MAPPING OF DROUGHT RISK AREAS IN AGRICULTURAL LANDS IN THE CHICHAOUA BASIN - MOROCCO NORTH AFRICA-USING TEMPERATURE INDEX (TCI)

1. Drought is a natural threat that tends to worsen in the context of climate change, with major socio-economic consequences, (Keyantash and Dracup, 2002; Wilhite, 2007), particularly in vegetation, the sector most vulnerable to this climatic hazard (Heim, 2002). To do so, it is important to have tools and means adapted to provide data on drought intensity. There are already several means to measure the drought episodes that characterize a given environment. These are indicators based on climatic data provided by meteorological stations, such as the TCI temperature index (Shaban and Houhou, 2015).

Indeed, data still remain difficult to access. This shortage of climatological data and the non-centralized nature of water resources data management are major obstacles to drought monitoring. In this sense, it proves important to find a method that ensures the monitoring and communication of spatio-temporal drought information for the whole territory. 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 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 (Hayes et al., 1999).

2. Materials and methods - The study area - The province of Chichaoua was created in 1991 and is part of the Wilaya of Marrakech. With a surface area of 2690 km², the Chichaoua basin is part of the Oued Tensift hydraulic system, which comprises ten or so sub-basins of varying importance (Fig. 1).

Chichaoua basin is located the furthest west in the Haouz Mejjat basin. This basin has an 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 together cover an area of about 3350 km², which represents about 18% of the Haouz-Mejjate basin area.

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 (Fig. 2) 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 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:

\[
TCI(\text{i}) = \frac{T_B^{Max} - T_B(\text{i})}{T_B^{Max} - T_B^{min}} \times 100
\]

\(T_B^{max}\) is the maximum temperature;
\(T_B^{min}\) at minimum temperature
\(T_B(\text{i})\) 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
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

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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 interpreting 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.

References


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