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Variance-Based Fusion of VCI and TCI for Efficient Classification of Agriculture Drought Using Landsat Data in the High Atlas (Morocco, North Africa)

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ABSTRACT

Drought assessment using drought indices has been widely carried out for drought monitoring. Remote sensing-based indices use remotely sensed data to map drought conditions in a particular area or region. Therefore, the objective of the present study is to make a study on drought risk based on the calculation of an indicator from biophysical parameters extracted from NOAA/AVHRR satellite data, namely TCI and VCI, to obtain a better understanding of the differentiation between each index, and their application for drought monitoring in the High Atlas of Marrakech on the Chchaoua Morocco watershed during 1980-2020. Landsat oli7 and8 data were used to construct the indices. The result showed that each index proved to be a useful, fast, sufficient, and inexpensive tool for drought monitoring. However, each index has its differences. The TCI was found to be drought sensitive during the dry season or in months when high temperatures occurred. While VCI detected drought more sensitively in the rainy season as well (December-January-February to May) than TCI and VCI. Meanwhile, VCI, including the improved TCI, combined two indicators to better understand drought occurrence. These indices were calculated using GIS, QGis, ArcGis satellite imagery scenes, and Landsat. After a comparative study of these years, from 1984 to 2020, the evolution of the VCI and TCI was highlighted.

INTRODUCTION

Drought is a natural threat that tends to worsen in the context of climate change, with major socio-economic consequences (Keyantash & Dracup 2002, Wilhite 2007), particularly in vegetation, the sector most vulnerable to this climatic hazard. Several definitions of this severe form of water deficit (Heim 2002, Boken et al. 2005). They are either conceptual or operational (Ndmc 2006). The conceptual definitions, which are rather general, are frequently recycled to set up water management policies (e.g., temperature increase, precipitation deficit, and yield loss). Thus, climate change may have major consequences on the evolution of droughts in several regions of the world.

In Morocco, an agricultural country with an arid to semi-arid climate, surface water resources are becoming increasingly limited and difficult to exploit, as most agricultural areas are strongly linked to the climate, precisely the temperature during the summer period. Due to the lack of planning, these resources would be threatened in case of probable climate change or variability of the average temperature (Augier & Blanc 2009).

To develop an adaptation strategy to a possible scarcity of water resources, it is necessary to know the drought and its evolution. To do so, it is important to have tools and means adapted to provide data on drought intensity. Several means already exist to measure the drought episodes that characterize a given environment. These are indicators based on climatic data from meteorological stations, such as the TCI temperature index (Hayes et al. 1999).

Unfortunately, this type of approach has limitations in Morocco. Indeed, data remain difficult to access (Shaban & Houhou 2015). This shortage of climatological data and the non-centralized nature of water resources data management are major obstacles to drought monitoring. In this sense, finding a method that ensures the monitoring and communication of spatio-temporal drought information for the whole territory is important. Indicators from satellite images can offer this possibility. The main objective of this study is, in a first step, to monitor the evolution of drought intensity in the Chichaoua catchment area for the period

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1982-2021, using satellite data from the NOAA-AVHRR sensor. The second objective is to understand the variations in drought intensity over the last few years using another drought indicator, the average TCI.

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
- To the east are the Marrakech Menara prefecture and Al Haouz province.

Its privileged geographical position constitutes an obligatory passage towards the South of the Kingdom and the West towards Essaouira and Safi. The perimeter of Chichaoua upstream is part of the physiographic unit of high-Atlasic Piedmont, with an altitude of about 339 m. It consists of the low terraces along the Chichaoua Wadi and its tributaries.

With a surface area of 2690 km², the Chichaoua basin is part of the Oued Tensift hydraulic system, comprising ten sub-basins of varying importance. Among these, the

Chichaoua basin is located the furthest west in the Haouz Mejjat basin (Fig.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.

Our watershed (Fig. 1), by its geographical position in relation to a framing mountain range, is characterized by an arid semi-arid climate that evolves towards a significant alteration of rainfall, plant cover, and soils. It is characterized by a rainy season that extends from October to March. In the summer, the influence of subtropical high pressure prevents any rising air and causes an absolute drought from June to September. The climatic conditions play a negative role on the water resources and, consequently, on the vegetation. In this context, it is important to monitor the drought intensity in this region of the Chichaoua watershed to provide local and national decision-makers with reliable information and results to facilitate the implementation of reasonable and efficient management of natural resources, focused on reducing drought-related risks.

Drought Indices

Over the past few decades, several drought indices have been established to monitor and assess drought and to provide early warning. Typically, a drought index is a key variable for assessing the effect of 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

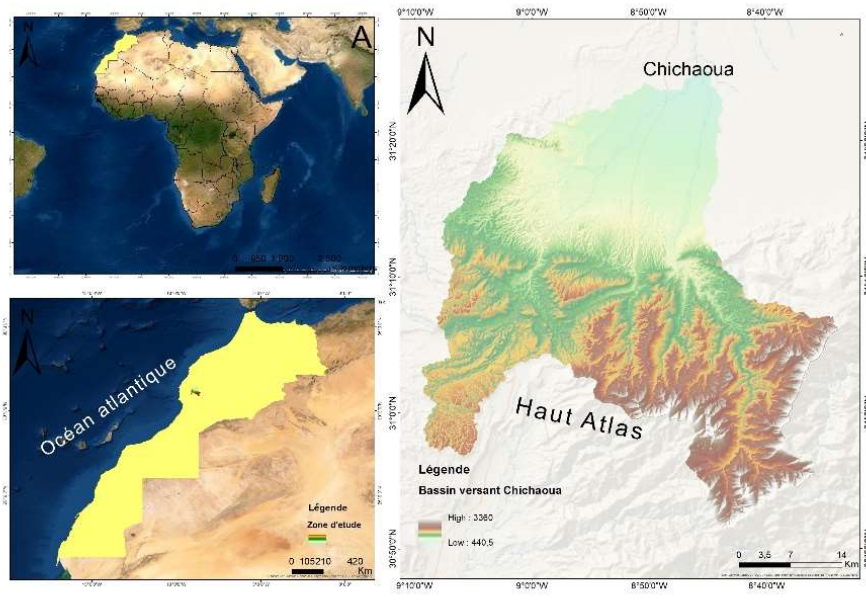

Fig. 1: Geographical location of the Chichaoua watershed.

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. Several indices have been developed to quantify a drought, each with its 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 the different intensity levels of different types of drought.

The following section will discuss the index we will use in our study and Fig. 2 shows the summary of the methodology used.

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) and monitoring rainfall and drought (Kogan 1990, Unganai & Kogan 1998, Viau 2000, McVicar & Bierwirth 2001, Boyd et al. 2002).

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

Where:

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

As this index is normalized, the effects of the illumination and viewing angles 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 depends on the satellite's characteristics.

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

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. Its interpretation becomes more difficult in heterogeneous regions where resources vary greatly over short distances (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 transforms the NDVI.

$$\text{VCI(i)} = \frac{\text{NDVI(i)} - \text{NDVImin}}{\text{NDVI max} - \text{NDVI min}} \times 100$$

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 & 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 a comparison of the effect of climate on different study areas.

The VCI thus improves the analysis of vegetation conditions 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. 2003).

For example, several teams have used the VCI to monitor drought conditions in South Africa and India (Singh et al. 2003). The VCI, like other satellite vegetation indices, has the same limitations associated with the data acquisition method. Moreover, the application of the VCI is strongly linked to the number of images available and 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.

Temperature Condition Index (TCI) (Kogan & Sullivan 1993)

This indicator is based on the brightness temperature. This indicator is calculated from NOAA AVHRR sensor images based on surface temperature. As with the vegetation indices, it is applicable on a regional or continental scale, instantaneously or for periods ranging from one day to one year.

It is applicable on a regional or continental scale, instantaneously, or for up to one year. The TCI also provides useful information on vegetation stress due to soil water saturation (Kogan 1997, Kogan et al. 2004).

The formula given by Kogan is:

$$TCI = \frac{100(\text{Tmax} - \text{T})}{(\text{Tmax} - \text{Tmin})} \times 100$$

- Tmax is the maximum temperature
- Tmin at a minimum temperature
- T at the temperature of the period under study

Vegetation Health System: Background and Explanation

The Global Satellite System is designed to monitor, diagnose and predict long and short-term terrestrial environmental conditions and climate-dependent socio-economic activities. The system is based on satellite observations of the Earth, the biophysical theory of vegetation response to the environment, and a set of algorithms for satellite data processing, interpretation, product development, validation, calibration, and applications.

Satellite observations are mainly represented by the Advanced Very High-Resolution Radiometer (AVHRR) operated by NOAA polar-orbiting satellites. The data are global, with a resolution of 4 km and a 7-day composite. The system contains vegetation health indices and Drought products.

Satellite Data Processing

Our methodology is based on the joint use of remote sensing and geographic information system to measure drought intensity. For this purpose, we used the VCI and the TCI obtained from satellite images.

Processed on the Arc GIS ESRI platform, it was possible to map them to follow the dynamics and the state of vegetation during the agricultural season in the face of

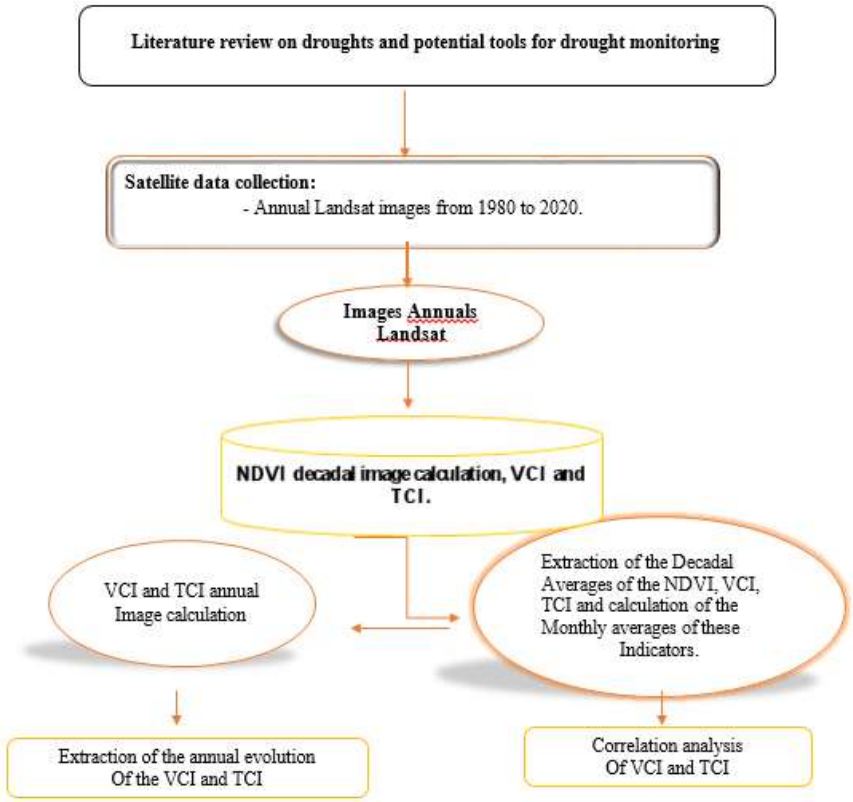

Fig. 2: Summary of the methodology used.

drought. In the Chichaoua watershed, the agricultural season extends from March (budburst) to April-May (entry into the senescence phase). Therefore, satellite images covering this period were selected and downloaded from the VOAA-AVHRR website.

Thus, we imported these data in TIFF (GEOTIFF) format using ARCGIS software. The images were projected in the standard UTM projection using the 29N zone. They were then classified on the ARCGIS-ESRI platform into five VCI and TCI classes ranging from 0 to 100 (Kogan 1997, Kogan 1995). Drought conditions are met when the indices are below 40. To perform this VCI and TCI classification and calculate the average drought-damaged area, we followed the following steps in GIS:

The "Split Layer Feature" is particularly useful for creating a new feature class, also called a study area or area of interest, containing a geographic subset. The "Mask extraction" is used to visualize only the area concerned by our study. Indeed, this treatment allows the extraction of the cells of a raster which correspond to the areas defined by a mask. The "Raster Calculator" tool allows to create and execute a spatial algebra expression that generates a raster output. In our case, it allowed us to select areas according to the range of drought intensity according to the Kogan classification. Each feature represents a VCI and TCI value in pixels, allowing us to estimate the drought intensity. This allowed us to calculate the average drought. Several factors can influence and limit the scope of the results. Indeed, the TCI and VCI index depends largely on the values of other

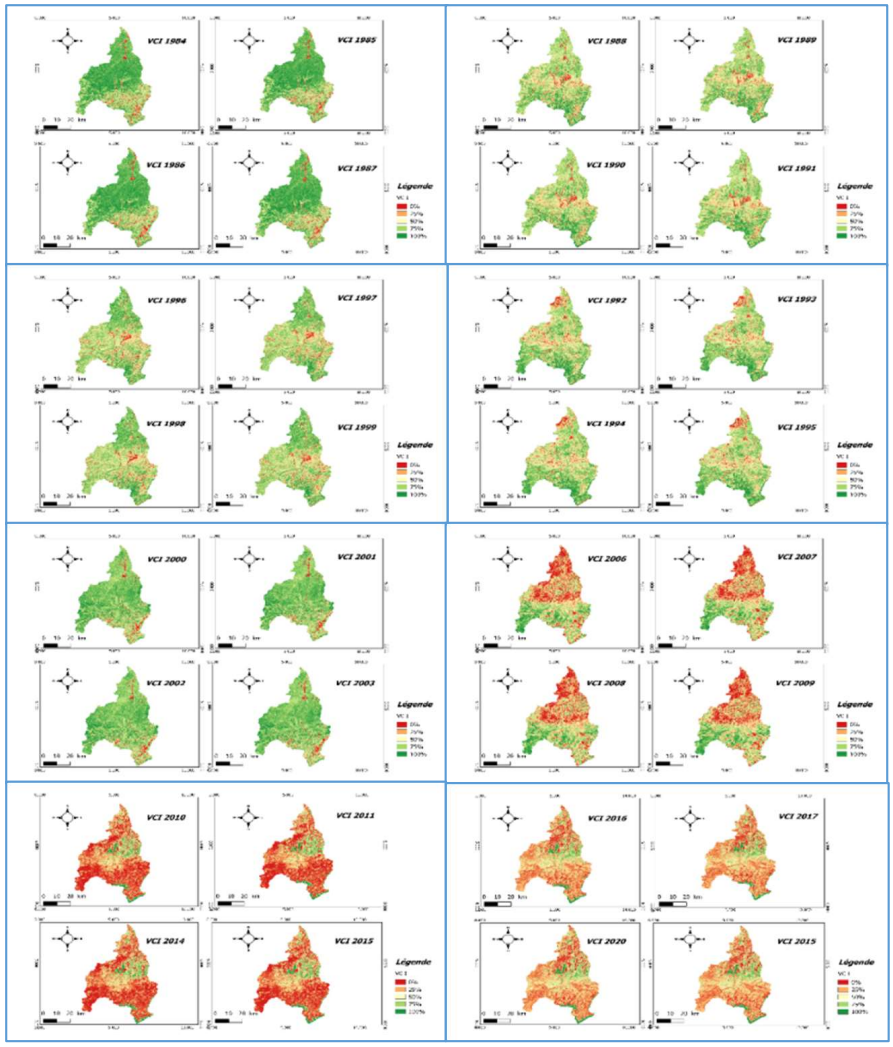

Fig. 3: Distribution of drought intensity estimated by the VCI in the Chichaoua watershed for the agricultural period 1982-2021.

indices, such as temperatures. However, we processed all the raster images obtained by the NOAA-AVHRR remote sensing center. Thus, the possible problem of value, in absolute terms, does not call into question the significance of the results since it is a question of examining the relative variations from one year to another.

RESULTS AND DISCUSSION

Evolution of the VCI and the TCI from 1982 to 2021:

To carry out this work, the study area used in our region was delimited and selected on the ARCGIS software platform using the Chichaoua watershed polygon.

Fig. 3 and Fig. 4 show the spatial distribution of the change in the VCI and TCI from 1982-2021. It shows significant variability in drought intensity in an area characterized by little change in vegetation during the study period between 1982-2021. The color gradient of each pixel represents the drought level. Green corresponds to the lowest value, and red to the most intense.

Table 1 shows the average value of the VCI and the TCI for each year from 1982-2021. The lower the value, the more the vegetation cover condition deteriorated, which could mean a higher drought intensity. The average of 28 reflects almost permanent drought conditions between 2001 and 2015. The VCI and TCI varied between 10 (2008) and 70 from 2001 to 2015, with a maximum of 80 in 1994. Drought impacted Some years more than others, such as 2001, 2008, 2010, and 2015.

From these results, we sought to assess the spatial distribution of different drought levels relative to the mean.

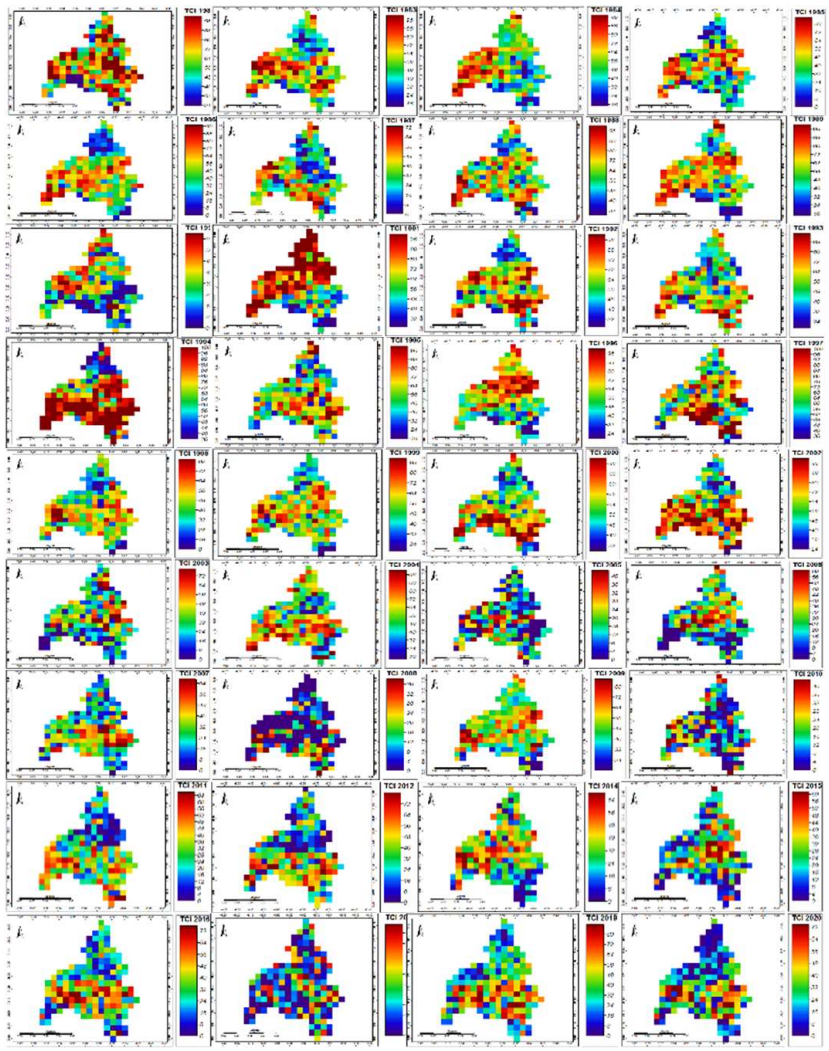

Fig. 4: Distribution of drought intensity estimated by the TCI in the Chichaoua watershed for the agricultural period 1982-2021.

Table 1: Average TCI and VCI value during the period 1982-2021:

Year	Average TCI	Average VCI
1982	70,32	19,59
1983	58,31	16,8
1984	55,86	26,97
1985	40,26	4,5
1986	48,34	27,77
1987	32,96	29,5
1988	64,72	42,36
1989	59,09	49,53
1990	28,52	37,3
1991	75,03	23,12
1992	66,34	43,42
1993	56,42	24,19
1994	80,92	49,12
1995	58,46	68,12
1996	62,55	51,26
1997	71,89	60,02
1998	44,72	8,57
1999	54,81	11,28
2000	66,66	35,54
2002	70,15	43,45
2003	31,99	35,5
2004	59,26	33,98
2005	15,81	51,25
2006	23,84	52,16
2007	30,25	53,71
2008	10,69	42,5
2009	50,92	14,76
2010	15,28	24,49
2011	28,84	15,81
2012	34,03	16,06
2014	31,3	19,44
2015	24,14	13,43
2016	33,54	19,59
2017	14,07	16,8
2018	58,24	26,97
2019	39,97	4,5
2020	26,65	27,77

To better interpret the 1982-2021 TCI results, we clustered TCI intervals to quantify the degree of drought. It allows us to distinguish three types: areas affected by high-intensity drought (TCI< 20), areas affected by low-intensity drought (between 20 and 40), and areas not affected by drought (TCI > 40).

71% to 90.5% of the study area is pretentious by low-intensity drought (Fig. 5). High-intensity drought does not exceed 30% of the vegetation, with the exception of 2008, when there was a significant peak of 10%. This drought could be problematic for agricultural activity, where most crops are irrigated, as farmers' practices are not adapted.

Fig. 5, which shows the spatial distribution of the average VCI and TCI for the period 1982-2021, shows that the mountainous part of the region is the most affected. It is characterized by a higher topography than the rest of the region and a predominance of crops.

87.4 percent of the vegetation cover is affected by drought, of which 51 percent is of the moderate type. On the other hand, the high-intensity drought affected 7.9% of the vegetation. It is noted that the extreme type of drought represents only 10% of the region's total area (Table 1).

The relationship between temperature, vegetation, and climate is essential for studying drought in a vegetative context. Drought, as a climatic hazard, can become a risk by disrupting the balance between the needs of society and the potential resources provided by a given environment (Charre 1977). Drought is a physical phenomenon determined by a rainfall deficit, temperature increase, and a water deficit in the soil. Thus, economic damage to crops can be expected after three successive months of rainfall deficit below 50% of the average (NDMC 2006).

The calculation of the VCI and the TCI made it possible to monitor the water stress of vegetation in the Chichaoua watershed, reflected in the increase in temperature that could affect the plant. The analysis and monitoring of this index thus allow us to identify the vegetation's temperature dynamics and estimate the impacts on the crops in place. There is a risk of a more intense drought during the agricultural season.

Our results for the period studied show that the vegetation of our basin was affected by a weak to moderate drought. We can relate these results to the study of Charre (1977). He distinguished two types of drought: the usual drought and the occasional drought. The usual drought is considered "normal" or "not dangerous" in traditionally dry regions, such as the Chichaoua watershed because the agricultural practices in place are adapted to cope with this type of drought.

We can draw several elements of reflection from this study. From a geographical point of view, we note that our area, located in the High Atlas Mountains, with an arid and semi-arid climate, is more affected than others. Indeed, in the plain, the water tables, the main source of irrigated ion water, are fed mainly by winter rainfall. A succession of

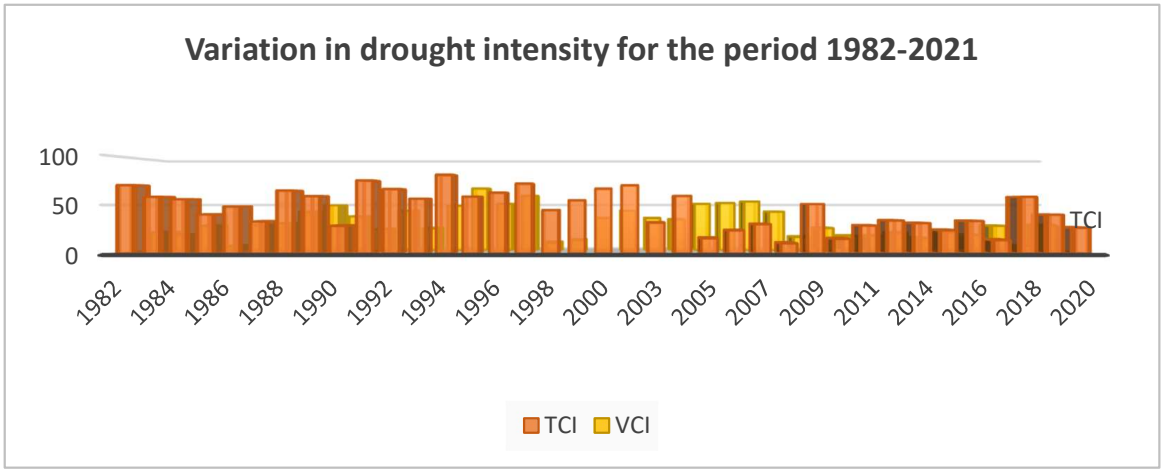

Fig. 5: Variation in drought intensity for the period 1982-2021.

months with insufficient rainfall can have a negative impact on the level of the groundwater and cause a groundwater drought. The consequences will quickly be felt: loss of yield in field crops. Other factors, such as a succession of periods of low rainfall, can influence the state of the vegetation. Strong periods of sunshine or wind influence the surface temperatures that constitute the TCI (Viau & Paquette 1997).

However, there are limitations to our study that must be taken into account when interpreting the results. Using satellite images over a longer time series (36 years) would be more appropriate for calculating the average TCI. Finally, drought is a complex phenomenon that combines climatic and human factors. Nevertheless, the TCI remains an indirect indicator of this major problem for vegetation.

CONCLUSION

The Chichaoua catchment area has experienced a permanent low to moderate-intensity drought over the last 36 years, with a peak of high-intensity drought considered "dangerous. "

Possible climate changes in the coming years predict an intensification of dry episodes, such as those observed in 2008. Climate change, combined with an increase in the number of refugees, is putting increased pressure on environmental resources, particularly water resources, which are becoming increasingly vulnerable. Today, drought monitoring has become a necessity in view of its consequences on the socio-economic activities of the territory. Despite the limits of the proposed indicators, they can constitute a relative and operational monitoring means.

However, in light of the results obtained, it appears that the climatic hazard is aggravated by anthropic pressure.

This drought index has been used in various applications since the advent of remote sensing from space. Its use for quantitative estimates raises several issues that can seriously limit its usefulness if improperly interpreted. They depend on many parameters (solar illumination, viewing angles, etc.) and are affected by several factors (sensitivity to atmospheric effects, soil types, and moisture content).

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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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