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Remote Sensing: Mapping of Drought Risk Areas in the Chichaoua Basin of the High Atlas (Marrakech-Morocco) using the Vegetation Condition Index (VCI) using Landsat Data from 1984 To 2020

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ABSTRACT

Drought is a complex natural phenomenon and does not have a precise definition. Thus, drought indicates the most frequent risk in the history of Morocco with negative consequences on the environment and the economy of the country. Indeed, the different regions of Morocco have experienced periods of intense drought in recent decades characterized by a decrease in rainfall and a trend towards higher temperatures. The Chichaoua watershed, which is part of the High Atlas with a semi-arid climate, has been exposed to drought episodes several times in recent years. Its effects can have negative impact on agriculture, water resources and immigration of the rural population. This study aims at characterizing the climatic drought at the level of the Chichaoua basin. It is based on the calculation of NDVI to have the calculation of the Vegetation Condition Index VCI, which also indicate the severe and sustainable nature of the drought in this area. This index was calculated using GIS, QGis and Arc Gis, and Landsat satellite imagery scenes. After a comparative study of these years from 1984 to 2020, the evolution of the VCI index was highlighted.

Key words : *Drought, NDVI, Vegetation Condition Index VCI, Landsat, GIS.*

Introduction

Drought is a natural phenomenon that affects several countries in the world such as African countries including Morocco. This phenomenon is distinguished from other natural hazards by the absence of a precise and undisputed definition (WMO, 2006). Meteorological type drought can be defined as a global deficit of annual rainfall compared to the average of a number of years over a given period of time.

Also, it is characterized by a reduction or poor distribution, or even absence of rainfall in a given area over a period of time. Drought has always been present in the history of Morocco. Studies have shown that Morocco has often experienced periods of intense drought in the past.

Indeed, the Moroccan territory has been exposed

([1]Research Scholar, [2]Assistant Professor & Head) several times to the risk of droughts during the years 1984-2020. The chronic and long-lasting drought is the one that Morocco experienced in the 1980s. This period of drought has an undeniable impact on water resources, agriculture, energy and negative consequences on the country's economic balance sheet.

Under some climate change scenarios, the occurrence and impact of droughts may increase in the coming years. The increase in the human population, which leads to increased pressure on the environment, is a major contributor to this.

As a result, it manifests itself only in certain clues and parameters that several researchers have tried to identify. Indeed, these indices make it possible to identify the drought, its intensity, its duration, its spatial extent and its probability of recurrence.

Most of these indices are based on two concepts: the normal year, and the threshold that indicates drought.

Indeed, some studies, such as those of Kogan (1993 and 1997), have already demonstrated the possibility of using remote sensing in drought monitoring through the calculation of certain indicators related to the brightness temperature and the standardized vegetation index. Being to produce the related drought indicators during a period.

In order to define this small bibliographical research, this work tries to integrate the potential of satellite imagery for example (Landsat Oli, Modis, ...) in the monitoring of drought conditions. According to produce a set of indices already pre-established:

NDVI, Végétation Condition Index VCI.

The objective of the present study is to use spatial remote sensing for drought detection and monitoring in the Chichaoua watershed.

Materials and Methods

The study area

The province of Chichaoua was created in 1991 and is part of the Wilaya of Marrakech, its administrative boundaries are :

- In the North, the province of Safi
- In the South the province of Taroudant
- In the West, the province of Essaouira
- In the East, the prefecture of Marrakech Menara and the province of Al Haouz.

Its privileged geographical position is an obligatory passage towards the South of the Kingdom and towards the West towards Essaouira and Safi. The perimeter of Chichaoua upstream is part of the physiographic unit of the high-Atlasic foothills with

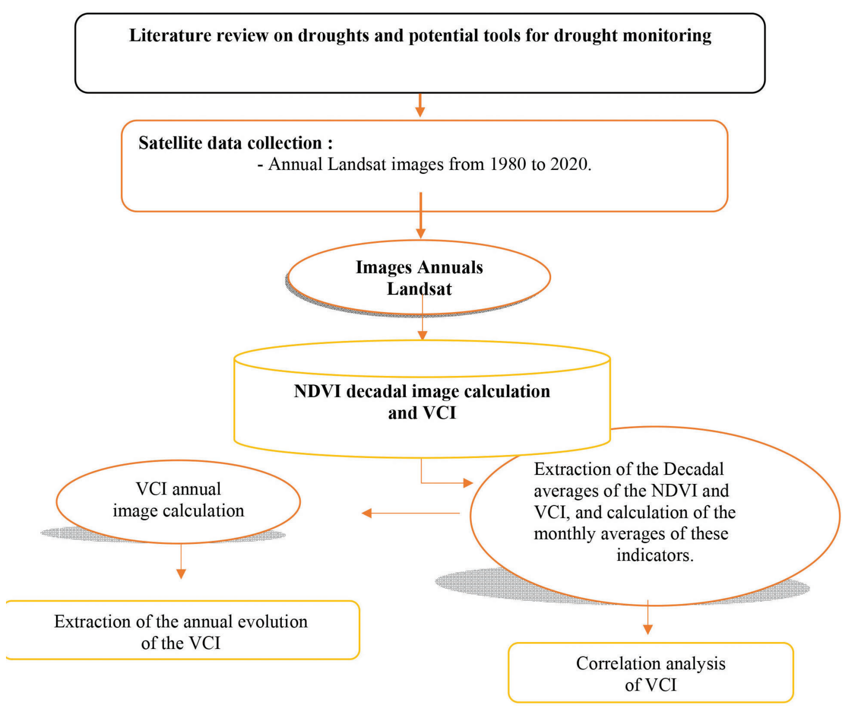

Fig. 1. Summary of the methodology used

an altitude of about 339 m. It consists of low terraces along the Chichaoua wadi and its tributaries.

Covering an area of 2690 km², the Chichaoua basin is part of the hydraulic system of the Oued Tensift, which includes a dozen sub-basins of varying sizes. Among these, the Chichaoua basin is located the most westerly at the level of the Haouz Mejjat basin (Map 1). It is bounded to the east by the Assif Elmal watershed, to the south by the High Atlas Mountains, to the north by Tensift and to the west by the Oulad Bousbaa Plain.

The Chichaoua basin has a surface area of about 660 km², located downstream of the basin in an intermediate position between the latter and the Assif El Mal basin. The Chichaoua basin and the intermediate zone, totals an area of about 3350 km² which represents about 18% more than the Haouz-Mejjate basin.

- **Area**: 6872 km^2
- Accidental reliefs
- **The plain zone** : vast **area** with flat relief and altitude less than 1000 m.
- **The mountainous area of the High Atlas**: in the form of stepped plateaus, gradually decreasing towards the west and east. The highest point reaches 3226 0m.
- **The piedmont zone** : stretching from Imintanoute to Ait Ourir and linking the plain to the High Atlas chain.

Methodology

This chapter presents the data used and the methodology used to develop the proposed research

Drought indices

Over the past few decades, several drought indices have been established to monitor and assess drought and also to provide early warning. Typically, a drought index is a key variable for assessing the effect of a drought and defining various drought parameters, which include intensity, duration, severity and spatial extent. It should be noted that a drought variable should be able to quantify drought for different time scales for which a long time series is essential. The most commonly used time scale for drought analysis is the year. It can also be used to extract information on the regional behavior of droughts. The annual time scale seems more appropriate for monitoring the effects of a drought in situations related to agriculture, water supply and groundwater withdrawals (Ramesh *et al.,* 2003).

A time series of drought indices provides a framework for assessing the drought parameters of interest. A number of different indices have been developed to quantify a drought, each with its own strengths and weaknesses. However, in our study, the selection of indices will focus on the following criteria:

- Data availability ;
- Their simplicity of calculation ;
- Their ability to represent specific rainfall conditions in the study area ;
- Their ability to differentiate, to a reasonable degree, between thedifferent levels of intensity of different types of drought.

The following section will discuss the index we will use in our study:

Vegetation indices

Green vegetation has a distinct spectral signature. Under favorable conditions, the chlorophyll present in the green vegetation absorbs the red (R) portion of the electromagnetic spectrum. However, in the near-infrared (NIR) portion, the waves are strongly scattered by the mesophyll structure of the leaves.

This results in a strong return from NIR to the satellite sensor (Gaussen (1961). Under water stress conditions, the NIR return to the sensor is lower while the R reflectance is higher. The NIR-R difference is therefore lower in periods of drought.

The difference in reflectance between these two portions of the electromagnetic spectrum has been exploited for several decades to characterize vegetation (Bonn and Rochon, 1992). Different combinations of these two spectral bands have been used to develop several vegetation indices. In a review of vegetation indices carried out in 1995, Bannari et al. identified about 35 different vegetation indices.

These indices try to perceive changes in the reflectance of the plant cover, caused by a water deficit or surplus. The advantage of vegetation indices is the ease of calculation. They offer a quick and efficient tool for comparing the state of vegetation for an area and not at one point in the territory. Their application is possible in an instantaneous way up to an annual temporal scale, and in a regional or continental way. As vegetation has an anisotropic response, the vegetation indices are all influenced to different degrees by the illumination angle and the viewing angle. They are also influenced by changes in soil color as well as changes in the signal to the satellite caused by atmospheric components (McVicar and Jupp, 1998).

The most common combinations are certainly the simple ratio of infrared to red (NIR/R), NDVI and VCI.

Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI), first proposed by Rouse et al. in 1973 is one of the well-known and widely used vegetation indices.

Like other vegetation indices, NDVI is sensitive to the presence of green vegetation. It is an effective tool for crop monitoring (Vogt, 1995) but also for monitoring rainfall and drought (Kogan, 1990; Viau *et al*., 2000; McVicar and Bierwirth, 2001; Boyd *et al.,* 2002).

$$NDVI = \frac{PIR - Rouge}{PIR + Rouge}$$

Where:

- PIR: Reflectance of the near-infrared spectral region.
- Red: Reflectance of the red spectral region.

As this index is normalized, the effects of illumination angle and viewing angle are reduced. Normalization also reduces the effect of sensor calibration degradation and minimizes the effect of topography. The NDVI calculated from Landsat satellite image data is dependent on the characteristics of the satellite.

This index remains sensitive to the viewing and illumination geometry, especially in areas where vegetation density is low and the presence of soil is high.

NDVI also suffers from rapid saturation in dense vegetation and the contribution of soil in areas of low vegetation density makes its interpretation questionable. Its interpretation may therefore be biased in arid or drought-prone areas (Vogt, 1992).

Nevertheless, NDVI remains an effective index for identifying areas of water stress, especially in homogeneous environments such as agriculture. In heterogeneous regions where resources vary greatly over short distances, its interpretation becomes more difficult (Kogan, 1990).

The Vegetation Condition Index (VCI)

The Vegetation Condition Index (VCI) is another index that measures the degree of green vegetation. Using the minimum, maximum and current NDVI values from several years as inputs, the VCI is a transformation of the NDVI.

$$VCI(i) = \frac{NDVI(I) - NDVI\ min}{NDVImax - NDVI\ min} \times 100$$

Where:

- NDVI : NDVI of the period studied (—)
- NDVImin : NDVI minimum of the period studied (—)
- NDVImax: Maximum NDVI of the period studied (—)

The VCI attempts to separate the short-term climate signal from the long-term ecological signal (Kogan and Sullivan, 1993). It therefore reflects the climatic distribution and not the differences in vegetation due to different ecosystems. In this sense, it is a better indicator of rainfall distribution than NDVI (Kogan, 1990). It also allows comparison of the effect of climate on different study areas.

The VCI thus provides an improvement in the analysis of vegetation condition for non-homogeneous areas (Kogan, 1990). Initially created to monitor drought conditions, the VCI has been used on several continents to detect large-scale drought situations, but also excessive moisture conditions (Kogan, 1997; Singh *et al.,* 2003; Kogan *et al*., 2004).

For example, several teams have used the VCI to monitor drought conditions in South Africa (Kogan, 1998) and India (Singh *et al*., 2003). The VCI, like other satellite vegetation indices, has the same limitations associated with the data acquisition method.

Table 1. Satellite bands (red and nearinfrared):

	TM5	ETM+	Landsat-8
Red (R)	B3 (660 nm)	B3 (660 nm)	B4 (655 nm)
Near Infrared(NIR)	B4 (830 nm)	B4 (835 nm)	B5 (865 nm)
NDVI	(NIR - R) / (NIR+R)		
VCI	$\frac{NDVI(i) - NDVI\ min}{NDVI\ max - NDVI\ min} \times 100$		

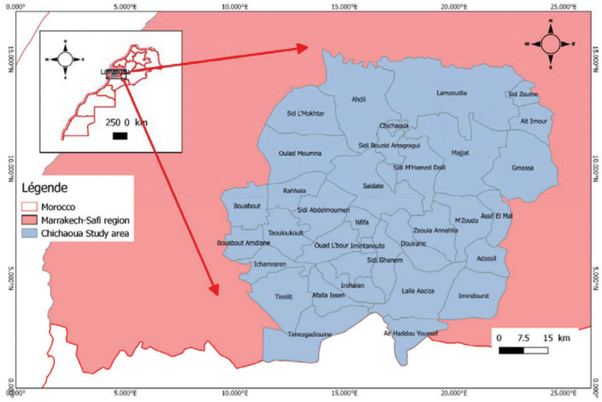

Fig. 1. Geographical location of the Chichaoua catchment area

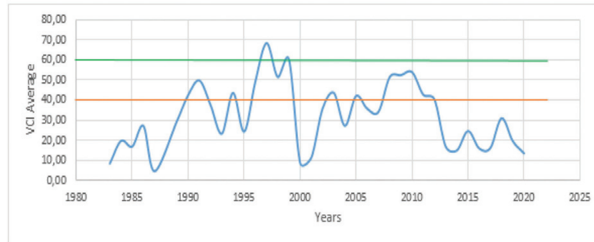

Fig. 3. Maps of VCI in the Chichaoua study zone from 1984 to 2020.

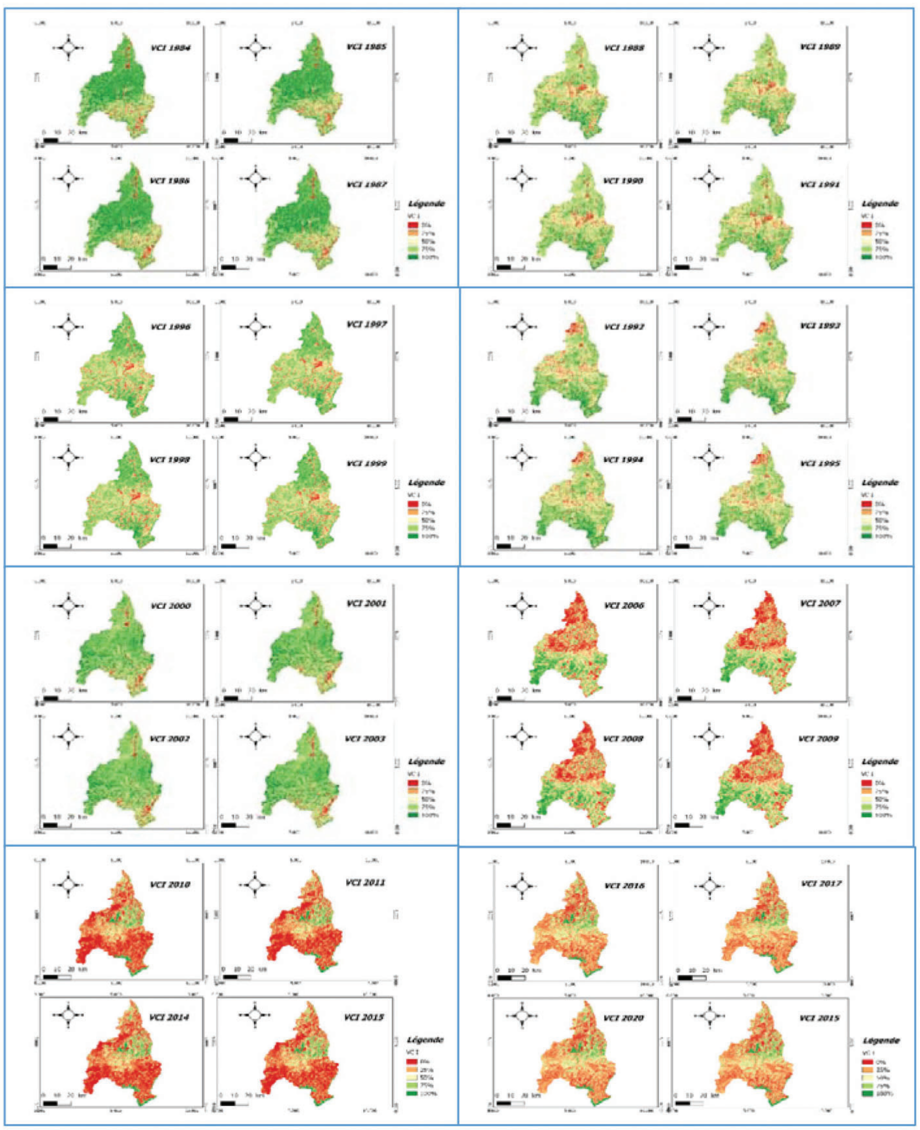

Fig. 2. Maps of VCI from satellite data

Moreover, the application of the VCI is strongly linked to the number of images available as well as the quality of these images. Since this indicator uses composite images, it is important to consider the days of acquisition associated with each pixel since the viewing angle and illumination angle can vary greatly from one pixel to another. In addition, the VCI assumes that the difference between the maximum NDVI and minimum NDVI represents the maximum possible variation for a given period of time and that all NDVI values within this difference have the same frequency.

Calculation of the VCI

In order, to carry out the comparative study on The Vegetation Condition Index (VCI), a scene taken in April for each year during 1984-2020 was used:

These images were processed with three programs: Saga Gis (System for Automated Geoscientific Analyses) (Conrad *et al.,* 2015) and Arcgis and Qgis. The first one presents multi tasking algorithms (remote sensing, geomorphology, terrain analysis, hydrogeology ...) and the second and third are designed for remote sensing, processing and analysis of satellite images.

For the evolution of the index from 1984 to the present day, several Landsat TM5 and ETM+ scenes have been selected and processed, exclusively, with Saga Gis and ArcGis.

Table 1 Ssatellite bands (red and near infrared)

The VCI is a vegetation index derived from the maximum and minimum NDVI values : the historical values (NDVI min and NDVI max) of the decade are taken from the decadal images.

A very low ICV reflects an NDVI that is close to the minimum NDVI. A high VCI reflects an NDVI that is close to the maximum NDVI. In other words, low VCI values represent water stress conditions while high ICV values represent favorable conditions. Several authors who have used the VCI for drought monitoring have concluded that drought conditions are met when the VCI is below 35 (Kogan, 1997; Kogan 1995; Kogan *et al*., 2004)

Results and Discussion

The maps presented below show the vegetation situation obtained from satellite data at the Chichaoua watershed level.

The VCI is a drought monitoring index that is produced using satellite data. This index gives us the result of vegetation stress. The following figure will show the VCI maps calculated annually over a period from 1984 to 2020.

Interpretation

From the results shown above, we can see: On the other hand, the southern part of the zone experienced good vegetation moisture.

- In ***1984****,* ***1985 and 1987,*** the northern, northeastern, northwestern and eastern parts of the region were not under any vegetation stress and good humidity was observed in the area.
- From ***1988*** *to* ***1990***, the center of the study area was affected by severe to extreme vegetation stress during the month of April.
- In ***1991, the*** northern, northeastern, northwestern, eastern, western and southern parts experienced severe vegetation stress.
- In ***1992*** *to* ***1995,*** the northern, northeastern, northwestern, eastern, western and southern parts of the area experienced good vegetation moisture.
- In ***1996,*** *the* entire area experienced very severe vegetation stress.
- In ***1997*** *to* ***2000***, there was an extreme drought.
- In ***2001*** *to* ***2004, there*** was significant vegetation humidity during the month of April. It indicates a surplus trend that is marked almost throughout the region.
- In ***2006***, severe to extreme vegetation stress occurred in the north, northeast, east, west, northwest and central areas. In the south, drought was limited to low intensities.
- In ***2007***, the entire study area experienced good vegetation moisture.
- In ***2008***, humidity was good in most of the area.
- In ***2009*** to ***2013***, the southern and western areas of the Chichaoua watershed region were affected by average vegetation stress during the month of April. On the other hand, the northern and central part of the region experienced good vegetation moisture.
- In ***2014*** *to* ***2015***, the northern part of the basin was affected by severe to extreme vegetation stress. With a moderate vegetation stress occurred in the north and east, this drought was limited to low to extreme intensities. This vegetation stress was limited especially in the low lying part.
- From ***2016*** *to* ***2017***, average vegetation stress occurred almost throughout the area. (2017 Map). Severe and extreme vegetation stress occurred almost throughout the area. So, drought was lim-

ited especially in the low lying part.

- In ***2018***, humidity was good throughout the region, except for the central part which experienced light to moderate vegetation stress, we find a very wet year with good moisture conditions that cover the entire area.
- In ***2020***, the basin was affected by extreme vegetation stress.

The distribution of the Vegetation Health Index for the years from 1984 to 2020 is shown in the figure above, respectively, which represents the overall health of vegetation in the Chichaoua Watershed Study Area on a given time scale.

Mild drought and normal conditions were spatially dispersed throughout the study area, while severe to moderate drought conditions were more often distributed in 1996 and 2000.

The temporal evolution of drought trends by VCI showed that the spatial distributions of moderate and severe droughts generally occurred from the beginning of the dry season in April and returned to normal or wet conditions at the beginning of the rainy season.

It was also noted that in April for the years 2000, 2006, 2007 and 2008, some locations in the study area experienced moderate drought, so the health of the vegetation was the most unfavorable in the region. This is explained by the fact that most of the area was subjected during this period to severe to extreme drought, while during the rest of the period, the state of the vegetation in Chichaoua was average.

The April maps from the years 1984, 1985, 1987, 2001, 2003 and 2007 show a good state of vegetation throughout the Chichaoua Study Area.The April maps from the years 1984, 1985, 1987, 2001, 2003 and 2007 show a good state of vegetation throughout the Chichaoua study area.

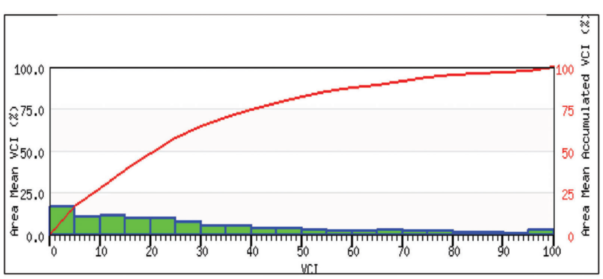

Fig. 5. Evolution of the average of the indicators for the Chichaoua catchment areaFor the April period (1984-2020)

Table 2. Average VCI during the April period (1984-2020) for the Chichaoua watershed

Year	VCI Average	Year	VCI Average
1984	19,59	2000	8,57
1985	16,80	2001	11,28
1986	26,97	2002	35,54
1987	4,50	2003	43,45
1987	27,77	2006	35,50
1989	29,50	2007	33,98
1990	42,36	2008	51,25
1991	49,53	2009	52,16
1992	37,30	2010	53,71
1993	23,12	2011	42,50
1994	43,42	2014	14,76
1995	24,19	2015	24,49
1996	49,12	2016	15,81
1997	68,12	2017	16,06
1998	51,26	2019	19,44
1999	60,02	2020	13,43

VCI averages

For a question of synthesis and for a follow-up of the results of the Chichaoua watershed, it was considered necessary to calculate the average VCI values for each year. For this purpose, the following table presents the average values of the VCI indicator for the Chichaoua watershed. It is therefore sufficient to consult the table to immediately know the values of the indicators during the period and thus conclude the state of drought in the area concerned.

As an illustration, if we take the Chichaoua basin, the average value of the VCI indicator shows a value of 55, which tells us, according to Kogan's classification, that the zone is characterized by average drought.

At the same time, it is important to analyze the evolution of this indicator over time.

As an example, for the Chichaoua watershed the temporal evolution is presented during the April period (1984-2020) as follows :

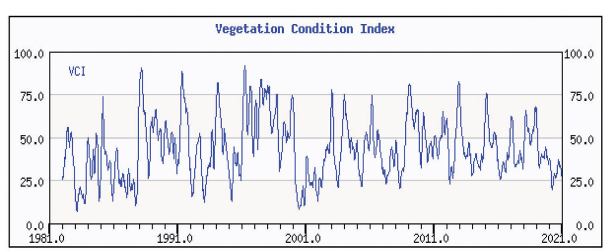

Fig. 6. Percentage of area with VCI for the Chichaoua catchment area For the April period (1984-2020)

Discussion

Factors such as soil moisture, temperature, wind, cloud cover and the temporal distribution of precipitation influence drought. Drought indices obtained from satellites are influenced by these factors and weather-based indices such as VCI depend on the amount of rainfall and its spatial distribution. This confirms that satellite drought indices can be reliable. Thus, these results clearly indicate that the temporal and spatial characteristics of drought in the Chichaoua watershed area can be detected and monitored using satellite image data. They show that environmental conditions over several years can be practically used for drought analysis by remote sensing indices. This study found that the ICV maps obtained from the NDVI time series describe very well the past drought episodes in the region.

Conclusion

The purpose of this work was to illustrate the potential of satellite imagery for monitoring drought conditions in our environment. The results of this study validated the use in the Chichaoua watershed of the VCI satellite indicators developed by Kogan (1997).

The satellite data come from the Landsat sensor. In total, images from 1984 to 2020 were used to derive the NDVI indicator. This indicator was then used to calculate the VCI decadal indicator.

At the end of this study, we can conclude that there is a significant trend in the severity of drought in the Chichaoua basin during the last six years. Drought has imposed itself dynamically in the watershed and represents a structural and characteristic element of the semi-arid climate. This tendency to dry out is causing a water shortage that is increasingly marked by an imbalance between water supply and demand.

The calculation of the Normalized Difference Vegetation Index (NDVI), in addition to other vegetation indices, has allowed the detection and monitoring of climate change and its influence on vegetation cover. It is also a tool that can help decision makers to target intervention strategies, adapt agricultural and pastoral projects to climate change and thus reduce the impact of drought periods.

Limitations and recommendations

Today, a generation of sensors makes it possible to use existing indicators with more precise data or to generate new indicators better adapted to the conditions studied. Thanks to technological advances and knowledge acquired in the past, some recently launched sensors have advantageous characteristics for drought monitoring. Among these sensors, Landsat (TM5, 7, Oli...) seems particularly interesting. This sensor has a ground track and a frequency of passage that allows a daily coverage of an area with a finer radiometric resolution. This sensor has several narrow spectral bands that allow a more accurate characterization of surfaces.

However, this study, like any other, has certain limitations that could be improved in future work. The image processing chain does not seem to remove all the cloud cover. This leaves the images with clouds that lower the NDVI values. This causes NDVI with clouds to appear to have the same values as NDVI in dry periods.

Then the VCI in drought period appears to be rather normal and does not reach representative values of water stress in plants. It would therefore be important to review the image processing chain before proceeding to re-evaluate the established classes of satellite indicators.

The use of a satellite-based indicator of vegetation condition that is less susceptible to atmospheric effects could also be tested.

At the same time, the use of a longer time series of satellite images would be appropriate. For this purpose a 6-year series of Landsat data was used.

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Disclosure statement:

Conflict of Interest: The authors declare that there are no conflicts of interest.

Data and Codes Availability Statement

The data and codes that support the findings of this study are available on request from https://earthexplorer.usgs.gov/ site and graphs from the NOAA AVHRR site https://www.star. nesdis. noaa.gov/star/index.php and processed exclusively, with Saga Gis and ArcGis. The data are not publicly available because they contain information that could compromise the privacy of research participants.

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