there is a negative trend of SDI values at different time scales.

Using quantile regression models, the variability of SPI and SDI values were analyzed with the years as an explanatory variable and SPI and SDI values as the dependent variable. The regression parameters are estimated for 0.1, 0.3, 0.5, 0.7 and 0.9th quantiles.

The trend based on quantile regression for Idriss 1ststation is shown in figures 5, as well as the quantile slopes for Idriss 1st in figures 6.

Table 3: Results of the Mann-Kendall test for SPI and SDI for time scales of 3, 6 and 12 months for Idriss 1st and Bab Marzouka stations.

		Mann-Kendall Test						
Stations	Variables	Kendall's tau	Mann-Kandall Statistic (S)	Var(S)	p-value (bilateral)	alpha	Test interpretation	Sen slope
Idriss 1st	SPI3	-0.036	-3479	9626903.0	0.262	0.05	Accept H0	-4.202E-4
	SPI6	-0.052	-4992	9432499.3	0.104	0.05	Accept H0	-6.445E-4
	SPI12	-0.042	-3959	9051431.0	0.188	0.05	Accept H0	-5.572E-4
Bab Marzouka	SPI3	-0.039	-4471	12172970.3	0.200	0.05	Accept H0	-4.510E-4
	SPI6	-0.067	-7555	11945458.3	0.029	0.05	Reject H0	-7.806E-4
	SPI12	-0.085	-9337	11498939.0	0.006	0.05	Reject H0	-0.001
Idriss 1st	SDI3	-0.1032	-12973	14098084.3	0.00055	0.05	Reject H0	-0.001
	SDI6	-0.1442	-17923	13847083.7	< 0.0001	0.05	Reject H0	-0.002
	SDI12	-0.1726	-20928	13354055.3	< 0.0001	0.05	Reject H0	-0.002
Bab Marzouka	SDI3	-0.1106	-13162	13103132.7	0.00028	0.05	Reject H0	-9.839E-4
	SDI6	-0.1554	-18371	12872367.7	< 0.0001	0.05	Reject H0	-0.002
	SDI12	-0.1630	-18809	12403308.3	< 0.0001	0.05	Reject H0	-0.002

In Figures 6, each OLS (Ordinary least squares) estimate is represented by a red line, while dotted red lines are the limits of the upper and lower confidence interval. The quantile regression estimates are represented by a broken black line with a gray zone of confidence of 90%. The slopes and the intercepts of each model estimated by linear quantile regression are plotted according to quantile Tau.

The results indicate, although no change in the average SPI values were not statistically detectable (especially for the Idriss 1st station), the dry years become more dry and wet years become more wet during the studies period. The trend curves estimated for the selected quantiles clearly showed the differences in the changes through the distribution of SPI and SDI.

For the coefficients of the quantile slopes SDI, the values are usually negative at different time scales accompanied by an increase thereof with the increase in quantiles. This means that for low quantile it was a higher decrease in SDI values.

For the coefficients of the quantile slopes SPI, the values are negative for those of less than about 0.65 and positive beyond this value. This shows that the extreme values of SPI (negative or positive) tend to intensify during the period of study (especially visible for SPI 12).

3.3. Correlation analysis between SPI and SDI

In this section, the relationship of meteorological drought (SPI) with hydrological drought (SDI) is explored. First; the coefficient of Pearson and Spearman correlation tests has been applied to explore the relationships between meteorological and hydrological droughts based on the SPI and SDI series, respectively. The results have shown that the highest correlation between SPI and SDI is for the 12-month time scale (table 4). In addition, the correlation between SPI and SDI show that the strongest correlation is related to the Bab Marzouka station which can be attributed to the location of the station.

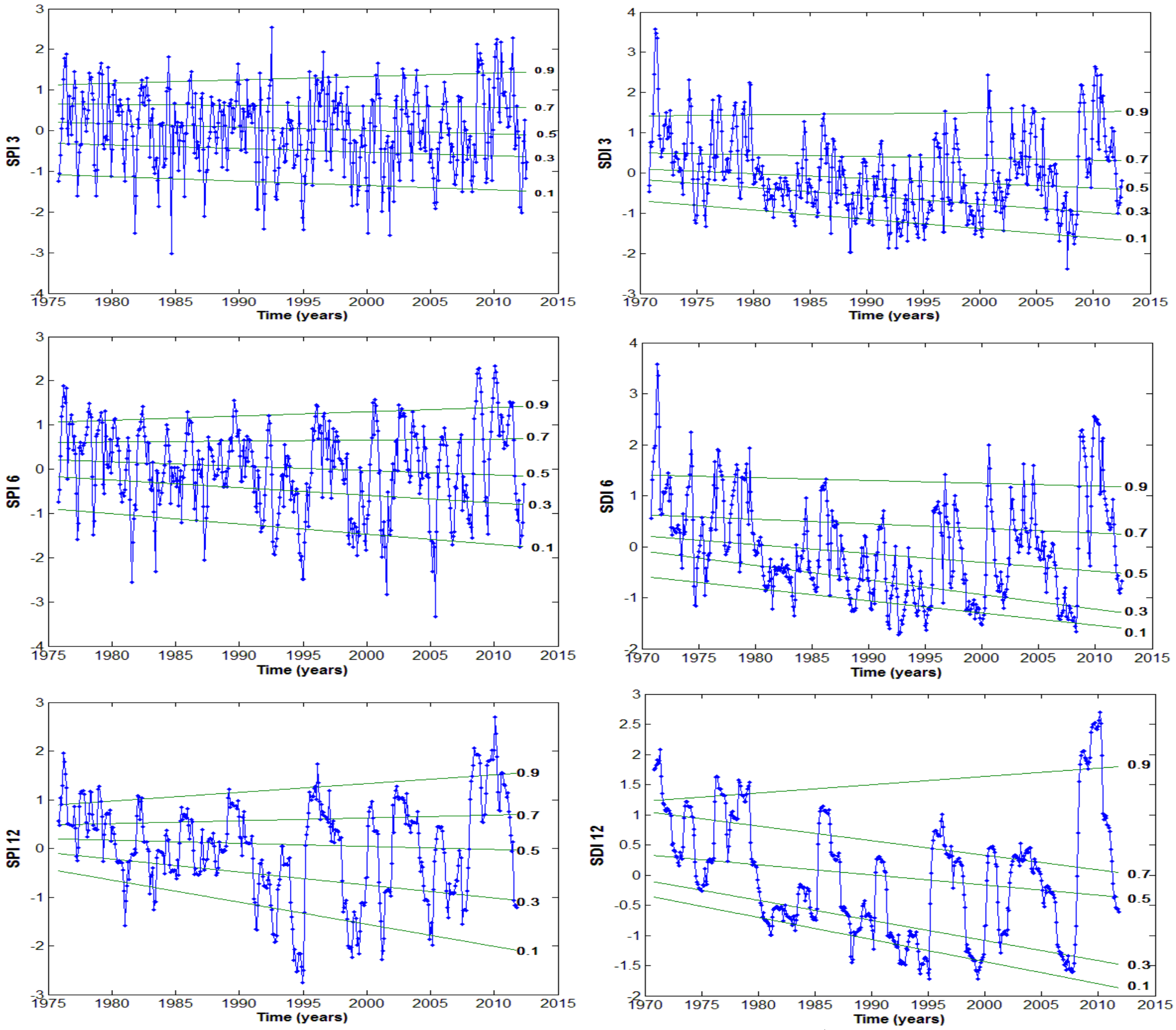

Figure 5: Quantile Regression Results of Idriss 1st Station

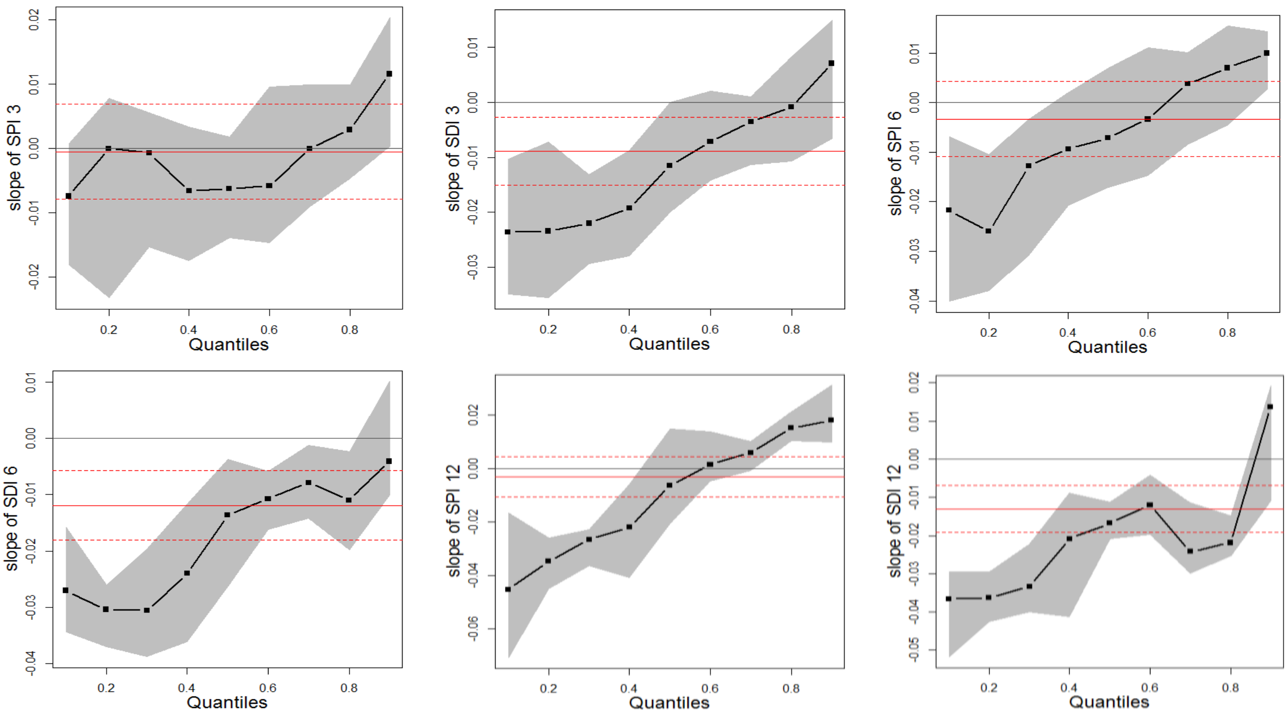

Figure 6: Quantile slopes of SPI and SDI at timescales of 3, 6 and 12 months and the corresponding 95% confidence interval (shaded area) for the Idriss 1st station. The horizontal red line represents the usual slope ordinary least squares with its corresponding 95% confidence interval (dotted red lines).

Table 4: The correlation coefficients between SPI and SDI at different time scales.

	X	SPI3	SPI6	SPI12
	Y	SDI3	SDI6	SDI12
Idriss 1st station	Pearson corrélation	0.60	0.70	0.78
	Spearman Rho	0.59	0.71	0.79
Bab Marzouka station	Pearson corrélation	0.62	0.76	0.86
	Spearman Rho	0.61	0.77	0.86

In the second step and for clearly visualize this relationship, the Pearson coefficient was calculated between each period of SPI and SDI and at multiple time scales (for 1, 3, 6 and 12 months). The results are shown in the figure 7 below.

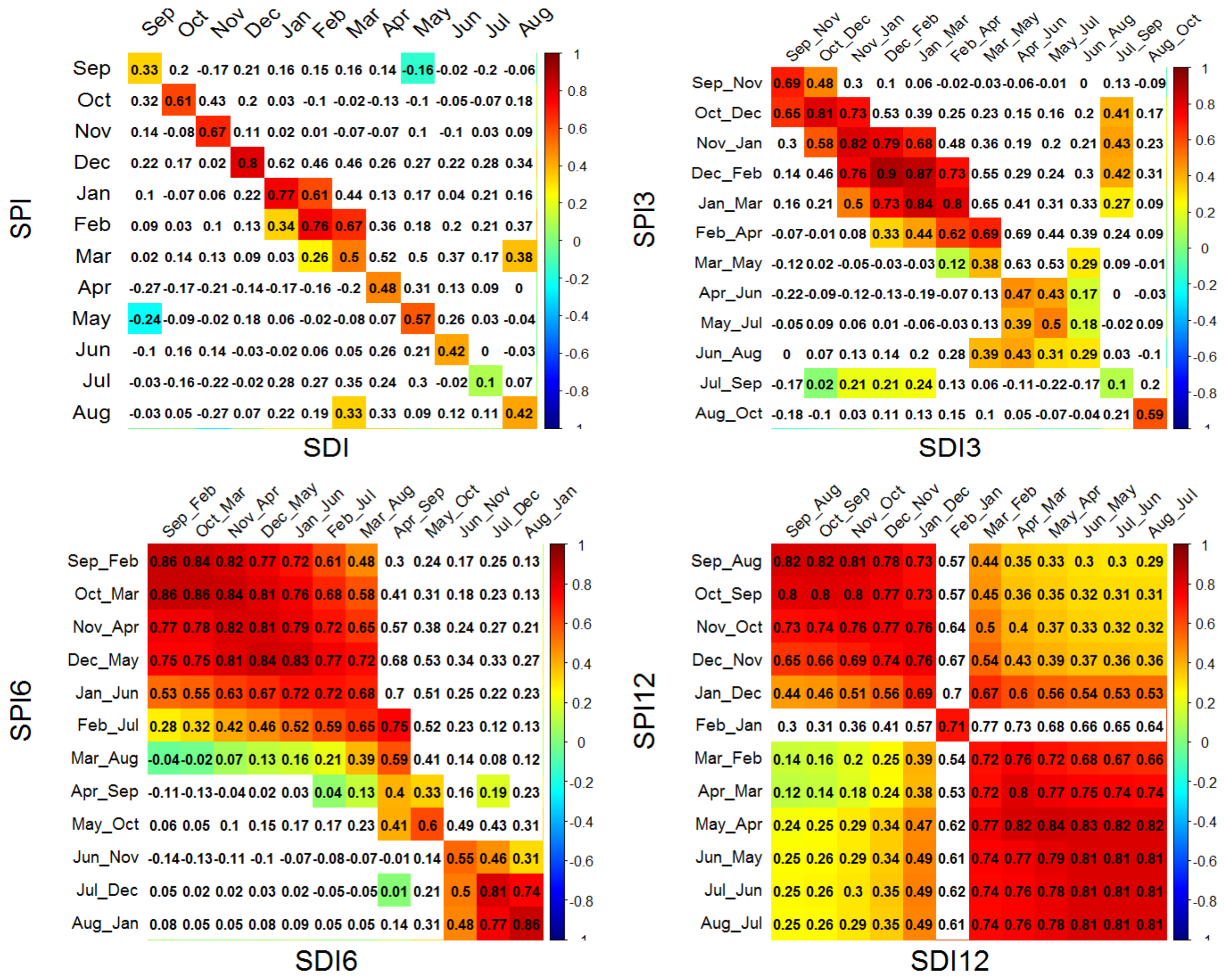

Figure 7: Correlogram representing the Pearson correlation coefficients between SPI and SDI at different scales (monthly, 3, 6 and 12 months) for Idriss 1st station for the period 1975-2011. The colored values are different from 0 at a level of significance alpha = 0.01.

On monthly scale, the results have shown that the highest correlation between SPI and SDI is for months of December, January and February (winter season).

For SPI3 and SDI3, the most marked positive correlation was registered between the period Dec.-Feb. of SPI3 with periods of Dec.-Feb. and Jan.-Mar. of SDI3.

For SPI6 and SDI6, a strong positive correlation is observed between periods Sept.-Feb., Oct.-Mar., Nov.-Apr. and Dec.-May. of SPI6 with the same periods of SDI6.

The long-term correlation analysis between the SPI and the SDI (scale of 12 months) shows that there is a strong positive correlation between periods Sep.-Aug., Oct.-Sept., Nov.-Oct., Dec-Nov. and Jan.-Dec. of SPI12 with the same periods of SDI12 and periods of Mar. –Feb., Apr.-Mar., May.-Apr., Jun.-May., July.-Jun. and Aug.-Jul. are in correlation with the same periods of SDI12.

However, hydrological drought is not fully explained by the meteorological drought. Indeed, geology and physical characterization of the basin, the soil occupation and land use as well as the relationship between rivers and groundwater are all of the parameters of more that combine to influence the hydrological drought.

Conclusion

In this study, meteorological and hydrological droughts based on SPI and SDI respectively have been analyzed for the Inaouen region located northwest of Morocco during the period from 1971-1972 to 2010-2011.

The results have shown that the frequency of episodes of drought varies according to the time scale considered. In addition, the percentage of time under drought stress during the period of study at different time scales is stable and approximately 32% for SPI but increases for SDI with the increase in the time scale. Also, and generally, the driest year, either on the basis of meteorological or hydrological drought index, was the year 1992-1993 with severity of more than 3 and duration of more than 3 years.

The results of trends based on Mann-Kendall test showed generally no tendency of the SPI series for time scales of 3, 6 and 12 months, whereas it was found a slight negative trend of SDI values at different time scales. On the other hand, quantile regression reveals negative slopes, especially at lower quantiles, generally induce more severe droughts (longer duration and greater severity) and positive slopes in particular to higher quantiles mostly visible for SPI 12. These asymmetric trends observed appear to be a common feature of recent climate change [16].

As for the correlation results, they showed that, for the time scale of 1 month, 3 months and 6 months, relations between meteorological (SPI) and hydrological (SDI) droughts are different depending on the periods considered. While for the scale of 12 months, a positive correlation is observed between all different periods. Noted, that the values of these correlations are significant at the 99% confidence level.

This research has allowed the highlighting of characteristics of the meteorological and the hydrological droughts over the study period in the Inaouen region, which will facilitate the development of strategies for water resource managers to mitigate the adverse impacts of these changes in the region.

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