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Spatio-temporal assessment of drought in the semi-arid region of Algerian steppe through index and remote sensing

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Abstract: The scarcity of annual rainfall, which sometimes spreads over successive years, causes persistent droughts. In order to study the drought severity on the Algerian steppe, we analysed precipitation data (1985–2015) from the weather stations of Ain Sefra, El Bayadh, Tiaret and Djelfa, using drought meteorological indices: the mean deviation, the standardised precipitation index, the rainfall index and the frequency analysis of the rainfall series. Thus, we adopted the diachronic study by satellite remote sensing for the years 2002 (the driest year) and 2009 (the wettest year), which allowed us to better understand the evolution of the steppe rangelands surface and to better interpret their spatial-temporal changes. Drought, as determined by the mean deviation index, occurred during two periods (in sequence and corresponds to 55% the sequences of deficit years), one over 12 years (from 1994/1993 to 2006/2005) and the other over 5 years (1985–1990) and with isolated years. The results of the diachronic study of the vegetation change demonstrate the obvious divergence of the vegetation cover between 2002 and 2009. Drought has impacts on vegetation composition, growth, productivity, structure and functioning of ecosystems, which limits regeneration of vegetation cover.

Keywords: drought, indices, remote sensing, spatial-temporal analysis, steppe

INTRODUCTION

The impact of climate change on living beings is a lived reality; it accentuates other natural phenomena, as is the case for drought, which affects more people than any other form of natural hazard [WILHITE, GLANTZ 1985]. This natural hazard has been of concern to scientists and policy makers for some time, due to its immediate and long-lasting consequences on the environment [JOUILIL *et al.* 2013].

According to CROPPENSTEDT *et al.* [2015], drought damage and losses amount to more than 15% of all natural disasters; for example, 9.3 mln people faced drought in 2018, when it accounted for 85.8% of livestock losses. Generally, the impacts of drought referred to as direct ones are the restriction of vegetation cover and the reduction of soil moisture and steppe vegetation. These effects thus lead to a reduction in water reserves, which in turn causes a decrease in crop productivity [FADHIL 2011].

Drought is a recurrent phenomenon of the climate, generally indicating a scarcity of water resources over a large geographical area and lasting for a relatively long period [ZARCH *et al.* 2011]. It can have various aspects, which vary according to the type of resource affected by this natural phenomenon and the type of economic activity most affected.

Different types of drought can be defined according to its characteristics, such as hydrological, hydrogeological, agricultural, edaphic, socio-economic and meteorological drought [BERGAOUI, ALOUINI 2001; DHAOU 2003; DHAOU *et al.* 2009]. The last one is the driving event for the other types of drought.

Meteorological drought occurs when rainfall is well below normal over a long period. According to DHAR *et al.* [1979], a meteorological drought is a shortfall of 20% or more below the normal average rainfall. Generally, it is measured for long-term records [Zakhem, Kattaa 2016].

Algeria has experienced three major droughts during the 20th century, with rainfall deficits recorded throughout the country [Boubakeur 2018]; these deficits are more significant in the steppe region, where the degradation of rangelands is considerable [Nedjraoui, Bédrani 2008].

The Algerian steppe extends over an area of about 20 million hectares of land, producing a significant amount of cereals, and sustaining a sheep population of 20 mln heads; it extends over a length of 1,000 km and a variable width, from 300 km in the West to 150 km in the East [Nedjraoui, Bédrani 2008].

According to Faci *et al.* [2021], this region is marked by high monthly and interannual variability in precipitation; this variation has resulted in repetitive drought sequences. The western part of the steppe is characterised by the recording of both dry and wet extremes.

The objective of this work is to analyse the impact of drought by using some meteorological indices of drought, and to make a diachronic study by satellite remote sensing in the steppe region; also, to better understand the evolution of the surface states of the steppe regions, in the west of Algeria, between a dry year and a wet year, to better interpret their spatial-temporal modifications. The modified soil-adjusted vegetation index (*MSAVI*) is a vegetation index, which is used to lift limits on applying the normalised difference vegetation index (*NDVI*) to the areas with a high composition of bare soil. It is an efficient and simple remote sensing information model for drought monitoring and assessment [Wu *et al.* 2019].

There is no single definition of drought; several drought indices are used around the world, depending on the affected climate or area. The choice is often based on local habits, which in the long run become real customs [Koudamiloro *et al.* 2017].

In the present study, four meteorological indices were used to identify and detect meteorological drought; the chosen indices are the mean deviation index (*MD*), the standardised precipitation index (*SPI*), the rainfall index (*RI*) and the frequency analysis of the rainfall series. These indices were applies to rainfall records recorded over a period of 30 years (1986–2015), in the stations of Ain Sefra, El Bayadh, Tiaret and Djelfa.

MATERIALS AND METHODS

STUDY AREA

The study area is located in the highlands of western Algeria, corresponding to the North African steppe zone, where the selected meteorological experimental stations are: Sidi Abderrahmane in Tiaret; Ain Sefra, El Bayadh, and Djelfa (Fig. 1).

This region is characterised by an arid and semi-arid bioclimate. Intense rains in autumn and spring and a minimum summer rainfall correspond to the hottest period, which makes them regions of a Mediterranean climate [Daget 1977].

USED DROUGHT INDICES

The indices used in the identification of climatic drought include the standardised precipitation index (*SPI*) which is calculated through the adjustment of the rainfall series collected over long periods at a probability curve [McKee *et al.* 1993]. The *SPI* provides a comparison of the precipitation over a specified period with the precipitation totals of an equivalent period for all the years available within the historical document. The *SPI* is comparable in both time and space, and it is not suffering from geographical or topographical factors [Gebrehiwot *et al.* 2011]. The mathematical formula for *SPI* is:

$$SPI = (P_i - P_m)/\sigma \tag{1}$$

where: P_i = the precipitation of year i, P_m = the average precipitation, σ = the standard deviation.

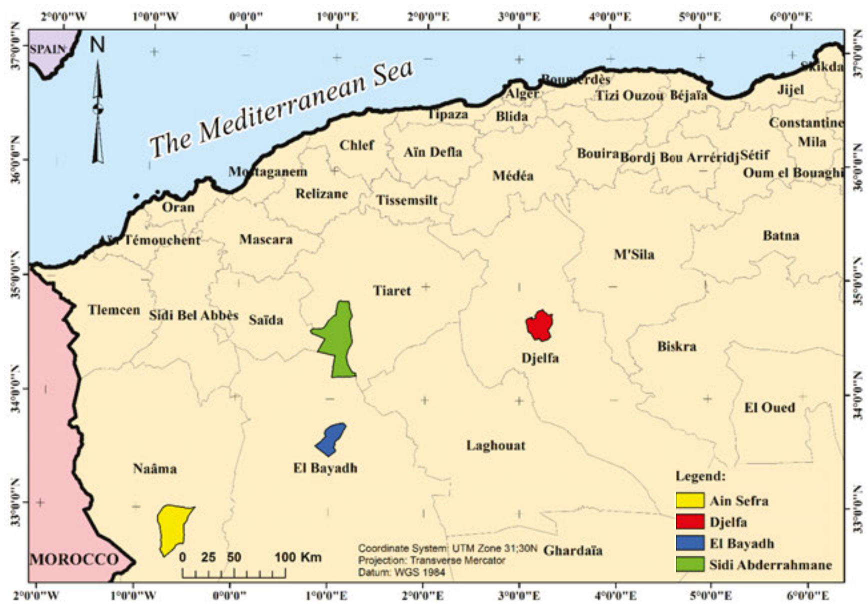


Fig. 1. Location of stations: Ain Sefra, Sidi Abderrahmane, El Bayadh and Djelfa; source: Scientific and Technical Research Center on Arid Regions (CRSTRA)

The mean deviation index (MD) is the difference between the annual rainfall height (P_i) and the annual average precipitation height (P_m) $MD = P_i - P_m$.

The rainfall index (RI) is the ratio of the annual precipitation height to the annual average precipitation height $RI = P_i/P_m$ is the frequency analysis of the pluviometry series. The annual rains are classified in ascending order according to their non-exceeding probability (F), the formula of which is as follows:

$$F = [r/(N+1)]100 \qquad (2)$$

where: r = rank of the year according to an increasing classification of rainfall amounts, N = number of years of observation [DHAOU 2003].

THE DIACHRONIC STUDY OF CHANGE THROUGH REMOTE SENSING

Satellite imageries have proven to be effective tools that provide spatially continuous information regularly during a timely manner with improved detail. [GEBREHIWOT *et al.* 2011]. Satellite Landsat images datasets Tm5–Tm7 and ETM + 30-m resolution images were downloaded from the US Geological Survey website (https://glovis.usgs.gov/). Radiation calibration, FLAASH atmospheric correction, image registration, and image clipping were pre-processed. The necessary pre-processing for the satellite imageries has been done [WU *et al.* 2019]. They permit to form a diachronic study within the study zones and detect the change using remote sensing, which is the process that allows to spot the various states of an object or a phenomenon when observed in intervals [BOUARFA, BELLAL 2018]. The diachronic study using remote sensing of the state of vegetation in the steppe region goes through several phases, the first is at the beginning the pre-processing of satellite images of the year 2002 (dry year) and 2009 (wet year). Then follows the supervised classification using the $MSAVI$ classification. This index has been proposed for the objective of correcting or at least reducing the influence of the soils underlying the vegetation cover on the signal measured at satellite sensor level. It is calculated using the following formula:

$$MSAVI = SAVI \qquad (3)$$

$$SAVI = [(NIR - Red)/(NIR + Red + L)] \cdot (1 + L) \qquad (4)$$

$$L = 1 - 2s \cdot NDVI \cdot WDVI \qquad (5)$$

where: $SAVI$ = soil-adjusted vegetation index s = slope of soil line, characteristics: ratio-based index, $NDVI$ = normalised difference vegetation index, $WDVI$ = weighted difference vegetation index, L = amount of green vegetation cover, NIR = pixel values from the near infrared band, Red = pixel values from the near red band.

Limited range: $-1 < MSAVI < 1$, L not a priori, but calculated [QI *et al.* 1994].

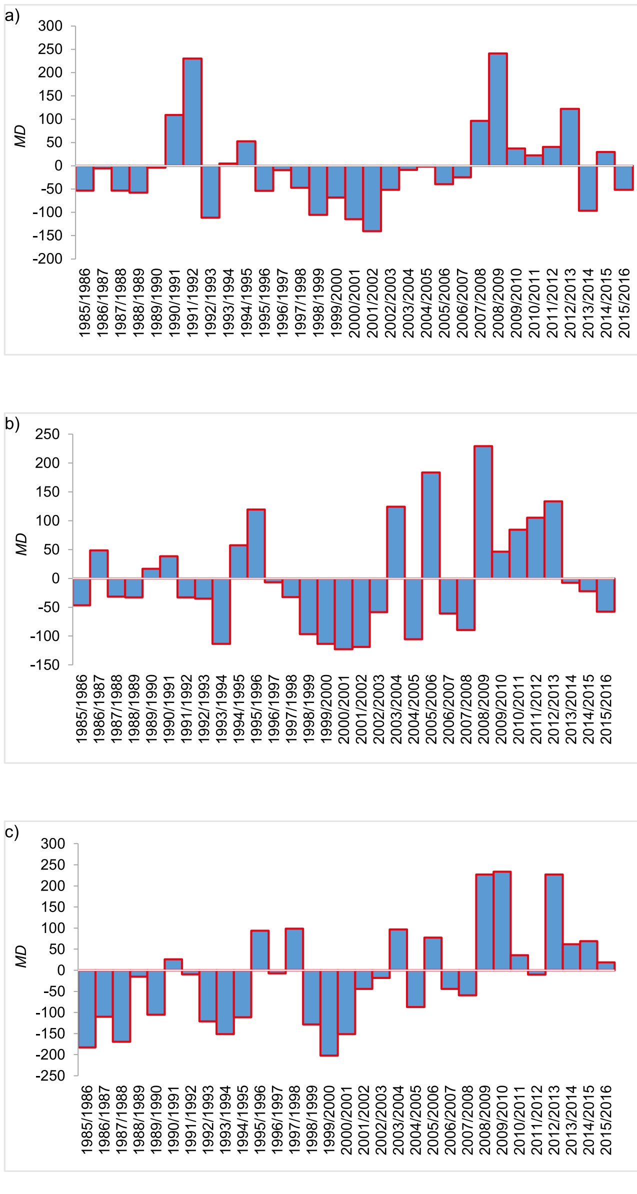
The importance of carrying out a supervised classification is to extract the areas of good range and degraded range; indeed, our essential objective is the study of the vegetation cover and its spatio-temporal dynamics for the driest year 2002, and the wettest year 2009 (Fig. 5). In this context, we chose the following classes: the good rangelands, the bare ground, which constitutes the much degraded steppe rangeland, and the agglomerations.

RESULTS AND DISCUSSION

The analysis of rainfall time series allowed us to calculate some drought indices in order to characterise deficit and surplus years in the different stations along the study period.

The evaluation of the drought index MD for the pluviometry series of the studied stations (Fig. 2, 3) allowed us to note that during an observation period of 30 years (1985–2015) the station of Ain Sefra recorded 39.3% of surplus years and 60.7% of deficit years, the station of Sidi Abderrahmane and El Bayadh recorded 40% of surplus years and 60% of deficit years while Djelfa station recorded 50% of surplus years and 50% of deficit years.

Drought, as determined by the mean index, occurred during two periods (in sequence and corresponds to 55% the sequences



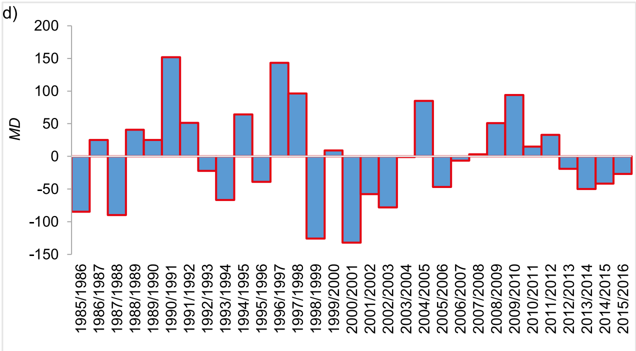


Fig. 2. The mean deviation (*MD*) for the pluviometry series of the studied stations in the period 1985–2015: a) Ain Sefra, b) El Bayadh, c) Sidi Abderrahmane, d) Djelfa; source: own study

of deficit years), one over 12 years (from 1994/1993 to 2006/2005) and the other over 5 years (1985–1990) and with isolated years.

The *SPI* provides a comparison of the precipitation over a specified period with the rainfall totals of the same period for all the years available within the historical paper [Lana *et al.* 2001]. The *SPI* is comparable in both time and space, and it is not affected by geographical or topographical factors. On the other hand, the analysis using the *SPI* reveals the main characteristics of the rainfall data series of the stations studied (Tab. 1).

By using the calculated drought thresholds, we were able to determine for each of the studied stations the frequencies of normal dry and wet years during the studied period in the 4 stations. This allowed us to observe 14.29% of dry years at Ain Sefra, 8.69% dry years in Sidi Abderrahmane, 15.84% dry years in El Bayadh and 18.01% dry years in Djelfa.

The analysis of drought using the rainfall index method (*RI*) and the cumulative differences reveal an alternation of sequences with an overall dry trend and sequences with an overall wet trend (Fig. 3).

Analysis of the indices showed greater precision for normal years compared to deficit and surplus years. Thus, Figure 4 shows the variations in annual rainfall as a function of hydrological years in relation to the different frequency classes.

Following the analysis of the dry year determined by the frequency analysis method at the examined stations, it is noted that for the entire region, the proportion of dry sequences which lasts only one year varies between 7 and 16%. The sequences of dry periods that last two consecutive years or more are more frequent and often exceed 50%. What is more, the analysis shows that the driest year was 2002 and the year 2009 was the wettest.

We deduce the simultaneous existence of two indices, and of two facts; the *SPI* and the frequency analysis, which is illustrated in Table 1, where both indices have the same results and descriptors.

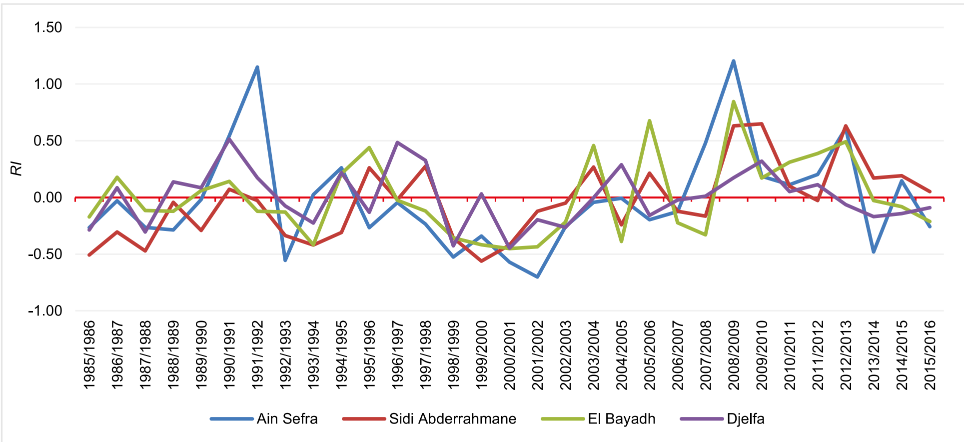


Fig. 3. The rainfall index (*RI*) from 1985 to 2015; source: own study

Table 1. Frequencies (in % from 1985 to 2015) of standardised precipitation index (*SPI*) classes in the period 1985–2015

Descriptor	Frequencies of standardised precipitation index (SPI) classes in the period 1985–2015 for stations							
	Ain Sefra		Sidi Abderrahmane		El Bayadh		Djelfa	
	%	description	%	description	%	description	%	description
Near to normal	69.88	normal 69.88%	81.99	normal 81.99%	68.01	normal 68.01%	66.15	normal 66.15%
Moderately wet	6.52	wet 15.81%	5.59	wet 9.32%	9.94	wet 16.6%	9.01	wet 15.81%
Very humid	5.59		0.00		3.11		4.04	
Extremely humid	3.73		3.73		3.11		3.42	
Moderately dry	7.76	dry 14.29%	7.14	dry 8.69%	9.32	dry 15.84%	10.56	dry 18.01%
Very dry	3.73		0.00		4.04		4.97	
Extremely dry	2.80		1.55		2.48		2.48	

Source: own study.

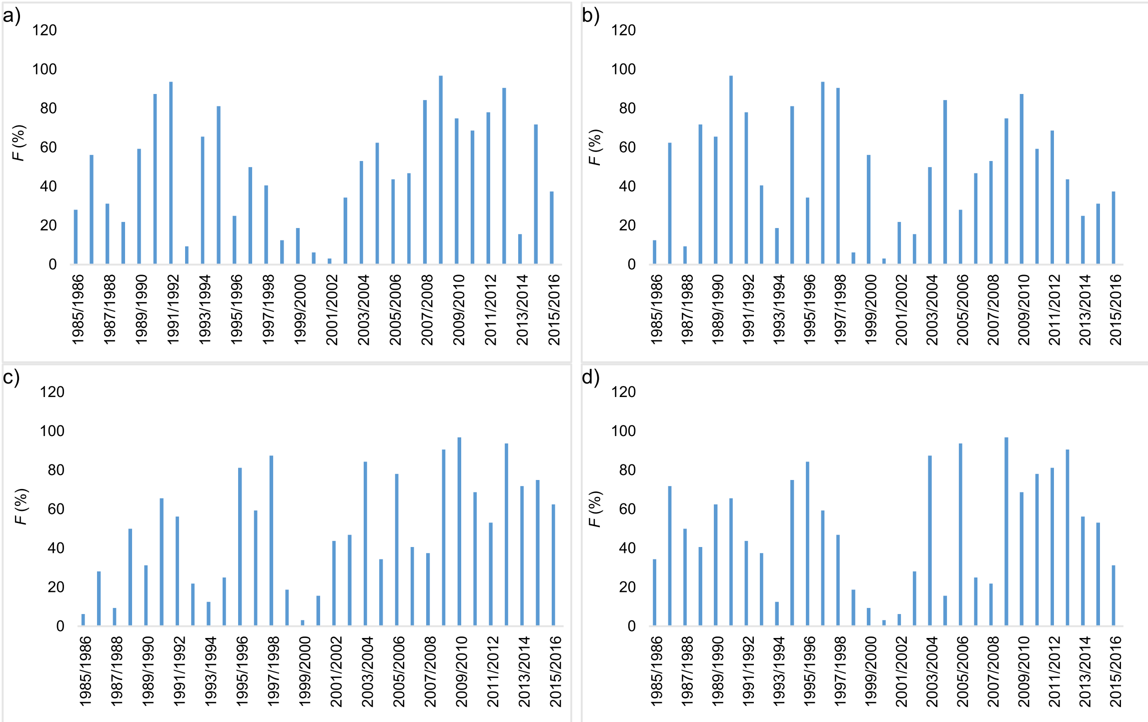


Fig. 4. Histogram of the frequency (*F*, %) analysis with the rainfall series stations from 1985 to 2015: a) Ain Sefra, b) El Bayadh, c) Sidi Abderrahmane, d) Djelfa; source: own study

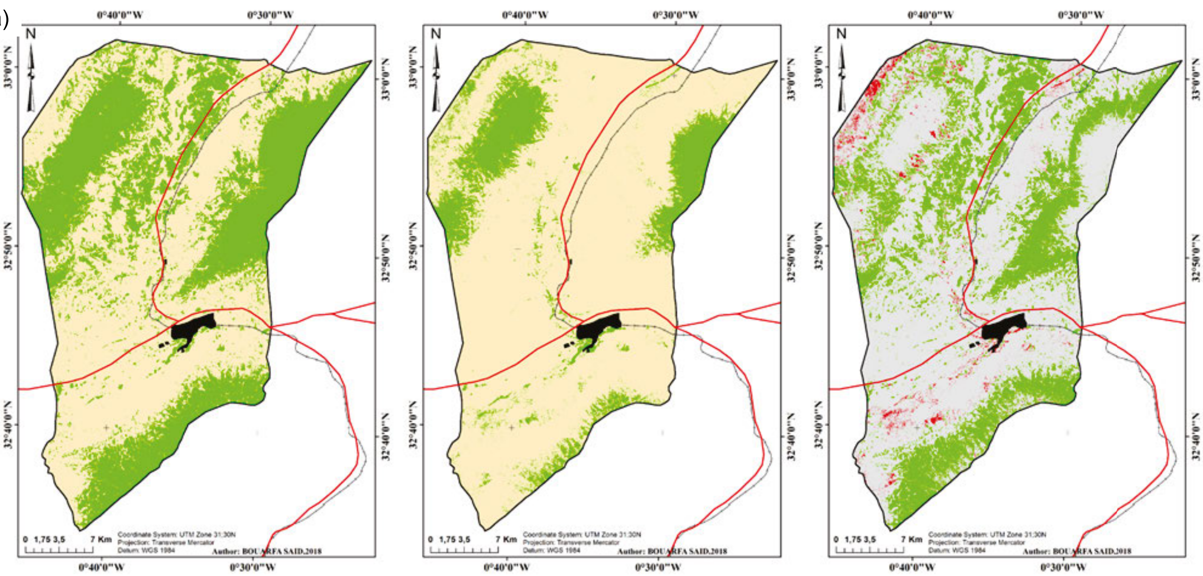
However, the frequency analysis provided more detailed explanations regarding the normal years compared to *SPI* and *MD*. Nevertheless, the frequency analysis does not allow us to identify the overall trends in rainfall at the level of the stations studied.

According to the analysis of rainfall data from stations, which represent the most illustrative model of the whole region, among several drought indices, we can retain that drought is a recurring phenomenon (Fig. 5).

These results coincide with several similar studies results that were carried out to determine and characterise drought in the Algerian steppe; mentioning a sequence of dry and wet years in Algeria in 1980–1990, and 1995–2005 [Meddi, Humbert 2000; Talia 2002]. Drought events have further occurred and are characterised by severity and duration rises for all studied plains during the end of 1970s, early 1980s and end of 1980s [Achour *et al.* 2020], noting that drought events substantially vary from one station to another [Habibi *et al.* 2018].

Many studies have also indicated that these regions have an increasing tendency to aridity especially the region of El Bayadh and Djelfa, where a drastic variability was recorded for all the monthly and annual rainfall from year to another with no seasonality. Namely, a strong hydric stress would threaten plants subsistence and cause summer flood that destroys soil and vegetation density, floral richness, and water resources availability [Benseghir *et al.* 2008; Belaroui *et al.* 2014; Boubakeur 2018]. A clear drought was characterised overall western and central

a)



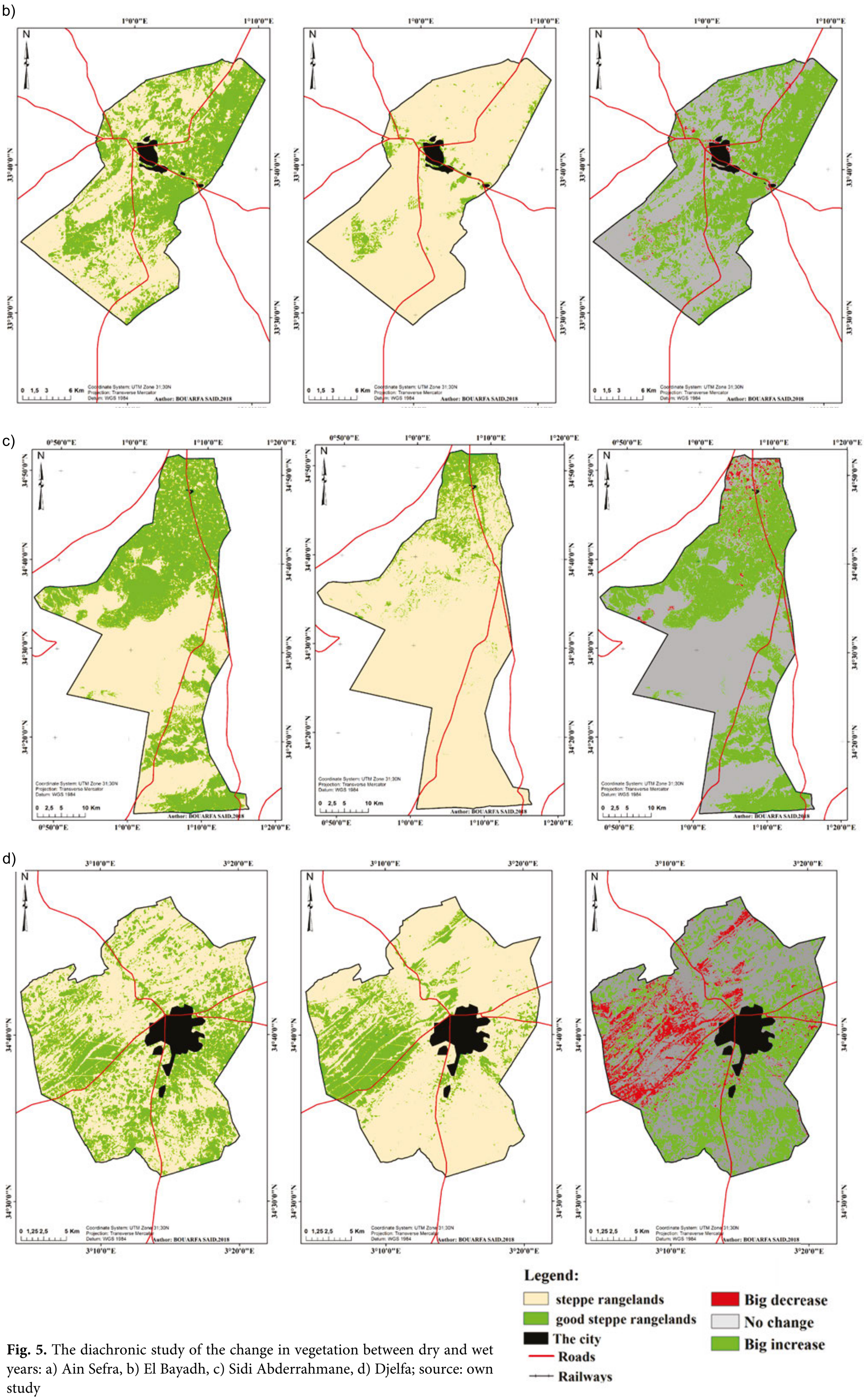


Fig. 5. The diachronic study of the change in vegetation between dry and wet years: a) Ain Sefra, b) El Bayadh, c) Sidi Abderrahmane, d) Djelfa; source: own study

steppes in Algeria particularly from October to December 2006, and December 2012 [Mega, Medjerab 2016].

The analysis of remote sensing data can offer a continuity to meteorological data and indices, by filling the gaps that sometimes could be found in long time series, as well as presenting plenty of information about vegetation and soil statues and land use. This is used often in drought studies in order to quantify growth and degradation of different land use items according to climatic factors (dry and wet periods) and human activities.

The classification of a satellite image is based on the identification and grouping of different themes according to their spectral signatures. In case of supervised classification, the operator defines the classes to constitute and collects a certain number of field realities relating to each of the classes that he intends to highlight [Bensaid 2006].

The classification assessment is based on a two-dimensional table called a confusion matrix, which asserted for each of the classes performed the level of reliability and the main confusions made during the classification of an image. Subsequently, the study attempted to find the relationship between the studied drought indices and the state of the steppe ranges.

The plant cover is vulnerable to climatic variations with semi-arid or arid characteristics [Abbas, Abdelguerfi 2005]. Drought impacts vegetation growth, productivity, structure, composition and functioning of ecosystems, and leads to litter accumulation, due to its sensitivity to climatic variations, which limits regeneration of vegetation cover [Black, El Hadi 1992].

The results of vegetation change through diachronic study, demonstrate the obvious divergence between 2002 and 2009. For the year 2002 the station of Ain Sefra recorded a low rate of good rangelands surface of 14.52%, while in 2009 it amounted to 40.06%, the station of El Bayadh recorded in 2002 holds rate of 4.79% of good rangelands, whereas in 2009 a rate it is 39.99%. For the station of Sidi Abderrahmane, the good rangelands surface was around 8.78% in 2002, and then reached 43.72% in 2009; finally, the station of Djelfa noted 19% in 2002, then a rate of 32.35% in 2009 (Fig. 6). Regarding these results of the difference of rainfall between two dry years, we can notice that the climatic conditions are unsuitable for the sustainability and resilience of the steppe ecosystems compared to the rangeland surfaces that increased due to wet years. In fact the diachronic study of the steppe change between 2002 and 2009 using remote sensing

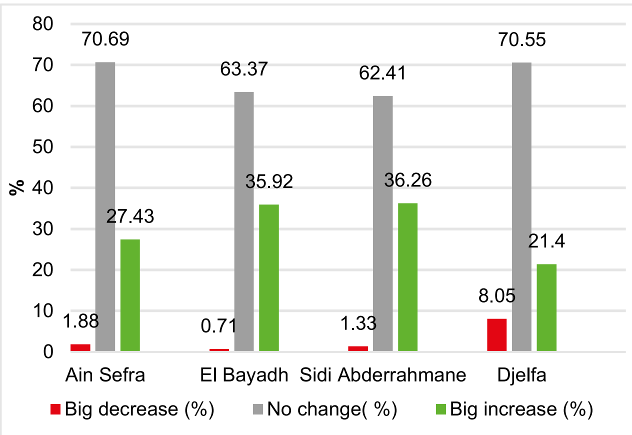


Fig. 6. The diachronic study of the change of area's in the steppe 2002/2009; source: own study

confirmed the results of climatic drought indices concerning the spatial-temporal extent of drought impact on steppe vegetation density and resilience.

In fact, the classification results show as well the increasing effect of human activities, deforestation and overgrazing on land degradation. These factors are of non-negligible impact on water resources and can cause even more severe droughts; the area of Djelfa, El Bayadh, and Ain Sefra experience a quick human and urban growth during the last decade leading to more pressure on water and soil resources. Figure 5 demonstrates the urban growth of these agglomerations; Djelfa province, for example, registered a demography growth from 977,707 in 1998 to 1,395,257 in 2010, as well as a significant increase in livestock number [Benseghir *et al.* 2008]. With the tendency of future drought, this situation threatens the environmental resilience of forests, steppes and agricultural lands leading to an overuse of water for irrigation, which jeopardises water and food security and contributes to transforming large steppes into bare soils [Boultif, Benmessaoud 2017].

CONCLUSIONS

The aim of this work is to assess the contribution of a certain climatic drought indices in the identification of the of spatiotemporal impact on steppe vegetation by integrating satellite remote sensing in order to monitor the state land use through two different years (dry and wet). Based on the analysis of rainfall data from the stations, which constitute the most representative examples of the entire area, through several drought indices, we can deduce that drought is a recurring phenomenon in the semi-arid region of Algerian steppe. The severity of drought is often more acute if one follows a year or dry years, a sequence of successive dry years is certainly more serious than an isolated drought.

Drought, as determined by the mean deviation index, occurred during two periods (in sequence and corresponds to 55% the sequences of deficit years), one over 12 years (from 1994–1993 to 2006–2005) and the other over 5 years (1985–1990) and with isolated years and by using the calculated drought thresholds. we were able to determine for each of the studied stations the frequencies of normal dry and wet years during the studied period in the 4 stations, which allowed us to observe 14.29% of dry years at Ain Sefra, 8.69% dry years in Sidi Abderrahmane, 15.84% dry years in El Bayadh and 18.01% dry years in Djelfa. The results of the diachronic study of the change in vegetation highlighted an obvious divergence in vegetation cover between dry year 2002 and wet year 2009; where a considerable increase in the area occupied by the good course unit has been demonstrated. The long drought period is one of the most important consequences of climate change, and solutions must be found to adapt to it, resist the phenomenon and reduce its severity.

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