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Remote Sensing and Meteorological Indexes of Drought Using Open Short Time-Series Data in Doukkala Region, Morocco

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ABSTRACT

Over time, drought affects all regions of Morocco, especially in the arid climate region, which has negative consequences on agriculture, economic and environmental. The present study aims to describe the intensity of drought in Morocco and more specifically their impact on the distribution of vegetation. Spatial and temporal remote sensing data are used to monitor drought in the Doukkala region of Morocco, using a set of Landsat images, including Landsat 5 (ETM), and Landsat 7 (ETM+) captured during the period 1964–2014. This was determined based on remote sensing parameters: temperature condition index (TCI), vegetation condition index (VCI) and vegetation health index (VHI). The Normalized Difference Vegetation Index (NDVI) was determined for the years 1966, 1984, 1988, 2000 2006 and 2009, in order to identify the vegetation categories and quantify the vegetation density in the Doukkala region. The NDVI obtained was analyzed using the SPI (Normalized Precipitation Index) based on the rainfall data of the years 1966, 1984, 1988, 2000 2006 and 2009. The results obtained showed that the correlation between NDVI and SPI indicated negative values or less than 1. The calculation of VHI showed low values (VHI < 40%) in one part of the studied area that indicate severe to extreme drought conditions, while in the other part the VHI showed high values (VHI > 40%), which mainly reflect favorable conditions for crop development (no drought). The results of this study can be used for monitoring and evaluation of the drought for sustainable management of the area.

Keywords: drought monitoring, meteorological indicators, NDVI, VCI, TCI, VHI, Doukkala region.

INTRODUCTION

In Morocco, a drought has always been present in history; it has imposed itself with force in the last decades as a structural element of the country's climate. It is a recurrent phenomenon that has affected all Moroccan regions with different intensities, durability and natural spatial extents of time, affecting the soils and the vegetation, with a decrease in precipitation and a clear tendency to increase in temperature. The study of drought indicators (meteorological and remote sensing) in the Doukkala region, Morocco, the evaluation and monitoring of the impact of drought on crops is therefore a substantial priority for agricultural management, which is recognized by its considerable agricultural potential in the whole Moroccan agriculture. The region shows two clearly distinct areas by the abundance or not of vegetation cover related to several parameters (proximity of the ocean, geological formations of the subsoil...). Several studies have noted that the Normalized Difference Vegetation Index (NDVI) has the utility of observing droughts in time series of satellite data, while providing further analysis of the relationships between annual precipitation, and NDVI (Di et al., 1994, Kogan, 1990). Having proven to be an effective indicator of moisture and vegetation conditions (Ji and Peters, 2003, Tadesse et al. 2005), significant correlations have been identified between meteorological parameters, the Standardized Precipitation Index (SPI) quantifies the precipitation variance of a period and remote sensing parameters: the Vegetation Condition Index (VCI) (Kogan, 1995) has been used to map both annual vegetation dynamics and drought patterns, and the Temperature Condition Index (TCI), This indicator is based on the brightness temperature. It is applicable at regional or continental scale, instantaneously or for periods up to one year. The health index (VHI), which is a near real-time monitoring tool between vegetation and temperature conditions and climate impact.

Thus, the objective of this study was to assess the drought between the years 1964-2014 in the Doukkala region, by calculating: (1) annual precipitation (PN); (2) standardized precipitation index (SPI); (3) normalized difference vegetation index (NDVI) and (4) VCI, TCI and VHI indexes.

STUDY AREA DESCRIPTION

Geographic and geologic setting

The Doukkala area is located in western Morocco between latitude 32°150 and 33°150 and covers the coastal mole, bounded to the north by the central plain, to the south by the Gantour phosphate plate, to the east by the Paleozoic of the Réhamna and to the west by the Atlantic Ocean (Figure 1). The Doukkala region is divided into two areas: the first is the Sahel (El Jadida plate) in the west which extends from the Atlantic Ocean from El Jadida to Safi in the south with a width of about 20 km, and the second is the basin of Sidi Bennour in the east. These areas are characterized by the presence or abundance of vegetation cover, some of which depends on geological formations of the basement.

The Sahel strip has a low vegetation cover and indications of quasi-chronic drought, in relation to a very reduced soil. It is an elevated area, and its subsoil is made up of carbonate formations and surmounted by sandstone-limestone dune strips. These formations (Figure 2) are composed of an alternation limestones and marls in the south of the Doukkala of Upper Jurassic age, surmounted by Dridrate limestone's of Upper Hauterivian age. To the north, the limestone's and yellow marls of the Cenomanian predominate. These complexes are surmounted by marine and dune sandstones of Plio-Quaternary age (Gigout, 1951; Ferré, 1969). In the inter-dunary zones, a relatively thick local soil develops as a result of the destruction of the plio-quaternary formations and favors the formation of a vegetation cover.

The Sidi Bennour basin extends from Jemaa-Shaim in the south to Sidi Smail in the north. It is a collapsed area where the soil is very thick and

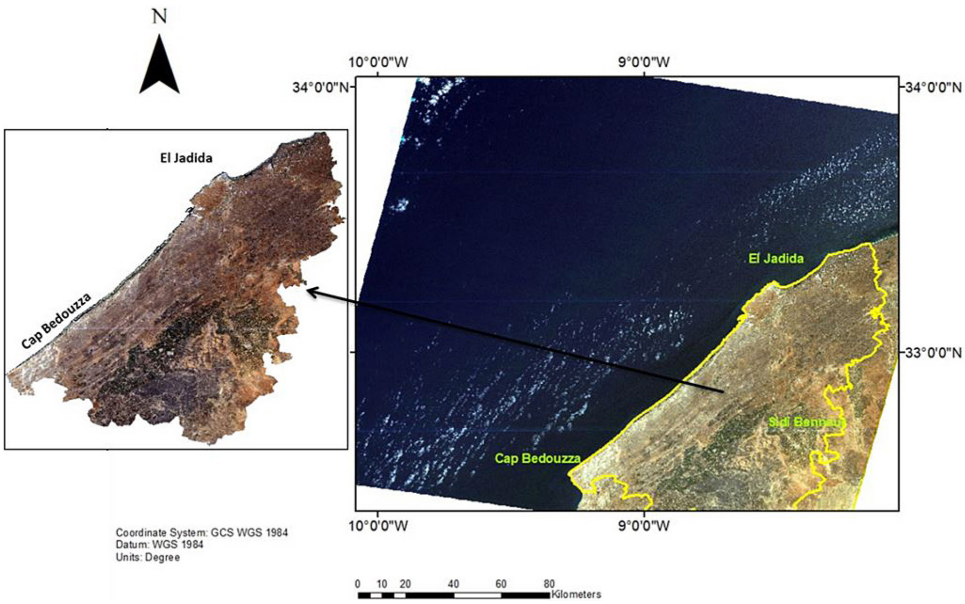

Figure 1. Geographic situation of the study area

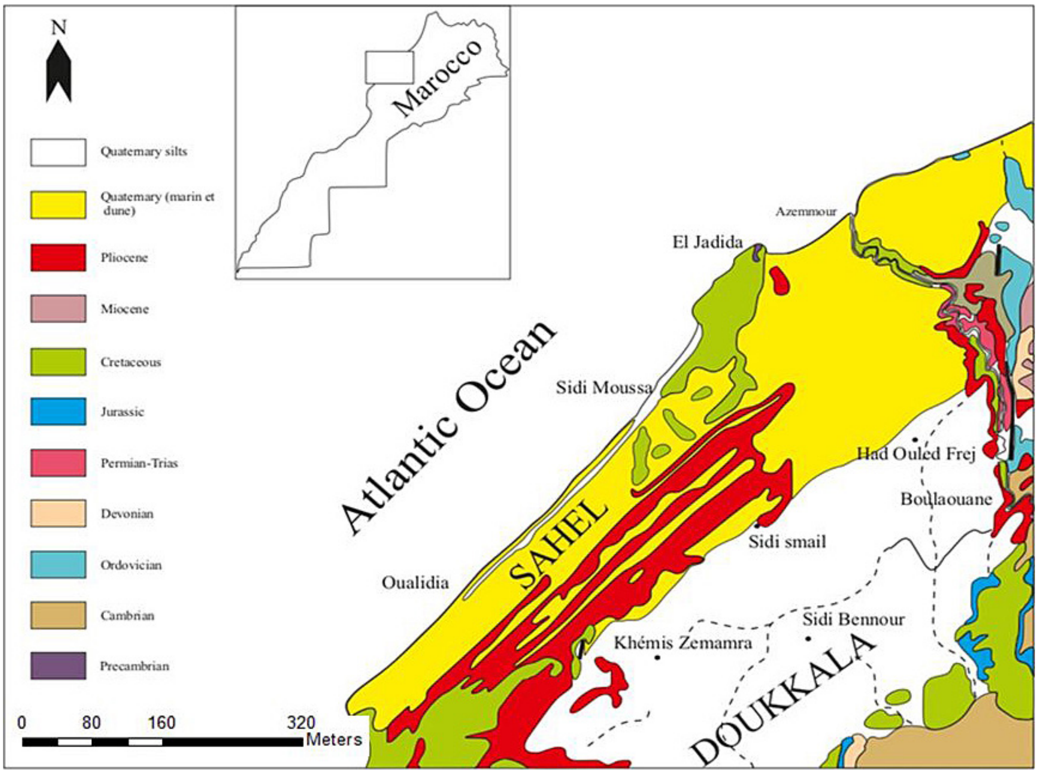

Figure 2. Simplified geological map of the Doukkala region (from the geological map of Morocco at 1/10000; Sadin**)**

the geological formations of the subsoil are buried deep. The vegetation cover is abundant and its density increases in the irrigated areas. These two parallel zones oriented NE-SE, which reactivate ancient Hercynian structures (Gigout, 1951; Ait Ayad, 2021) are the result of atlas tectonics in the horst and graben.

Climate and vegetation

The Doukkala area is characterized by a semi-arid climate. With no marked relief, the climatic effects are often influenced by the Atlantic Ocean with moderate temperatures in its western part. Inland, temperatures are more contrasted. Temperature data for the last 25 years (1992–2017) show that the average annual temperature is 19 °C with a minimum of 5 °C and a maximum of 30-40 °C. July and August are the warmest months with an average monthly temperature of 28 °C. January and February are the coldest months with a monthly temperature of approximately 15 °C (El Ghandour, 2019). However, the Sahel has a quasi-chronic aridity in relation to the subtabular limestone layers at the outcrop which do not favor the development of vegetation cover despite the proximity of the Atlantic influence.

DATA AND METHODS

Data background

Landsat datasets were downloaded from the U.S. Geological Survey website (i.e., landsat.usgs.gov). Only the months of September, November and July were included. These months they are taken during the summer period and thus the vegetation is at its minimum (irrigated areas are generally bare). The land use to correspond to perennial plants, summer crops and forests. The datasets were a combination of four different satellites: Landsat 5 (ETM) and 7 (ETM+) (launched on 28 September 1988 and 16 November 1994, respectively), containing14 satellite images, Landsat 7 (launched on 27 July 2000, 28 July 2006 and 22 September 2009). Landsat images are a collection of high resolution satellite imagery, with a spatial resolution of 30 m, provided in a standardized, orthorectified format (Faour Gh, Mhawej M, Abou Najem S.2015). Rainfall data were obtained from the Regional Office for Agricultural Development of Doukkala (ORMVAD) for the period from 1964 to 2014. The methodology used was shown in the flowchart (Figure 3) :

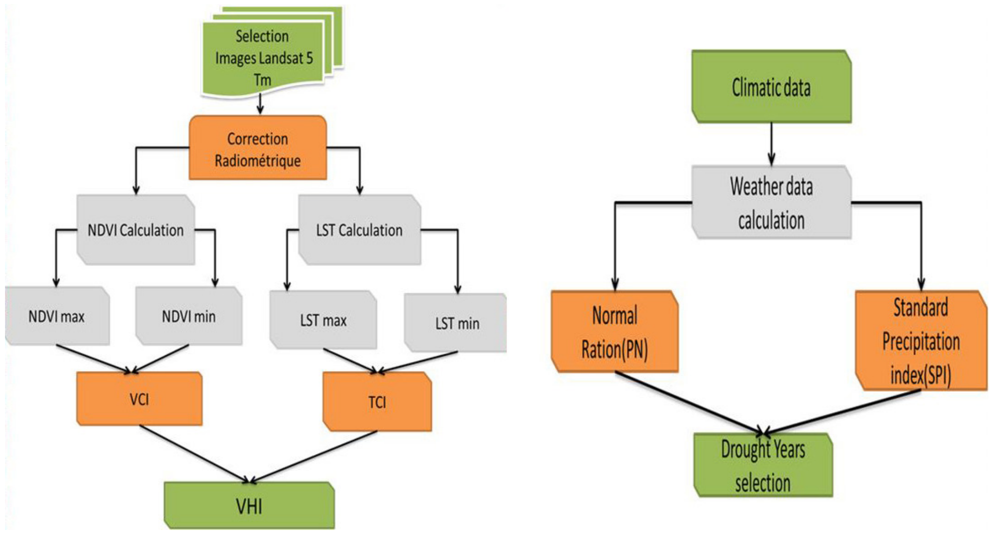

Figure 3. Flowchart of the methodology

Methodology

Normalized difference vegetation index (NDVI)

The Normalized Difference Vegetation Index (NDVI) used in agriculture to assess the distribution and quantity of vegetation by measuring the chlorophyll content of plants via satellite sensors. The calculation of NDVI uses the reflectance of red (R) and near infrared (PIR) channels measured in the visible band by satellite sensors. It is expressed according to the following equation:

$$\mathrm{NDVI} = \frac{(\mathrm{PIR} - \mathrm{R})}{(\mathrm{PIR} + \mathrm{R})} \quad (1)$$

where: NDVI values range between −1 and 1.

Normalizing by the sum of the two bands reduces the effects of illumination. The NDVI maintains a constant value regardless of the overall illumination, unlike the simple difference which is very sensitive to illumination variations. The vegetation cover has positive NDVI values, ranging from 0.1 to 0.7, with the lowest values corresponding to the least dense vegetation. These values are close to 0 for bare soil where the red and near infrared reflectance's are close.

Surface temperature (LST)

Satellite data can be used to extract an apparent temperature that reflects the prevailing surface conditions at any point in a region. These conditions correspond to the surface temperature perceived at the satellite sensor. The calculation surface temperature (LST) is essential to determine the Temperature Condition Index (TCI). This calculation is done in two steps. The first step consists in the conversion of the Digital Number (DN) into radiance by applying the following Equation 2:

$$L\lambda\,(\mathrm{W}) = ((\mathrm{LMAX}\,\lambda - \mathrm{LMIN}\,\lambda) / (\mathrm{Qcal\ max} - \mathrm{Qcal\ min})) * (\mathrm{Qcal} - \mathrm{Qcal\ min}) + \mathrm{LMIN}\,\lambda \quad (2)$$

where: Lλ– radiance, LMax–maximum radiation band 6, LMIN –minimum band radiation of band 6, Qcal max–la valeur minimale de pixel calibré quantifié en DN (1).

$$L\lambda = ((15.303 - 1.238) / (255 - 1)) * (\text{"Band 6"} - 1) + 1.238 \quad (3)$$

The radiance is converted to surface temperature (LST) by the following Equation 4:

$$LST(en°\mathrm{C}) = \left(\frac{\mathrm{K2}}{\mathrm{ln}}\left(\left(\frac{\mathrm{k1}}{L\lambda}\right) + 1\right)\right) - 273{,}15 \quad (4)$$

where: LST – surface temperature, K1 – calibration constant 1, k2–calibration constant 2.

Vegetation condition index (VCI)

The VCI index is a transformation of the NDVI using the minimum, maximum and current NDVI values over several years. It provides information on the degree of green vegetation in the period studied in relation to the extreme situations (Min and Max). It is calculated by the following Equation:

$$\mathrm{VCI} = \frac{\mathrm{NDVIi} - \mathrm{NDVImin}}{\mathrm{NDVImax} - \mathrm{NDVImin}} \times 100 \quad (5)$$

The VCI separates the short-term climate signal from the long-term ecological signal (Kogan and Sullivan, 1993). It reflects the climatic distribution and not differences in vegetation due to different ecosystems. It is a better indicator of precipitation distribution than NDVI (Kogan, 1990). It also allows comparison of the effect of climate on different study areas. The ICV provides an improvement in the analysis of vegetation condition for inhomogeneous areas (Ramesh et al., 2003). The VCI has been used on several continents to detect large-scale drought situations, but also excessive moisture conditions (Kogan, 1997; 2003; Kogan et al. 2004). Thus, this index has been used to monitor drought conditions in South Africa (Unganai and Kogan, 1998**),** India (Singh et al., 2003)**,** Greece **(**Domenikiotos et al., 2004) and Spain (Beaudin, 2006; Beaudin et al., 2007).

Temperature condition index (TCI)

The Thermal Condition Index (TCI) can be calculated from the surface temperature TSL (Kogan and Sullivan, 1993), is to be applied at a regional scale for periods ranging from day to year. Combined with VCI, it improves the accuracy of monitoring drought conditions and helps explain the contribution of temperature in drought analysis. VCI also provides useful information on the impact of soil saturation on vegetation stress (Kogan, 1997; Singh et al. 2003; Kogan et al. 2004).It is calculated by the following equation:

$$\mathrm{TCIi} = \frac{\mathrm{LSTmax} - \mathrm{LSTi}}{\mathrm{LSTmax} - \mathrm{LSTmin}} \times 100 \quad (6)$$

Vegetation health index (VHI)

The vegetation health index (VHI) is obtained by the combination of the two indexes TCI and VCI (Kogan, 1997). This combination improves the accuracy of monitoring drought conditions and its impact on vegetation. It is a good way to value the impact of climate on vegetation and the stress caused by drought. The VHI is calculated according to the following equation:

$$\mathrm{VHIi} = \alpha 1 \times \mathrm{VCIi} + \alpha 2 \times \mathrm{TCIi} \quad (7)$$

where: VCI – vegetation condition index, TCI – temperature condition index.

Ratio to normal (PN)

The PN index is the ratio of precipitation to normal and represents the percentage difference in precipitation for a year compared to the historical normal for that period. It is calculated according to the following Equation:

$$\mathrm{PN} = \left(\frac{\mathrm{P}}{\mathrm{Pm}}\right) * 100 \quad (8)$$

where: P – annual average precipitation, Pm – historical annual average (1964–2014).

Standardized precipitation index (SPI)

The SPI (McKee et al., 1993) is a statistical indicator used to characterize local regional droughts based on long-term precipitation history. It is calculated according to the following Equation:

$$\mathrm{SPI} = (\mathrm{P} - \mathrm{Pm})/\sigma \quad (9)$$

where: P – annual average precipitation; Pm – annual average from 1964 to 2014 and σ is the historical standard deviation of precipitation.

RESULTS AND DISCUSSION

Evolution of precipitation

The precipitation in the Doukkala region attained a minimum of 306.5 mm in 1964 and a maximum of 591.91 in 1995 (Figure 4). The precipitation data during the last 50 years (1964–2014), show that the average annual precipitation is 320 mm/year with a minimum value of 124.99 mm (1994) and a maximum value of 591.91 mm (1995). Similarly, the annual average precipitation has a decreasing trend in parallel with a change in annual average temperatures over the last 50 years highlighting a slight warming trend (El Ghandour, 2019). The meteorological index uses precipitation measurements collected at weather stations to describe drought conditions. Their purpose is to compare current values with the historical trend. From the precipitation data for the period 1964 to 2014, the calculation of the meteorological indices (PN and SPI) will allow us to select the years where droughts are accentuated.

Ratio to normal (PN)

The calculation of the NP indicated that years with a precipitation deficit have values below 100. The more these values reduce, the drier the years are. In the Doukkala region and over a period (1964–2014) the years with the least rainfall are presented in the following Figure 5.

Standardized precipitation index (SPI)

The historical standard deviation σ is the average of the annual standard deviations σa from 1964 to 2014 (SPI figure 1964–2014). According to the SPI scale of McKee et al. (1993), negative values indicate dry years. The smaller the negative

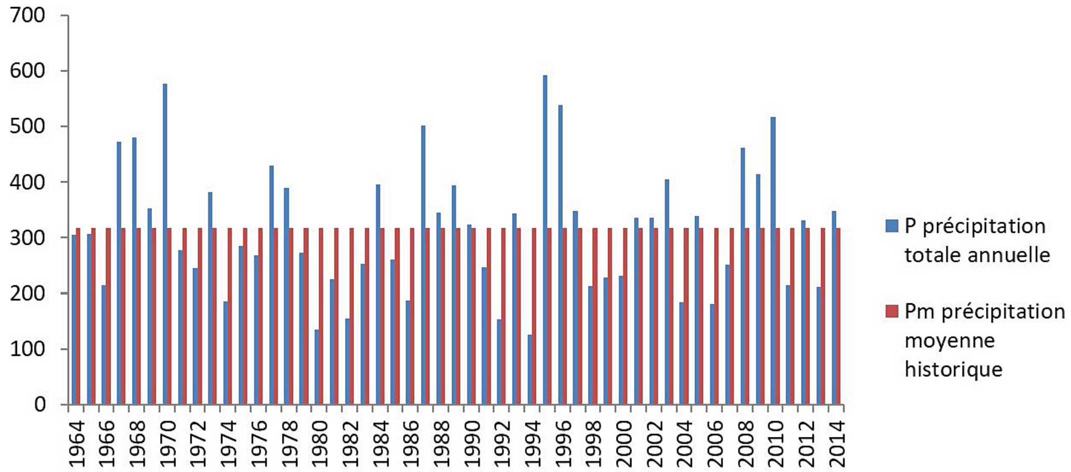

Figure 4. Evolution precipitation of 1964 to 2014 (By Moroccan Meteorological Service)

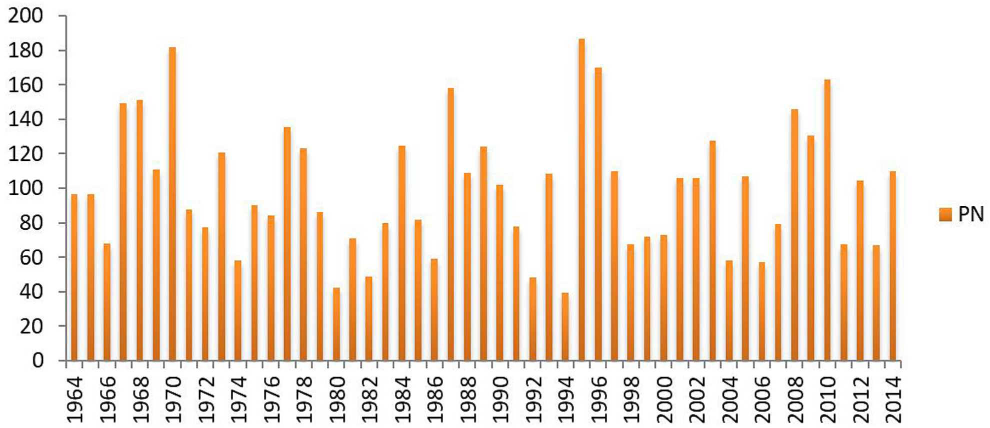

Figure 5. Ratio to normal PN (1964–2014)

values, the drier the years. In the Doukkala region and over a period of 50 years (1964–2014), the driest years are presented in the following Figure 6. Comparing the two indices PN and SPI for the selected years (Figure 7), the results are concordant and satisfactory with PN values largely below 100 and negative and lower SPI values. The years used according to the availability of satellite data and their calculated PN and SPI indexes are presented in the following table (Table 1)

Vegetation condition index (VCI)

The following maps show the vegetation and temperature situation obtained from satellite data covering all land use classes (forests, summer crops, etc.). In the Doukkala region, Figure 8 presents the VCI indicator calculated, in summer, over a period of 25 years with an interval of about 4 to 6 years. This indicator provides information on the state of the vegetation for the years 1984, 1988, 1994, 2000, 2006 and 2009, over this period, in relation to the extreme values of the NDVI for the same years over the period 1984–2009. The VCI maps obtained reveal that the classes of high values of VCI (VCI>40%) indicate vegetation conditions close to the maximum values of NDVI, were dominant over the majority of the Doukkala region. The low values of this index indicate that the vegetation conditions close to the minimum NDVI values are concentrated in the Sidi Bennour basin area. This situation concerns all these years except 1988. In the latter, vegetation is at its minimum in the Doukkala territory except for the Sidi Bennour basin with high values of NDVI compatible with favorable conditions for crop developments (Table 2).

Temperature condition index (TCI)

In summer, the calculation TCI index (Figure 9) for a period of 25 years with an interval of

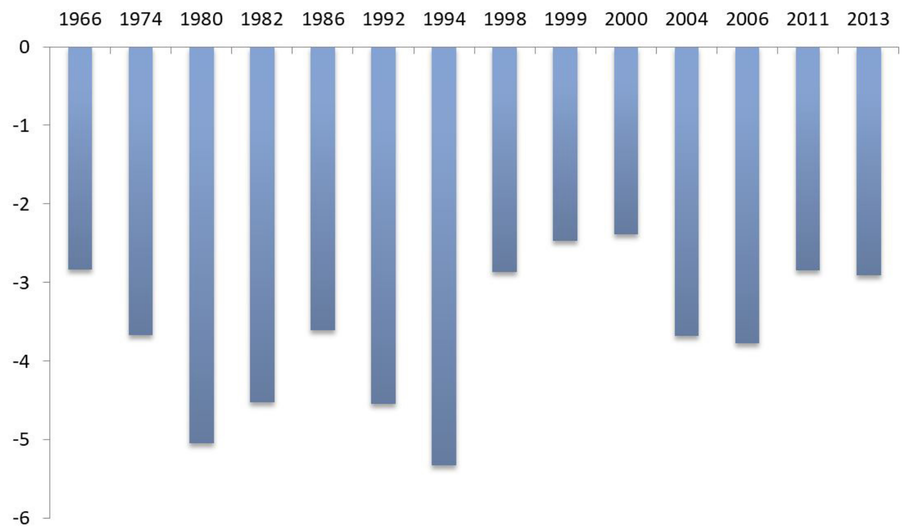

Figure 6. Values of the SPI index

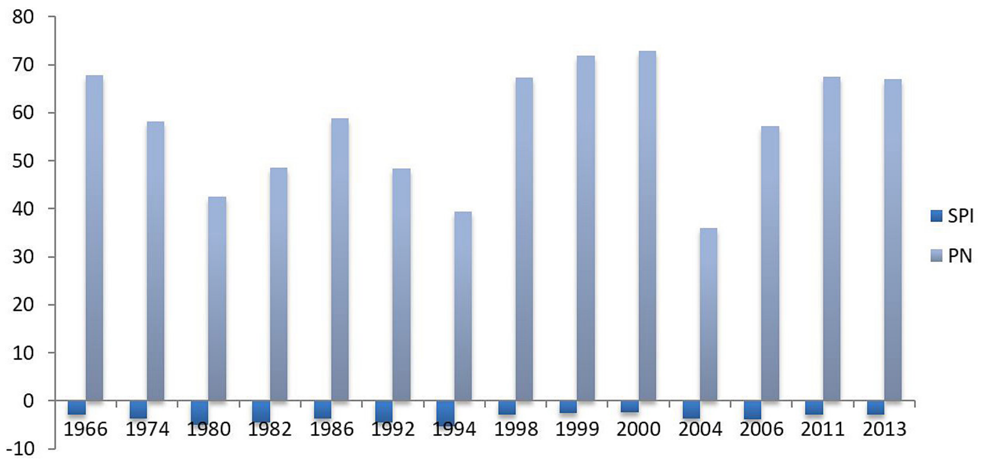

Figure 7. SPI and PN (1964–2014)

about 4 to 6 years. The low values of this indicator correspond to temperatures close to the maximum values, which can mean unfavorable conditions for crop development. While the high values of the TCI index correspond to temperatures close to the minimum values of temperatures recorded in the years 1984, 1988, 1994, 2000, 2006 and 2009, the low TCI values show severe weather conditions and high temperatures. While the high TCI values reflect favorable conditions for vegetation with milder temperatures (Table 3).

The results obtained from the TCI maps for the years 1984, 1994, 2009, show that the classes of high values of TCI (TCI>40%) indicate generally favorable conditions for crop development, during the summer period in the Doukkala region. The year 1994 shows low values of TCI compatible with a drought only in the Sidi Bennour basin. For the years 1988, 2000 and 2006 the ICC values

Table 1. SPI and PN (1984-2009)

Years	SPI	PN
1984	2.18	124.78
1988	0.78	108.85
1994	-5.33	39.44
2000	-2.39	72.82
2006	0.63	57.14
2009	2.67	130.4

Table 2. The classification of VCI

VCI Classification	
0–10%	Extreme drought
10–20%	Severe drought
20–30%	Moderate drought
30–40%	Low drought
40% <	No drought

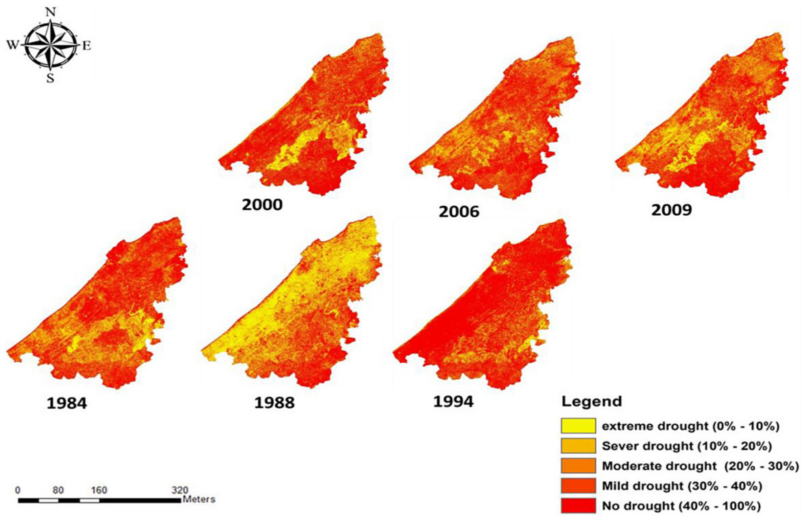

Figure 8. Map of the VCI index (1984–2009)

are low (ICC <40%) for the whole Doukkala region. These values correspond to a dry climate and unfavorable to the development of crops.

Table 3. The classification of TCI

TCI Classification	
0–10%	High temperature
10–20%	Average temperature
20–30%	Moderate temperature
30–40%	Low temperature
40% <	Very low temperature

Vegetation and temperature condition index (VHI)

The results obtained show that the low values of the VHI indicate severe to extreme drought conditions in relation to the period surveyed. The high values (VHI > 40%), mostly reflect favorable conditions for crop development (no drought) (Table 4). For the years 1984, 1988, 1994, 2000, 2006 and 2009, Figure 10 shows the calculation of the Vegetation and health Condition Index (VHI) derived from the combination of the two indicators VCI and TCI. The VHI maps indicate

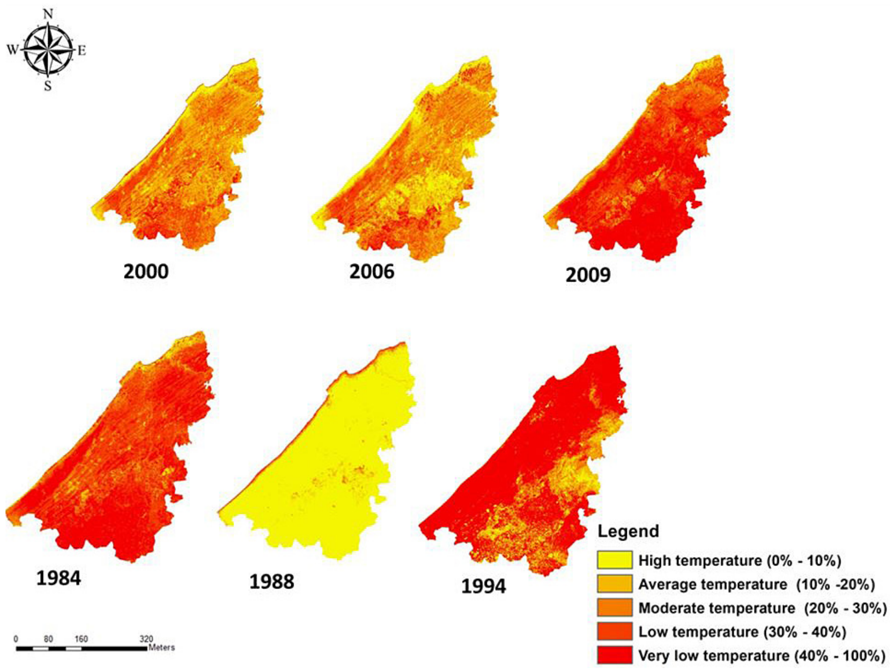

Figure 9. Map of the TCI (1984–2009)

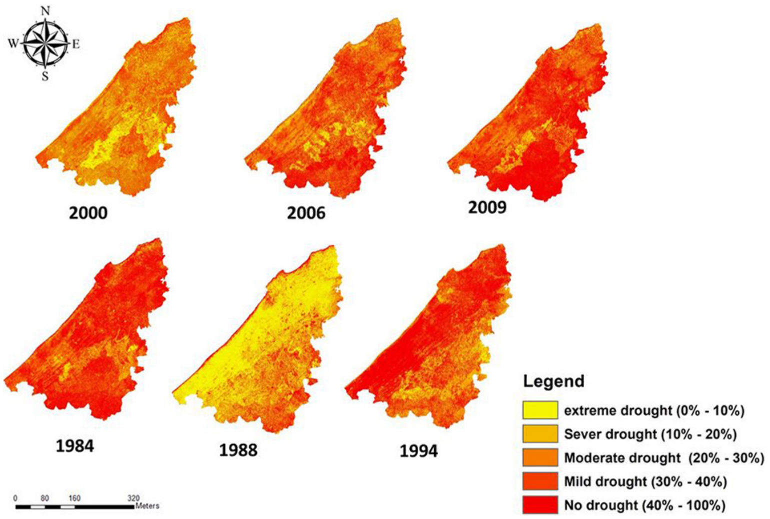

Figure 10. Map of the VHI (1984-2009)

Table 4. The classification of VHI

VHI Classification	
0–10%	Extreme drought
10–20%	Severe drought
20–30%	Moderate drought
30–40%	Low drought
40% <	No drought

drought situations when the values of this index are less than 40% (Kogan, 2002). This indicator provides information on the condition of the vegetation in those years.

The result of the maps obtained from the VHI during the years 1984, 1994 and 2009 show that the value class of the VHI indicator was high, and is consistent with a generally favorable development situation in the majority of the Doukkala region. The VHI shows normal situations of vegetation condition: favorable temperature conditions and vegetation indices close to the maximum values. These maps also show that the VHI values were very low in the years 1988, 2000 and 2006 and are consistent with an unfavorable development situation in most of the Doukkala region.

CONCLUSIONS

Many advanced remote sensing instruments (e.g., Landsat 5 (ETM), Landsat 7 (ETM+)), have been launched to collect information to monitor different aspects of drought. The development of advanced processing and analysis techniques and improved computing capabilities has resulted in new approaches that can be used for drought monitoring. In this paper, the Vegetation Condition Index (VCI), resulting from the Normalized Difference Vegetation Index (NDVI), and the Temperature Condition Index (TCI), derived from Land Surface Temperature (LST), were combined to produce a Vegetation Health Index (VHI) map for 1984 to 2009. By comparing the SPI values with the results obtained from the parameter indicators, it is deduced that in the years 1984, 1994 and 2009, with high classes of VCI, VHI and TCI values, are consistent with an overall favorable development situation in most of the Doukkala region and show respective SPI values of 2.18, -5.33 and 2.67. The years 1984 and 2009 are very wet and therefore consistent with a favorable crop development situation. The negative SPI of the year 1994 is rather related to the drought recorded in the basin of Sidi Bennour with low values of TCI. The years 1988, 2000 and 2006, with low values of VCI, VHI and TCI, are consistent with an unfavorable development situation in most of the Doukkala region and show SPI values of 0.78, -2.39 and 0.63 respectively. This negative SPI (year 2000) or close to zero (years 1988 and 2006) confirms the results obtained by the VCI, VHI and TCI. This alternation of wet and dry years is consistent with a semi-arid climate where years are relatively dry and crop development is normal to unfavorable. However, the development of the vegetation cover can be affected by the geomorphology of the region with the Sidi Bennour area as a silty subsident basin and the carbonate plateau of the Sahel as a horst. However, for a regular monitoring of drought, this coupling of historical meteorological data of a region or a country with remote sensing data must be applied on smaller and regular periods (monthly for example) with a choice of satellite images taken at the same time of the chosen period (same day of each month).

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