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Climatic sensitivity in the Algerian steppes: Drought indices and remote sensing

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Abstract. These last years, the Algerian steppe has known a strong degradation caused in particular by the scarcity of the annual rainfall. It spreads in certain cases to successive years generated by a persistent drought. A series of indices were applied to rainfall records recorded for 30 years (1985-2015) in the treated stations to identify the severity of the drought in the steppe regions. The present work proposes to study and compare the performance of some drought indices to identify a permanent monitoring system in the steppe. The indices studied are Pluviometric Deficit Index (PDI), StandaPDIzed Precipitation Index (SPI), and the Ratio compared to the Normal (RN). We can deduce Climate variability is manifested by regressive spatio-temporal dynamics, thus, drought is recurrent phenomenon in the Algerian steppe

Keywords. steppe, drought, indices, remote sensing, spatio-temporal

1. Introduction

Drought is considered as one of the most complex extreme weather conditions, affecting more people than any other hazard and any other form of natural disaster [1]. The effects of drought are generally referred to as direct effects [2]. These effects are reflected in a reduction in crop productivity, a reduction in water surfaces, and a reduction in water availability [3]. Algeria has experienced an intense and persistent drought over the last twenty years. A rainfall deficit is recorded almost everywhere on its territory [4]. The climate of the high steppe plains of Algeria is marked by a conflict between the influences of the Mediterranean climate, characterized by mild winters and a long hot summer period, tempered by sea breezes, and the Sahara, with a hot and dry wind (the sirocco) [5]; blowing north of the Sahara during the summer season; Bringing dust and sand storms to the coastal regions [6]. Several studies have analyzed the variability of precipitation globally, especially in the Mediterranean region and North Africa. The linear trends for 1901-2005 show a very high spatial variability, showing a significant decrease in annual totals in Africa, particularly in the Mediterranean basin [3].

This study analyzes the climatic indices on an annual scale to assess the climatic sensitivity of the Algerian steppe. Climatic sensitivity is particularly important in the steppe region, given the degradation of pastures due to the considerable decrease in annual rainfall. In some cases, a persistent drought extends over several years [7] [6]. This work aims to analyze the impact of drought using some meteorological indices of drought. This study allows us to better understand the evolution of surface conditions of the steppe rangelands between a dry and a wet year and to better interpret their spatio-temporal changes[8] . To this end, many meteorological indices have been used to identify and detect climatic drought in the study of steppe regions. They include the Rainfall Deficit Index (PDI), the StandaPDIzed Precipitation Index (SPI), and the Ratio compared to Normal (RN). These indices were applied to the stations' rainfall records recorded for 30 years (1985-2015).

2. Material and methods

2.1. Study Area

Physically, the Algerian steppes, located between the Tellian Atlas in the North and the Saharan Atlas in the South, cover 20 million hectares. They are limited in the North by the 400 mm isohyet, which coincides with the extension of dry cereal crops. In the South, the 100 mm isohyet represents the southern limit of the extension of esparto (Stipa tenacissima). The bioclimatic stages range from cool lower semi-arid to cool upper per arid. Researchers are currently revising this bioclimatic zoning by investigating the impact of climate change and the desertification process on these boundaries[9].

Between the Tellian Atlas and the Saharan Atlas lies a wide band of 300 to 350 kilometers containing the high cereal plains, the pre-Saharan steppe with pastoral vocation, and the most characteristic Endorheic basins. It is an area where groundwater predominates, and the sensitivity to desertification is particularly important [10]. In Algeria, the arid steppe ecosystems are marked by a great landscape diversity concerning great variability of ecological factors. In regions with a pastoral tradition, the population is essentially composed of pastoralists-breeders (Fig. 1), most former nomads, with a strong tendency to sedentarization today [10].

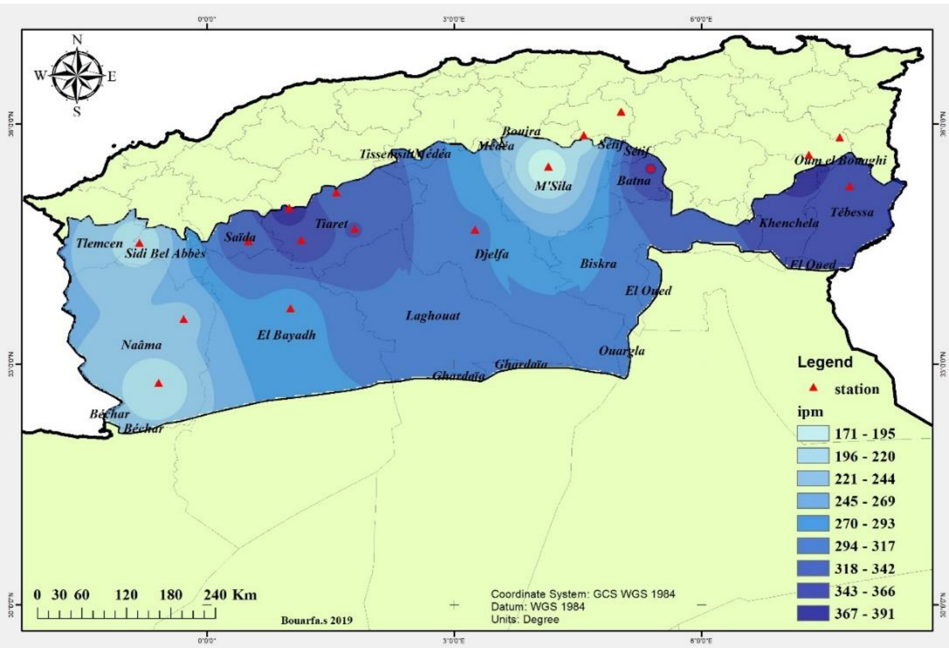

Fig. 1: Location of the weather stations (ipm : Average Annual Precipitation).

2.2. Data collection and methodology:

Standardized precipitation index ; The Normalized Precipitation Index is a simple, powerful, and flexible index based on rainfall data and is equally good at verifying wet and dry periods/cycles. The SPI compares the precipitation over a period - normally 1 to 24 months - to the long-term average of precipitation observed at the same site. However, at least 20 to 30 years of monthly rainfall records (preferably 50 to 60 years) are required to calculate the SPI [11]. Given the lack of data sets for many sites and the fact that many drought-prone areas do not have sufficient rainfall stations [12], interpolation techniques may be required to fill in the temporal or geographic gaps. The mathematical formula for SPI is as follows:

$$SPI = (pi - pm) / \sigma \quad (1)$$

Where, Pi is the precipitation in year i, Pm is the mean precipitation, and σ is the standard deviation or standard deviation.

Pluviometric deficit index : We used the proportional deviation from the mean to situate a rainfall in a long series of rainfall records. Eq (2) expresses it as follows:

$$PDI (\%) = (Pi - Pm) / Pm \times 100 \quad (2)$$

Where, PDI is rainfall deficit index (in percent), Pi is annual precipitation (in mm), and Pm is average precipitation (in mm).

This index, also known as “departure from normal”, allows us to visualize and determine the number of deficit years and their succession. A year is considered wet when this index is positive and dry when negative. The accumulation of the indices of successive years makes it possible to identify the major trends, disregaPDIng the slight fluctuations from one year to the next. When the sum of the differences increases, it is a wet trend. The opposite is a “dry” trend.

Ratio to normal ; This index is expressed mathematically as a percentage as follows:

$$RN (\%) = (Pi/Pm) \times 100 \quad (3)$$

Where, Pi is the precipitation of year I, and Pm is the average precipitation for the same period studied.

This ratio allows a point estimate of precipitation in relation to the normal: a year is classified as dry if the rainfall is below the normal, i.e. when the NR is less than 100 [13].

Deviation from the average ; This index is most used to estimate the rainfall deficit of a given year, the deviation from the mean is the difference between the annual precipitation height (Pi) and the average height annual precipitation (Pm), we used the proportional deviation from the mean to situate a rainfall in a long series of rainfall records. It is expressed by Eq. (4):

$$D = Pi - Pm$$

Where, D is the deviation, Pi is annual precipitation (in mm), and Pm is average precipitation (in mm).

This index, also known as “standard deviation”, makes it possible to visualize and determine the number of deficit years and their succession. A year is considered wet when this index is positive and dry when negative. The accumulation of the indices of successive years makes it possible to identify the major trends, disregaPDIng the slight fluctuations from one year to the next. When the sum of the differences increases, it is a wet trend. The opposite is a “dry” trend.

Table 1: Climatic data of the studied stations:

Y	X	STATION	PI	SPI
32.751753	-0.587722	Ain Sefra	200.6	-0.02902
34.797924	1.128845	Tiaret	360.1	0.05762
33.683936	1.011675	El Bayadh	271.6	-0.01667
34.662726	3.250267	Djelfa	294.9	-0.02567
34.758967	0.14502	Ain Elhdjar	333.4	-0.00231
35.453451	4.141909	Ain Khermane	170.6	-0.00775
35.178162	1.496684	Souguer	328.3	-0.00125
33.54848	-0.283625	Mechria	238.01	-0.00698
35.795872	7.393718	Ain Baida	401	0.07
36.138864	5.025443	Kasdalli	378	0.001
36.076791	7.820129	Mdaourchoue	323	0.04
34.891947	1.243385	Medrissa	343	0.04
35.547209	6.166911	Batna	368	0.00167
35.840861	4.56889	Ksob	198.5	0.07281
34.497842	-0.819639	Ras El Ma	203	0.04281
35.4	8.12	Tebessa	358	-0.00738
35.07	1.05	Ferenda	391	0.00445

2.3 Spatial interpolation and reclassification:

The indices used are mapped following the spatial interpolation method. Using the inverse distance weighting (IDW) provided by the extension of the Analyst Spatial under the ArcGIS program, this method is based on inverse distance weighting. Nearby values contribute more to the interpolated values than distant observations. In other words, the influence of the data from a known point is inversely proportional to the distance of the location of the unknown point that will be estimated [14]. In other words, an input point has an isotropic influence on an interpolated value. Once the various mapped (interpolated), the next step is to reclassify each index layer into value intervals using the ArcGIS reclassification tool). Scores from 1 to 5 were assigned to each class, where 1 represents a favorable value class, e.g., for the SPI, enter “1” as a score for a class of values that ranges between 0.15 and 0.34 means that this class is climatically more favorable than the class where values range between -0.22 and -0.42 to which a score of “4” is given. The sensitivity map is obtained following an unweighted overlay (extension: spatial analyst on ArcGIS) (Fig. 2).

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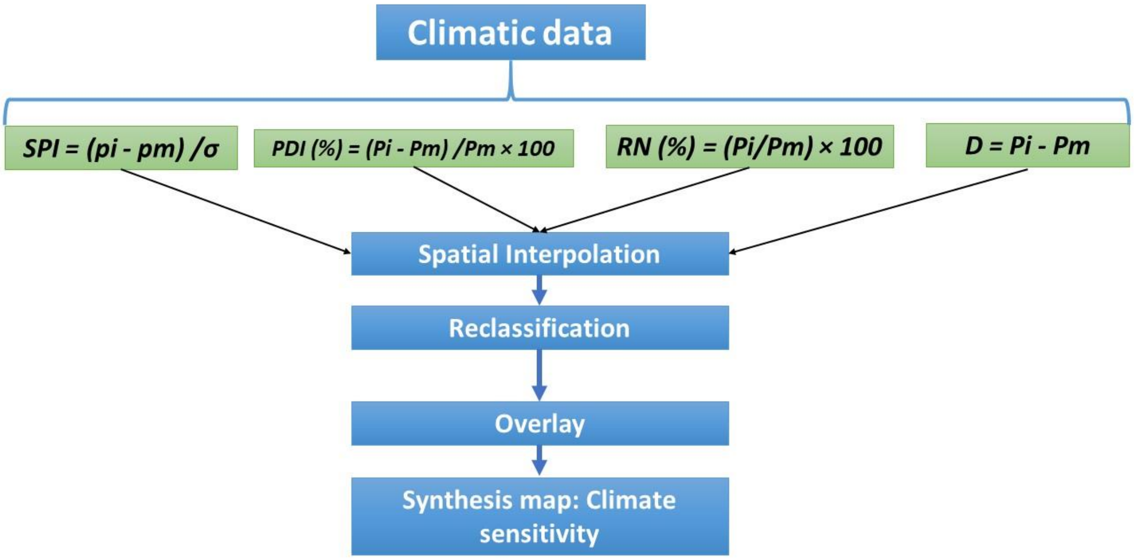

Fig. 2: Spatial interpolation and reclassification**.**

3. Results and discussion

The values of the SPI index during the period 1985 - 2019 vary between 0.34 over the regions of Djelfa, Frenda, Tiaret, Batna, Ain el Baidha, Tebessa and -0.42 over the regions of Ain Safra, Mechria, and even Ain Kerman, the climate of these regions is therefore classified as close to normal to moderately wet. Compared to normal, the index values reach 127.48 on the wilaya of Djelfa, the South of the wilaya of Khenchela, Tebessa, and Saida. The values decrease to 84.01 on the territory of the wilaya of Naama, and the North of El Bayadh. (Fig. 3).

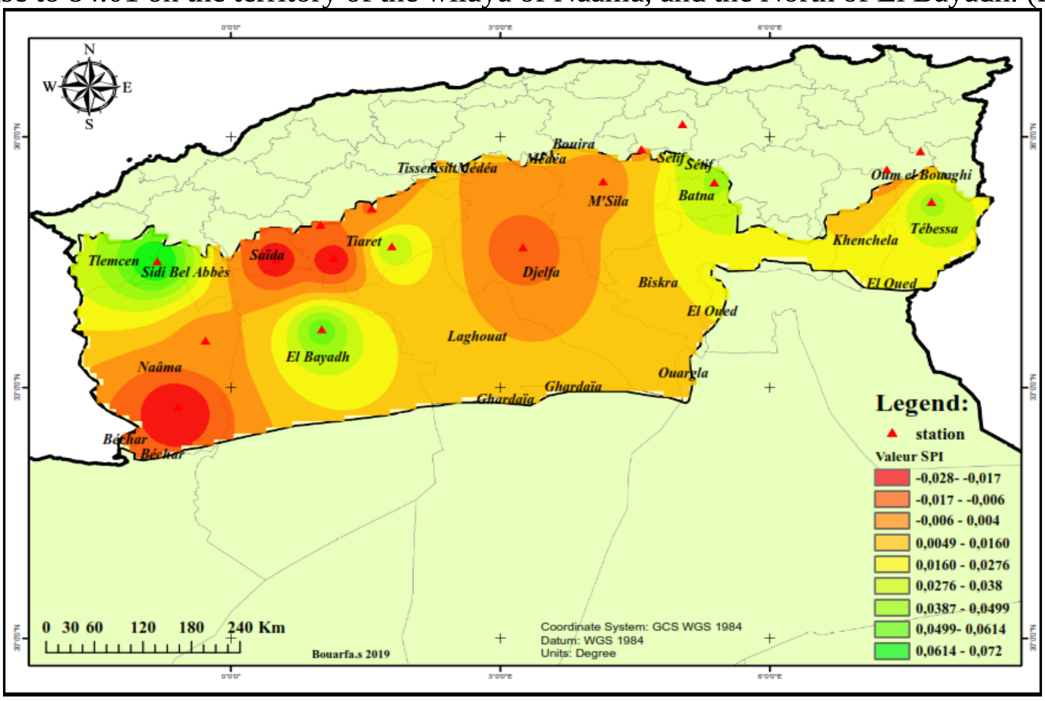

Fig. 3: Average StandaPDIzed Precipitation Index (SPI) of the selected stations.

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The values of the index "deviation from the average" show the same distribution of values as the two previous indices, with values that reach 68.82 on the wilaya of Djelfa, Khenchela, and Tebessa and values that indicate a severe climate in the southern regions: Naama and El Bayadh, and also on the South of the wilaya of M'sila. Similarly, the PDI index shows a favorable climate in Djelfa, where the values reach 107.85. In contrast, the southern regions of the steppe have a deficiency of precipitation where the values reach -15.98 around the region of El Bayadh and Naama.

The compared to normal ratio index reaches its best values on the steppes of Djelfa, Tebessa, Oum Bouaghi and Souk Ahras and representing almost 73% of the study area, values that represent an unsuitable climate form almost 25% of the study area. (Fig. 4).

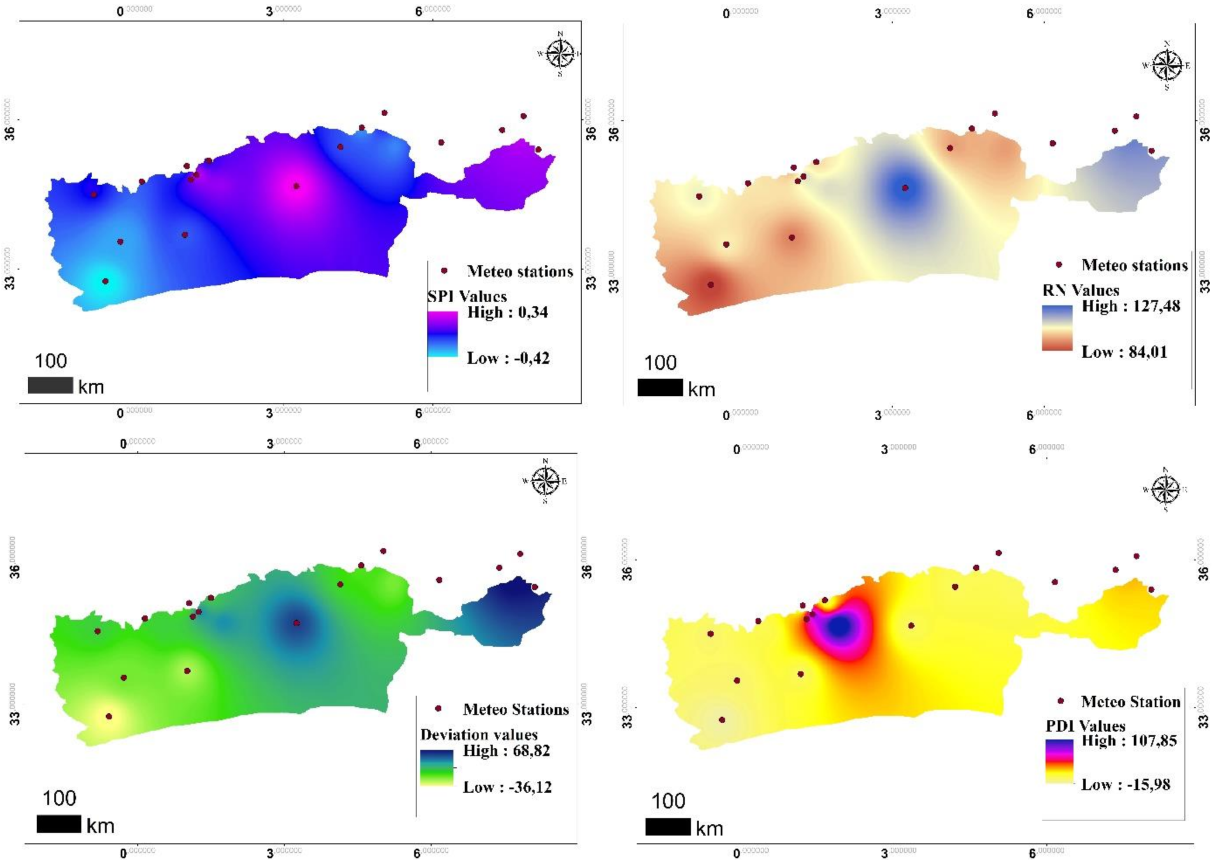

Fig. 4: The map of index values.

The final sensitivity map shows that 51016.36 sq. km, i.e., 23.68% of the Algerian steppe is in a situation of low climate sensitivity (Djelfa, Tiaret, Medrissa, South of Batna, Ain Baida, Khenchela, Tebessa) and that 110873.68 sq. km, i.e., about 51.46% is in medium sensitivity (Biskra, South of M'sila, Laghouat, Tlemcen, Sidi Belaabes, and on the North of the wilaya of Naama and El Bayadh), while 53550 km ² is highly sensitive (South of Naama, El Bayadh, South of M'sila and the West of Batna). (Fig. 5).

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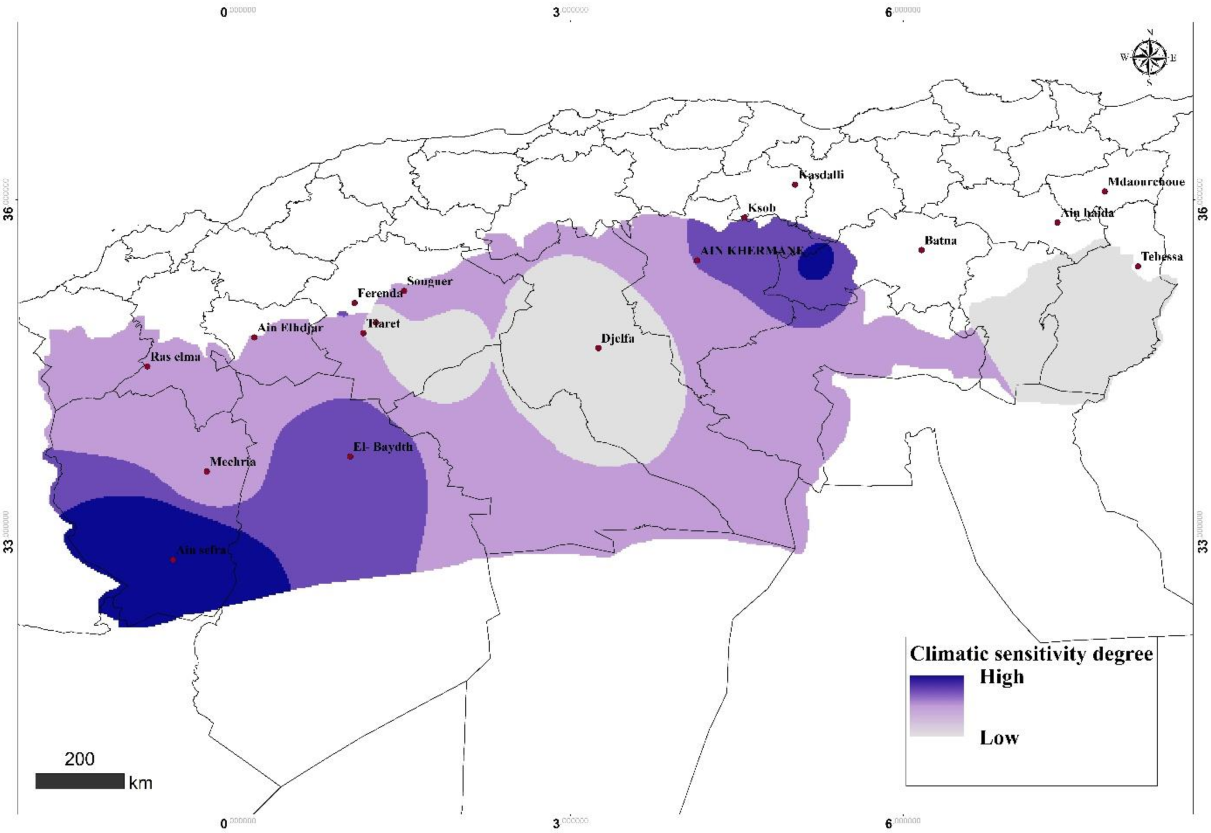

Fig. 5: Sensitivity map

4. Conclusion

Due to its location in central Algeria, in a transition zone between the humid and sub-humid bioclimatic stage of the North and the hyper-arid and desert stage of the South, the steppe region has a climatic peculiarity. The climatic analysis and the construction of maps of parameters and climatic indices showed the irregularity of rainfall distribution because the mountainous regions (more than 800 m of altitude) are characterized by a more or less favorable climate where precipitation varies between 250 and 400 mm. In contrast, the South of the region is characterized by low rainfall (190 to 220 mm). Djelfa, Tiaret, Khenchela, and Tebessa regions have low sensitivity. At the same time, the sub-Saharan areas present a high sensitivity (Naama and El Bayadh), even the area located in the south-west of the Aures going to the low altitudes of Chott El hodna (Barika region, Bitam to M’sila also show a medium to high sensitivity).

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