

context, it is important to monitor the drought intensity in this region of the Chichaoua watershed in order to provide local and national decision-makers with reliable information and results to facilitate the implementation of a reasonable and efficient management of natural resources, focused on the reduction of drought-related risks.

2.1. *Methodology* - The study was conducted at The laboratory : Geosciences, Geotourism, Natural Hazards and Remote Sensing. Cadi Ayyad University, Faculty of Sciences Semlalia. Morocco by satellite images from the period 1982-2021.

2.1.1. *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. Satellite observations are mainly represented by the Advanced Very High Resolution Radiometer operated by NOAA polar-orbiting satellites. The system contains vegetation health indices and products such as Temperature Condition Index ; Drought products.

2.1.2. *Selection and characterization of the NOAA-AVHRR sensor* - In the absence of measured field data, remote sensing is a privileged tool to provide information related to drought conditions and dynamics. For our study, we chose to use the Temperature Condition Index is based on 10.3 - 11.3 μm AVHRR radiation measurements converted to Brightness Temperature, which was enhanced by completely removing high frequency noise.

2.1.3. *Choice of drought indicator : Temperature Condition Index, (TCI)* - The study area is characterized by a heterogeneous surface where several types of land use can be found such as vegetation, cultivated land, buildings,... A versatile vegetation index was therefore required. The TCI, calculated from the NOAA-AVHRR sensor data.

This TCI has been shown to be effective in monitoring and assessing droughts over different vegetation types (Seiler *et al.*, 2007). The TCI is defined such that the surface temperature. This indicator is used to describe the state of vegetation, especially in heterogeneous areas (Kogan, 1995).

Temperature Condition Index (TCI) (Kogan and Sullivan, 1993) - This indicator is based on the brightness temperature. Based on surface temperature, this indicator is calculated from NOAA AVHRR sensor images. 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 periods up to one year. The TCI also provides useful information on vegetation stress due to soil water saturation (Unganai and Kogan, 1998, Seiler *et al.*, 2007).

The formula given by kogan is:

$$TCI_{(i)} = \frac{T_B^{Max} - T_B(i)}{T_B^{Max} - T_B^{min}} * 100$$

T_B max is the maximum temperature;

T_B min at minimum temperature

T_B (i) at the temperature of the period under study.

T_B : represents the brightness temperature derived from band 4 of the AVHRR sensor.

The low value of TCI indicates a difficult climatic condition (high temperature) in relation to the period studied, while the high values mainly reflect favourable conditions.

The TCI obtained by satellite could sometimes be influenced by cloud cover preventing good detection of the sensor and distorting the surface temperatures constituting the TCI.

2.1.4. *Calculation of TCI* - The TCI is an indicator derived from the brightness temperature. The reason is that this indicator evaluates the situation in relation to the situation that represents dry conditions.

2.1.5. *Satellite data processing* - Our methodology is based on the joint use of remote sensing and geographic information system to measure drought intensity. Processed on the Arc GIS ESRI platform, it was possible to map them in order to follow the dynamics and the state of vegetation during the agricultural season in the face of drought. Drought conditions are met when the TCI is below 40.

The “Split Layer Feature” is particularly useful for creating a new feature class, also called 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 to extract 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.

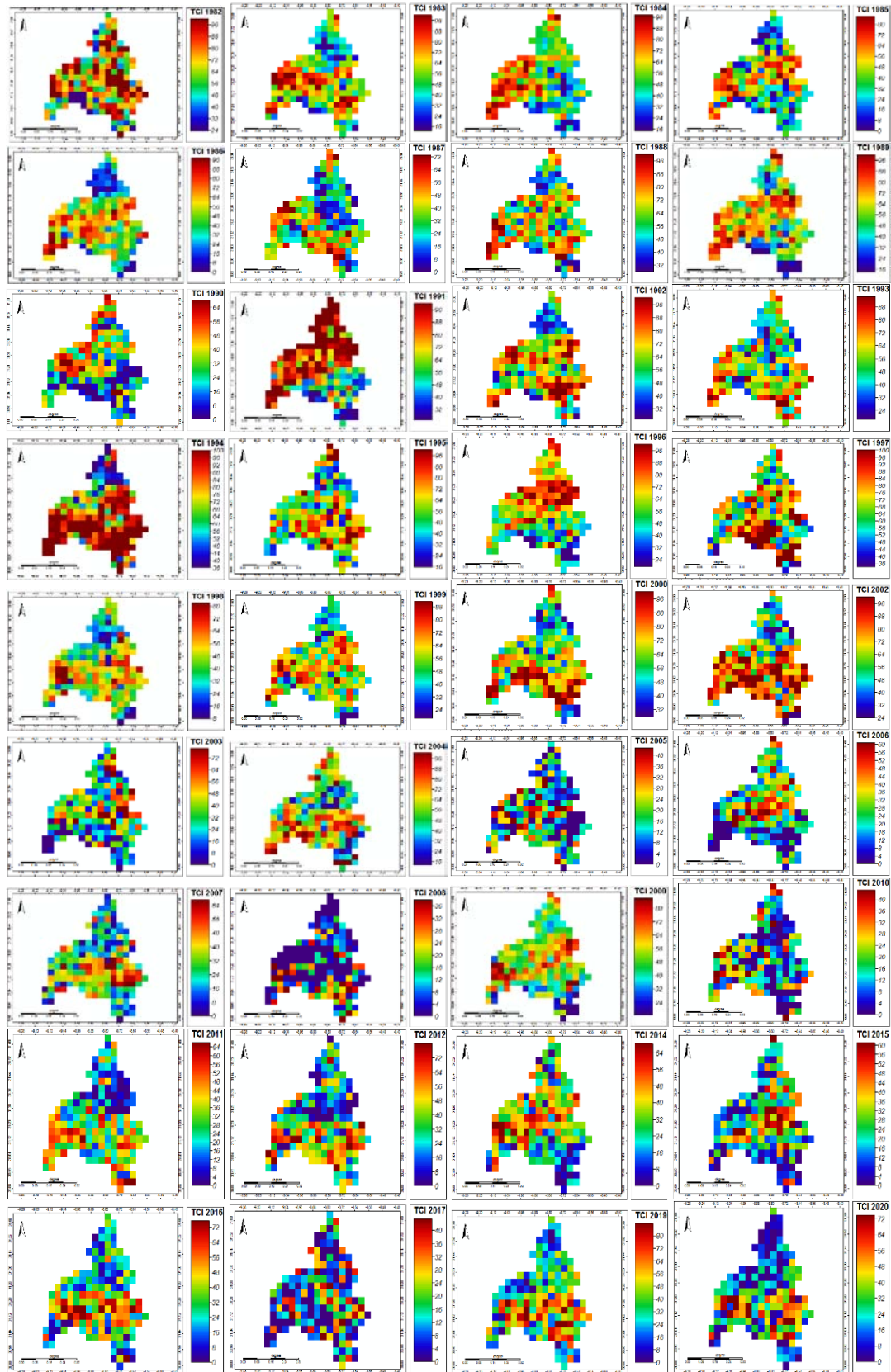


Fig. 3. Distribution of drought intensity estimated by the TCI in the Chichaoua watershed, for the agricultural period 1982-2021

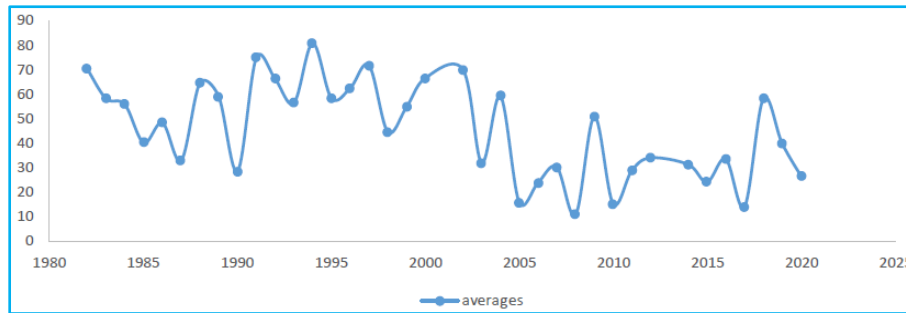


Fig. 4. Variation in drought intensity for the period 1982-2020

TABLE 1

Average TCI value during the period 1982-2021

Year	Averages	Year	Averages
1982	70,32	2000	66,66
1983	58,31	2002	70,15
1984	55,86	2003	31,99
1985	40,26	2004	59,26
1986	48,34	2005	15,81
1987	32,96	2006	23,84
1988	64,72	2007	30,25
1989	59,09	2008	10,69
1990	28,52	2009	50,92
1991	75,03	2010	15,28
1992	66,34	2011	28,84
1993	56,42	2012	34,03
1994	80,92	2014	31,3
1995	58,46	2015	24,14
1996	62,55	2016	33,54
1997	71,89	2017	14,07
1998	44,72	2018	58,24
1999	54,81	2019	39,97
		2020	26,65

Each feature represents a TCI value in pixels, allowing us to estimate the drought intensity. This allowed us to calculate the average drought.

3. *Results and discussion - Evolution of 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, 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, red to the most intense.

The lower the value, the more deteriorated the vegetation cover condition, which could mean a higher

drought intensity. The average of 28 reflects almost permanent drought conditions between 2001 and 2015. The TCI varied between 10 (2008) and 70 from 2001 to 2015, with a maximum of 80 in 1994. Some years were more affected by drought than others, such as 2001, 2008, 2010 and 2015 (Table 1).

From these results, we sought to assess the spatial distribution of different drought levels relative to the mean. In order to better interpret the 1982-2021 TCI results, we performed a clustering of TCI intervals to quantify the degree of drought. It allows us to distinguish three types: area affected by high intensity drought (TCI < 20), area affected by low intensity drought (between 20 and 40) and area not affected by drought (TCI > 40).

71% to 90.5% of the study area is affected by low intensity drought (Fig. 4). High-intensity drought does not exceed 30% of the vegetation, with the exception of 2008, when there was a significant peak of 10%. This type of drought could be problematic for agricultural activity, where the majority of crops are irrigated, as farmers' practices are not adapted.

Fig. 3, which shows the spatial distribution of the average 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 per cent of the vegetation cover is affected by drought, of which 51 per cent 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 total area of the region.

The Chichaoua watershed, an endangered vegetative zone - The relationship between temperature and climate is essential for studying drought in a vegetative context. Drought, as a climatic hazard, can become a risk through the disruption of the balance between the needs of a society and the potential resources provided by a given environment (Charre, 1977). Drought is a physical phenomenon determined by a rainfall deficit and an increase in temperature and a water deficit in the soil. Thus, it is after 3 successive months of rainfall deficit below 50% of the average that economic damage to crops can be expected (NDMC, 2006).

The calculation of the TCI made it possible to monitor the water stress of vegetation in the basin, 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 irrigation water, are fed mainly by winter rainfall. A succession of 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 have an influence on the surface temperatures that constitute the TCI (Viau and Paquette, 1997).

However, there are limitations to our study that must be taken into account when interpret in the results. The use of satellite images over a longer time series (36 years) would be more appropriate to calculate 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.

4. *Conclusion* - The Chichaoua catchment area has experienced a permanent drought of low to moderate intensity over the last 36 years with a peak of high intensity drought considered «dangerous».

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. In spite of the limits of the proposed indicators, they can constitute a relative and operational monitoring means.

This drought index has been used in a wide variety of applications since the advent of remote sensing from space. Its use for quantitative estimates raises a number of issues that can seriously limit its real usefulness if not properly interpreted. They depend on many parameters (solar illumination, viewing angles, etc.) and are affected by several factors (sensitivity to atmospheric effects, soil types and their moisture content).

Geolocation information - You can index the study area of our article Chichaoua basin of the High Atlas (Marrakech-Morocco) accurately in Journal Map's geographic literature database and make our article more accessible to others.

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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.

Disclaimer : The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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