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Analysis of environmental impacts of meteorological drought on agricultural activities in Steppe Zone (Algeria)

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ABSTRACT

The effects of climate change on the water cycle are harmful. Drought prediction is a complicated process in hydro-climatic studies. Water demand for Agricultural activities in the last decade has increased however; agriculture yield becomes more dependent to rainfall. To identify parameters whose control drought and its impact on irrigation we launched a study in Djelfa watershed to characterize the meteorological drought in semi-arid zone by applying the standardized daily precipitation index (SPI-365). Three parameters that control the climatic regime are considered (temperature, relative humidity and precipitation) as well as other parameters (instantaneous and absolute pressure of the water vapor).This study allowed us to clarify the relationship between the SPI-365 with other atmospheric parameters. The observed results show to distinct two periods in the hydrological year, wet period that lasts 54 days and another dry period of 311 days.Which explains why, in the Djelfa watershed, soil moisture is very low, and requires continuous irrigation during these 311 days of the year.

Key words: *Climate change, Standardized daily precipitation index, Semi-arid area, Djelfa, Irrigation*

Introduction

The Mediterranean countries are among the most vulnerable by water stress (SEBBAR *et al.*, 2001; Rochdane *et al.*, 2012) as a result of climate change and global warming. Therefore the continuous decrease of the amount of precipitations and arises of the temperature create a long-term changes in the local hydrologic regime by reducing soil moisture, surface runoff and the aquifer recharge.The drought, effect directly the hydrological systems around the world, many countries suffer the insufficient water resources. Needs for water resources continue to grow in same time with population growth up (Wang Xiao-Jun *et al.*, 2011).

In other way, the extent of human activities that influence the water resources (quality and quantity), has increased during the last few decades (Westerling *et al.*, 2006) In addition, climatic changes and global warming influenced the availability of surface freshwater and reduced natural recharge of aquifer systems; which make a lot of semi-arid areas under hydrologic drought which unbalanced the economic development and agricultural activities (Renard *et al.*, 2008). Landuse evolution has direct relationship with population growth and effect the local ecological system by reducing biomass (Pielke *et al.*, 2007), theses factor are related to Drought, that can be defined as a natural phenomenon occurs as a result of continuous deficit in precipitation (McKee *et al.,* 1995; Rusticucci And Barrucand, 2004; Pashiardis and Michaelides,2008; Sillmann and Roeckner, 2008; Seleski, 2008; Svoboda, 2009; Singla *et al.,* 2010; Pizarro *et al.,* 2012).

To study the impact of climate change on water resources in semi-arid zone, a procedure followed by application of daily Standardized precipitation index (SPI) and the statistical study of the values of SPI in order to reach a comprehensive understanding of the impact of meteorological drought on our water resources (Sahin and Kerem, 2010) . The change in hydrological cycle is one of the real concerns for the global warming projections (Räisänen *et al.,* 2004) . For water resource management, and agricultural purposes (Kimoto *et al.,* 2005).

The assessment of the effects of climate change on surface water resources; is followed by the continuous-wide annual weather parameters characterizing the atmosphere and the parameters that control the surface runoff. Topographical nature, geological settings, density of vegetation, slope and rain intensity plays a fundamental role in the surface flow process; these factors control the watershed runoff volumes (Chibane and Ali-Rahmani, 2015). The irrigation is needed when the vegetation growth can't satisfied by the moisture available in soils , however the object of this paper is to show how the short period of precipitation in Djelfa watershed influence the agricultural activities.

The statistical aspect of calculation of the standardized precipitations index when the distribution of the time series follows a normal distribution model.

Materials and Methods

This work is based on the daily hydro-climatic data of the Djelfa region (rainfall, temperature, air moisture). The SPI values are calculated based on daily record.

Location and Area

The area under research (The Djelfa River Basin) is located at 300 Km South of Algiers (Algeria); between (44° 26' 20" - 44° 19' 8") E and (35° 30' 42" - 35° 23' 13") N is Figure 1. it was characterized by a moderate climatic regime. With an annual rainfall between (200-350 mm) and an average annual temperature, about 15 °C. The topography ranged from (914) in the northwestern part to (1571) m in the southwestern, Figure 1. Geomorphologically, the study area can be divided into two main parts. The first part consists of flat terrain including some hilly and undulating plains, whereas the second part consists of mountains area,which covered about 1300 km². Hydrogeologically, the depth of the ground water varies due to the topography, structure, and type of the aquifer; it ranges from less than 100 m up to 1200 m above sea level. The exposed formations in the area under consideration have wide stratigraphic range extending from Tertiary up to Quaternary deposits.

Region of Djelfa has been touched by several episodes of drought of indeterminable levels of severity and impact. The impact of the drought phenomena includes mass starvation, most especially in the rain-fed agriculture region, which constitutes the main stay of the rural economy, desertification, and loss of forests and vegetation cover. The picture in Fig.2 shows the signs of drought in the river of Sidi Slimane in winter period in February 2016.

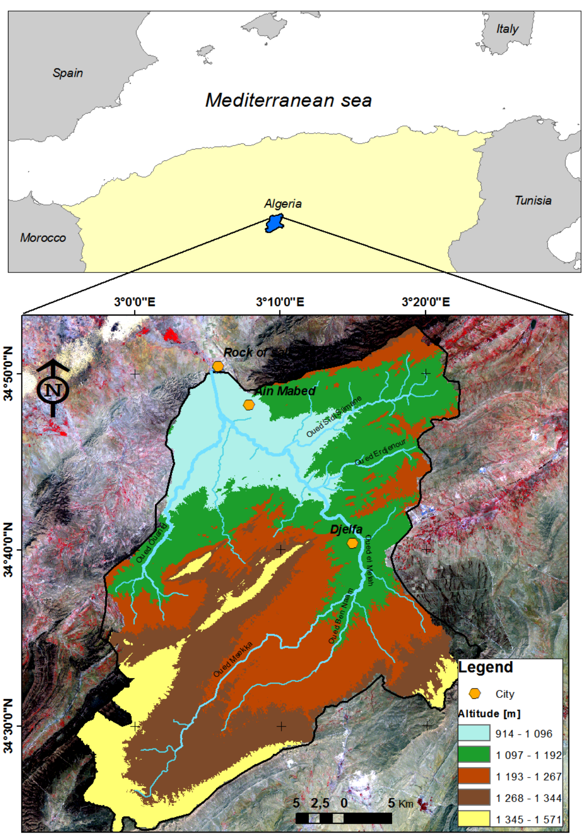


Fig. 1. Location of the study area (Ali rahmani and Chibane, 2018)

Fig. 2. Sidi Slimane River picture ticked in 14 February 2016, signs of drought are characterized in the heart of winter period.

Climatic Study

The hydroclimatic variables that are studied to the daily time scale are: average daily temperature, daily precipitation, and daily relative humidity. These parameters play a fundamental role in the atmospheric circulation and water cycle.

Daily Rainfall

The variation of daily precipitation is shown in Fig. 3. The Daily precipitation varies between **0** and **20** mm/day. High pick of rainfall are observed in the winter period, where Watershed receives a significant amount of rainfall. Impulses in Fig.3 show clearly the irregularity of rainfall (Duration, intensity and time).

Under continental and oceanic effects, the region of Djelfa receive precipitation coming from two kind of airmass (Tropical continental and polar maritime). These airmass play the essential role in climatic regime of the region.

Air temperature

The air temperature helps us to understand phenomena that control air flow, humidity and pressure. The daily variation of the average temperature is shown in figure (Fig. 4).

The daily variation of average annual temperature is vary between 0 to 31 °C , the low temperature are measured in winter period which runs from December to last of march. The high amplitude of average air temperature between winter and summer explained the severity of the climate of the region of Djelfa. The low temperature in the winter help in groundwater recharges process and soil moisture accumulation which help in vegetation development. High temperatures in summer and low precipitation control eavpotranspiration intensity and drought severity (Westerling *et al.*, 2006; Xu *et al.*, 2007).

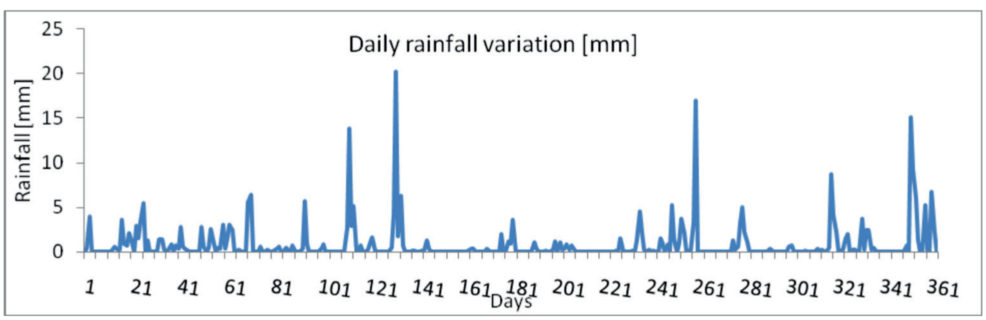


Fig. 3. Daily variation of Rainfall

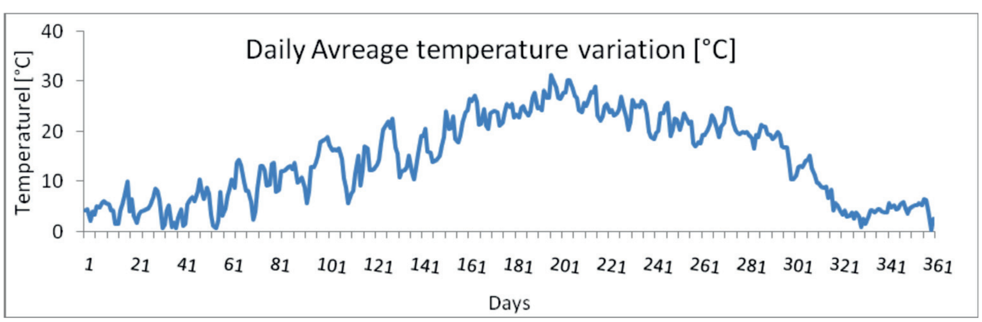


Fig. 4. Daily variation of average temperature

Relative humidity

The relative humidity is the ratio of the partial pressure of water vapor to the pressure of saturation water vapor. This value expresses the degree of saturation of air with vapor. It depends on the temperature and water vapor pressure in air. The daily variation of relative humidity is illustrated in the Figure 5.

The daily relative humidity (Hr) varies from 15 to 94 %; Hr values arise in winter and decrease in summer, relative humidity is a good indicator about atmospheric state.

The low humidity are observed in summer where the high temperature and the very low soil moisture reduce the volume of water vapor in atmosphere , this state are observed in many semi-arid areas, as far from sea. Air moisture is very low (dry air).

Standardized precipitation index

Standard Precipitation Index (SPI) is a statistical parameters used to monitor drought in the spatial and temporal scale. This index helps in understanding of the influence of changes in precipitation on drought (McKee *et al.,* 1995). This index was developed by McKee *et al.,* 1993 (Svoboda, 2009). The SPI is calculated using the formula given by equation (Eq.1) (Fuchs, 2012)

SPI drought index classes were given in Table-I.

$$SPI = \frac{Pi - P_m}{\delta} \quad (1)$$

With Pi: daily precipitation corresponds;

Pm average precipitations of the study time series;

ä: the standard deviation of the precipitations study series.

Results and Discussion

The study of meteorological drought in semi-arid areas was down by using the daily standard precipitation index (SPI-365), its variation show the influence of irregular changes of climatic regime at regional scale (precipitation, temperature, air moisture and water vapor pressure) on water cycle.

Table 1. Climate classication according to the Standardized Precipitation Index (SPI) values.

SPI value	Class	Abbreviation
2.00 and more	Extremely wet	EX
1.50 to 1.99	Very wet	VW
1.00 to 1.49	Moderately wet	MW
0.99 to 0.00	Normal	N
0.00 to -0.99	Near normal	NN
-1.00 to -1.49	Moderately drought	MD
-1.50 to - 1.99	Severe drought	SD
-2.0 and less	Extremely drought	ED

These changes have direct effects on evapotranspiration; runoff and also on groundwater recharge. It allows us to anticipate the disruption of components of the water cycle as surface runoff and groundwater recharge.

The variation of the daily relative humidity based on the temperature (Max and Min) is given by the figure (Fig. 6). The high difference between the two extreme temperature minimum and maximum is an indicator about the severity of the climate in the region, the high temperature reduce significantly the soil moisture.

The relative humidity is an important parameter that describes the state of the atmosphere, which is the ratio between the instantaneous pressures of water vapor in the atmosphere at the absolute pressure of water vapor.

According to the 2D plot (Fig. 6), we note that the relative humidity is very high whenever the maximum and minimum temperatures are decreased. In contrary, air moisture decreases each time the maxi-

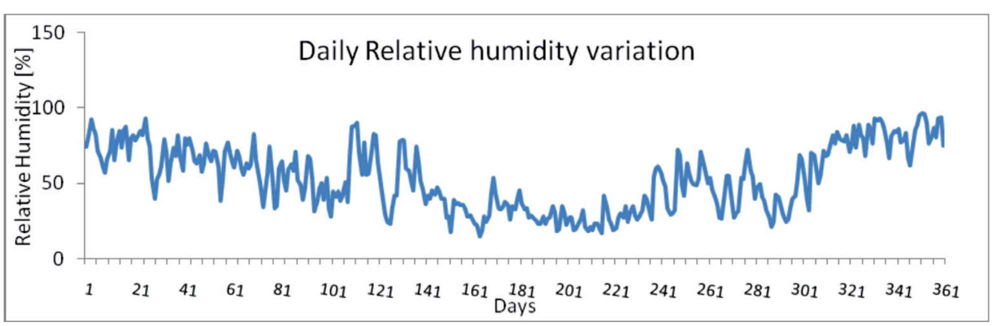


Fig. 5. Daily variation of relative humidity

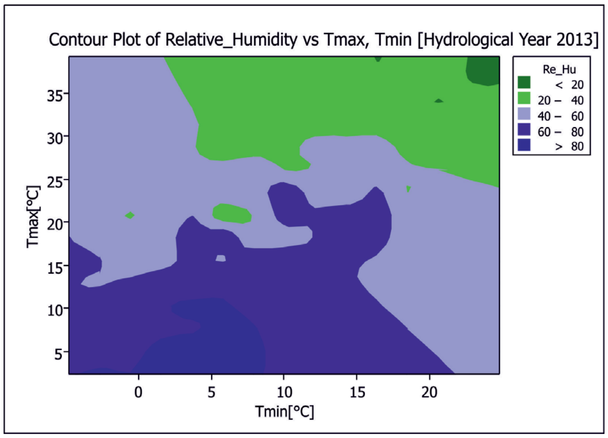


Fig. 6. Contour plot show the daily variation of relative humidity vs Tmax and Tmin for the hydrological year 2013.

mum and minimum temperature increases; three classes was distinguished; the first class correspond to an relative humidity less than 40 % case of high temperature , this phenomena has observed in summer time in many semi-arid areas where there a lack of vegetation cover and low water vapor in the atmosphere.

Linear regression shows the mathematical linearity between humidity and temperature with good fitness (R=0.85).

The graph in Fig. 7 show the good correlation between the average daily temperature and the daily relative humidity with a good fitness (R^2=0.72).The regression model was given by equation (Eq.2)

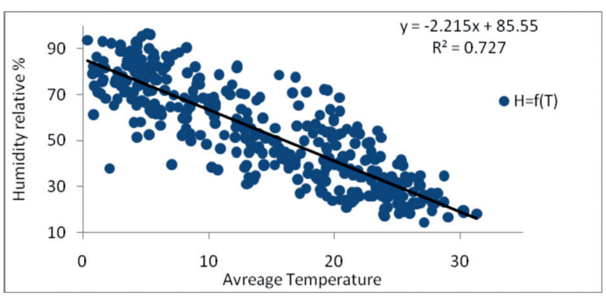


Fig. 7. Correlation between Relative humidity and daily Average temperature

$$Hr = -2.215 * T + 85.554 \qquad (2)$$

With Hr: Relative humidity in % ; T: average temperature in ° C.

The visual representation of the variation of SPI-365 based on the minimum and maximum temperature allowed us to draw 2D contour plot (Fig. 8), this visualization helps interpretation of this fluctuation.

Fig. 8 contour plot show the daily variation of SPI vs Tmax and Tmin for the hydrological year 2013.

From the 2D contour map (Fig. 8) the variation of SPI-365 shows values above 0 (wet period) for low temperatures that correspond to the winter period where rainfall is important; in the opposite side we note that this index is less than 0 (drought period) for high temperatures.

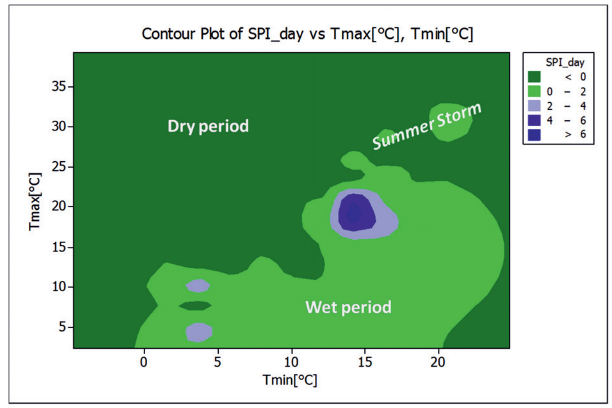


Fig. 8. Contour plot show the daily variation of SPI vs Tmax and Tmin for the hydrological year 2013.

Figure 9 shows the variation of SPI-365 in function of the average temperature and water vapor pressure, the figure illustrate the 2D variation of SPI-365 based on these two parameters. SPI values are greater than 0 for the highest values of water vapor pressure, and low temperatures; SPI is less than 0 for low pressures and high temperature. Fig. 10 shows the variation of the SPI-365 in function of the water vapor pressure and relative humidity.

Fig. 9 contour plot show the daily variation of SPI vs. Air pressure and average temperature.

In general, the 2D contour plot of figure. 10 show that the SPI-365 follows the variation of water vapor

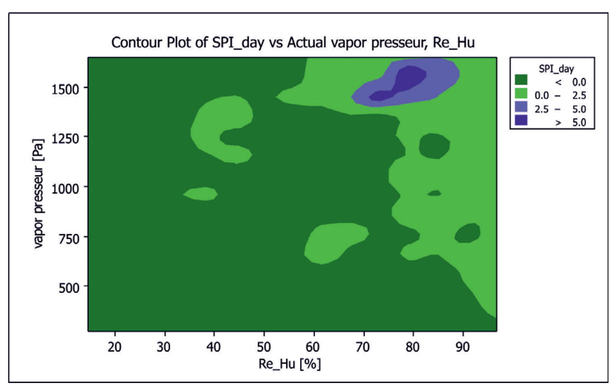


Fig. 10. Contour plot show the daily variation of SPI vs. relative humidity and vapor pressure

pressure and the relative humidity at the same time; that is to say whenever the two variables increase the SPI values increase.

Two classes can be distinguished: a dry period (SPI <0) for water vapor pressure values and low relative humidity which corresponds to the dry days of the year; the second class is the Wet period (SPI> 0) for the high values of water vapor pressure and relative humidity.

Visual analysis of these graphics let us identified 54 wet days (SPI-365> 0) and 311 dry days (SPI-365 <0). Table.2 gives the number of days for the parameters studied.

Groundwater recharge, was occurred in the wet period, however soil moisture and surface runoff are reaching the maximum in this few period.

Irrigations are not necessary in this time because soil moisture is high which help plant and crop growth. In dry period that start from last April irrigation are necessary to favorite the development of some plant growth.

Analysis of the drought index at daily scale has shown that changes in precipitation and temperature could have serious effect on water availability (soil moisture, surface runoff and groundwater). Air temperature controls the most atmospheric conditions (water vapor pressure, Air moisture and evapotranspiration process).In addition, the precipitation control water availability at local and regional scale (Groundwater recharge, Soil moisture, and surface runoff) (Joseph Alcamo *et al.,* 2007).

The graphics of the figure (Fig. 11) show the daily variations of the standard precipitation index (SPI-365) for the 12 months of the hydrological year.

The graphic of Fig.11 allow us to calculate the number of wet day and dry day for each month, results obtained are shown in the Table.3

From table.3 we can identified 54 wet days that present only 15% of year against 311 days which represent more than 85 % of year.

However, water reserves are formed in the period of winter when precipitation and low temperature favorite a significant infiltration and reaching the unsaturated media, the hydroclimatic variations are considered as an important parameters in drought understanding (Olusegun Adeaga, 2011).

The short wet period, don't favorite a high crop growth with good yield, however for some crops, irrigation will be necessary in all period of growth up, which influenced the availability of water resources. With economic growth, need of water to supplies emerging industrial and agricultural activities become more important.

To test the relation between the precipitation and soil moisture, we have calculated the standardized soils moisture index with the equation;

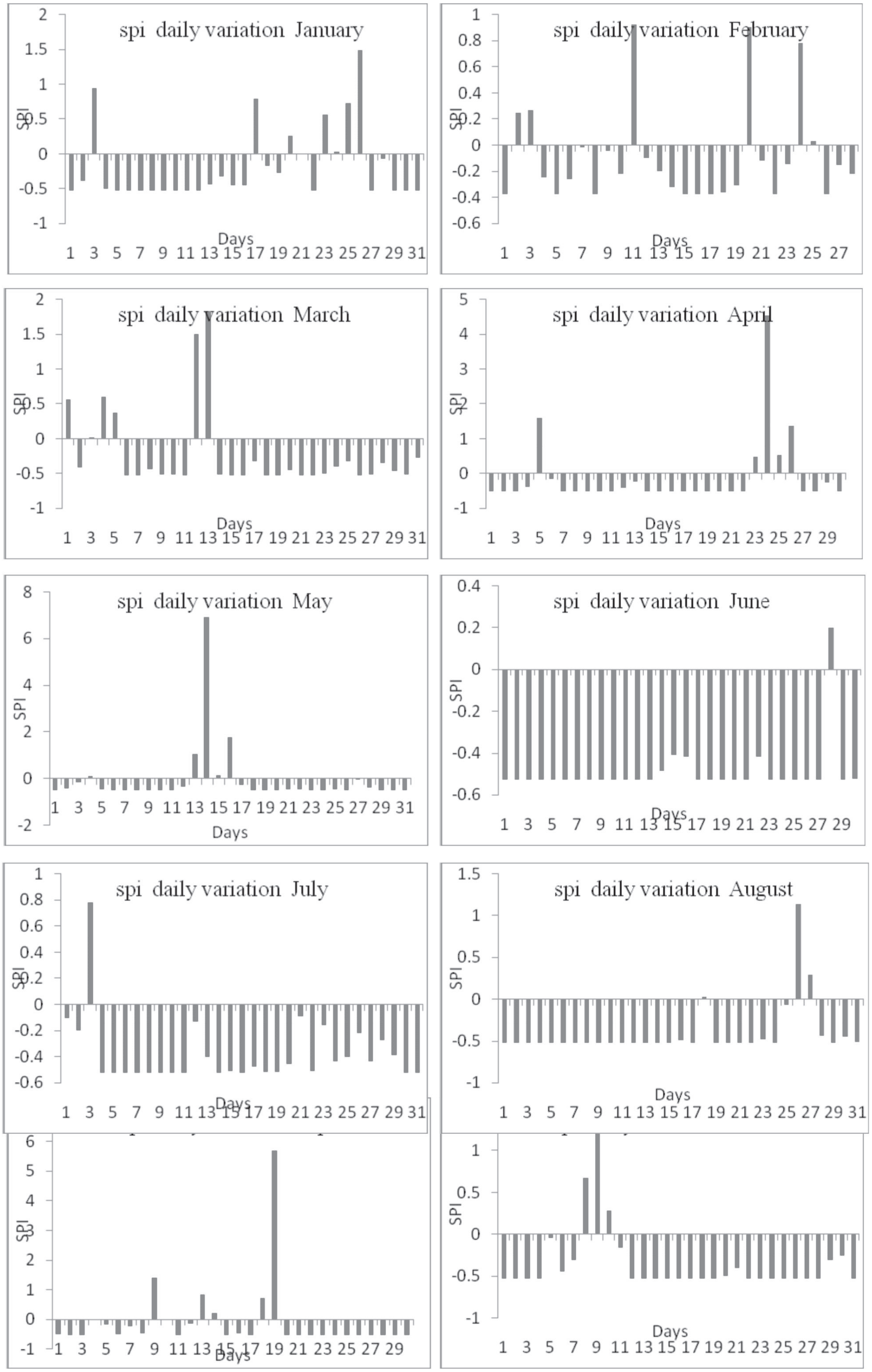
$$SSMI = \frac{SM - Sm_{Avg}}{Sdv} \quad (3)$$

Table 2. Numbers of days for studied parameter

Parameters	Number of days
SPI-365 >0	54
SPI-365 <0	311
HR > 50%	196
HR < 50%	169
Tmean >15	179
Tmean <15	186

Table 3. Number of dry and wet days classed per month

Month	SPI>0		SPI<0	
	Number of day	Percent	Number of day	Percent
January	7	22,58%	24	77,42%
February	3	10,71%	25	89,29%
March	6	19,35%	25	80,65%
April	5	16,67%	25	83,33%
May	5	16,13%	26	83,87%
June	1	3,33%	29	96,67%
July	1	3,23%	30	96,77%
August	3	9,68%	28	90,32%
September	6	20,00%	24	80,00%
October	3	9,68%	28	90,32%
November	6	20,00%	24	80,00%
December	8	25,81%	23	74,19%
Total	54	14,79%	311	85,21%


spi daily variation January
spi daily variation February
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spi daily variation July
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SPI
Days

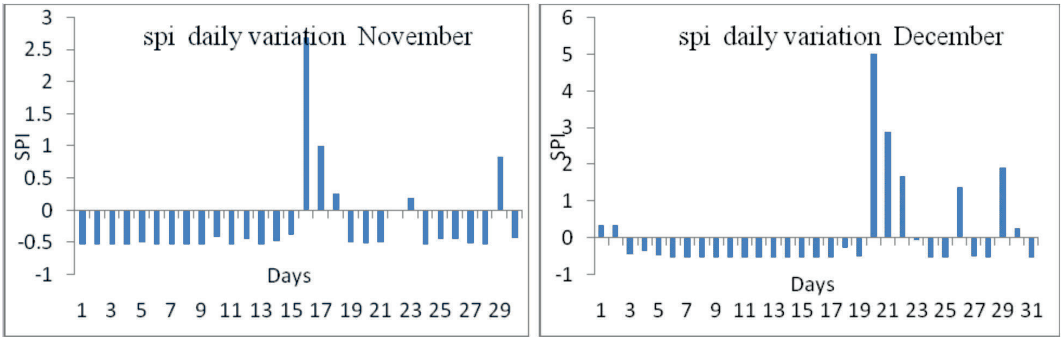

Fig. 11. Daily variation of SPI index for the 12 months of the Hydrological year

SSMI: standardized soil moisture index

SM: soil moisture

SM_{Avg}: average of soil moisture

Sdv: standard deviation of soil moisture time series.

The results has been illustrated in the Figure 12.

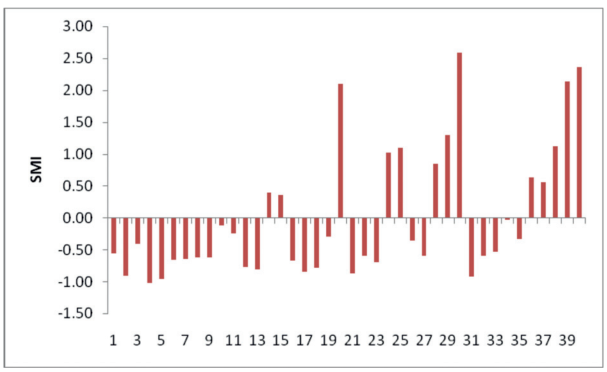

Fig. 12. Variation of Soil moisture standardized index

From the graph in Figure 13, it is clear that soils moisture deficit is great than the normal. The soils moisture limit is about 4%. Under this value, the deficit in soil moisture can be considered as local drought. The two study show the high dependence of soils moisture to the precipitations, where the irrigation is a necessary action in this deficit situation. Actually, we look to find a relationship between soil moisture and precipitation to determine a new soil-precipitations index.

Conclusion

Following this work, we studied three parameters characterizing the water cycle and the atmospheric circulation (temperature, air moisture and precipitation). We introduced the standard daily precipitation index (SPI-365) to study meteorological drought in semi-arid region and the effects on agricultural activities, SPI provides a useful drought monitoring and characterization tool. The 2 D contour plots give us a clear idea about the influence of temperature and other parameters as air moisture, water vapor pressure and temporal variation in rainfall on drought. Indeed we have identified the number of days for each period (Humid Period or SPI-365> 0) is 54 days; and a dry season (SPI-365 <0) with 311 days, this results show that the area used to agricultural activities suffer of water lack for a long period of season, where the evaporation process reduce soil moisture rapidly which conduct to a direct water stress of the vegetation type. Temperature also plays a very important role in the meteorological drought phenomenon; it controls evapotranspiration, and soil moisture.

Furthermore, this article, as modest as it is, is intended as an alert for the local, regional and even national community in order to ensure:

- A better understanding of the risks of drought and anticipating the crisis in the Algerian steppe region.
- Put in place an institutional framework favorable to the management of drought risks.
- Guarantee better preparation of institutions and actors to ensure effective intervention in the event of a hazard.
- Put in place an institutional framework favorable to the management of drought risks.
- Strengthening of the environmental and socio-economic resilience of the Algerian steppe region in the face of drought risks.

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