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REMOTE SENSING: MAPPING OF DROUGHT RISK AREAS IN THE CHICHAOUA BASIN OF THE HIGH ATLAS (MARRAKECH-MOROCCO) USING TEMPERATURE CONDITION INDEX (TCI) AREAS USING LANDSAT DATA FROM 1982 TO 2022

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Abstract: The analysis of the drought risk of the Chichaoua watershed allows to characterize the climatic regime by means of statistical analysis methods in order to reach a good understanding of the dynamics of this basin in the mountainous region of Morocco. This study also makes it possible to analyze the dynamics and the space-time evolution of the temperatures within this catchment area which is characterized by the semi-arid climate and to highlight the sensitivity of the flow of the wadis to the climatic and physiographical variations of this catchment area.

Therefore, the objective of the present study is to make a study on the drought risk based on the calculation of an indicator from biophysical parameters extracted from NOAA/AVHRR satellite data covering the Chichaoua watershed region. The drought alert requires the use of macro-geographic data elaborated on a regional scale on an annual basis (April-May of each year). The analysis of these data allows calculating indicators of conjunctural vulnerability, among them we quote the temperature condition index (TCI) which is used for the characterization and analysis of temperature dynamics and drought monitoring at the level of Chichaoua watershed.

Keywords: Chichaoua watershed, Drought, TCI, NOAA/AVHRR, GIS, Morocco

I. 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 *et al.*, 2007), particularly in vegetation, the sector most vulnerable to this climatic hazard. Several definitions of this severe form of water deficit (Wilhite and Glantz, 1985; Heim, 2002; Boken *et al.*, 2005). They are either conceptual or operational (Ndmc, 2006). The conceptual definitions, which are rather general, are often used 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 the majority of 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 a probable climate change or a variability of the average temperature (Augier, 2009).

In order 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. 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 (Hayes *et al.*, 1999) .

Unfortunately, this type of approach has limitations in Morocco. Indeed, data still remain

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difficult to access (Shaban and 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, it proves important to find a method that ensures the monitoring and communication of spatio-temporal drought information for the whole territory. 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 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.

II. MATERIALS AND METHODS

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

i. In the North, the province of Safi
i. In the South the province of Taroudant
ii. In the West, the province of Essaouira
iii. To the east, the prefecture Marrakech Menara and the province of Al Haouz.

Its privileged geographical position constitutes 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 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, which comprises ten or so sub-basins of varying importance. Among these, the Chichaoua basin is located the furthest west in 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 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.

Area: 6872 km2

2. Rugged Reliefs- The plain area: vast expanse with flat relief and an altitude of less than 1000 m.

3. The mountainous area of the High Atlas- in the form of terraced plateaus, gradually lowering towards the West and the East. The highest point reaches 3226m.

4. The piedmont area- extending from Imintanoute to Ait Ourir and linking the plain to the High Atlas chain.

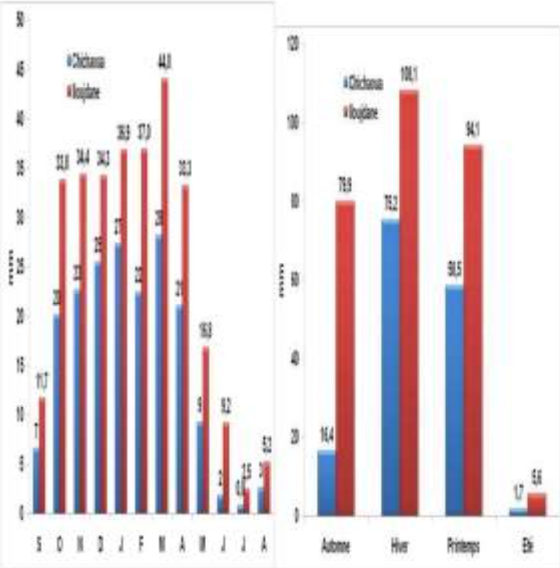
Figure 1: Geographical location of the Chichaoua watershed

Our watershed (figure 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 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.

III. CLIMATOLOGICAL FRAMEWORK

The climate in the province is influenced by the continental situation, and also by the High Atlas. Also, the rainfall varies between 150 mm in the plain to 400 mm in the mountains.

i. The province records annual rainfall of about 190 mm in Chichaoua, 300 mm in Imintanoute and 282 mm in Iloujdane (Seksaoua). The rainy season generally extends from October to May.



The average annual temperature varies from 15 to 20°C, the contrasts are remarkable with diurnal, seasonal and annual variations. Generally speaking, the climate of the province is arid in the plain, semi-arid in the foothills and in the mountains.

1. Precipitation- Monthly and annual rainfall- The average distribution of monthly rainfall measured at Chichaoua and Iloujdane shows the existence of two characteristic periods (Figure 2):

i. A wet season from October to April, when almost all the rainfall occurs, i.e. more than 85 to 89% of the annual rainfall;
ii. And a dry season from May to September with less than 11 to 15% of the annual rainfall. The maximum is reached in March and the minimum in July.

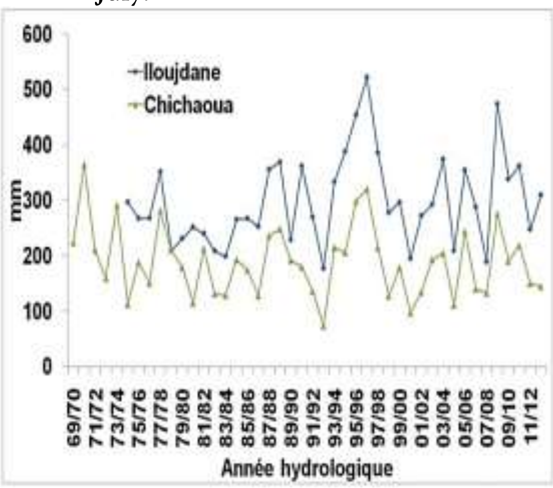


Figure 2: Distribution of monthly and seasonal average rainfall - Chichaoua station (1969-2012) and Iloujdane (1974-2013) Source: ABHT data

The annual average is about 181 mm in Chichaoua and 282 mm in Iloujdane, with a maximum of 522 mm (96/97) and a minimum of 177 mm (92/93) in Iloujdane and a maximum of 320 mm (92/93) and a minimum of 74 mm (96/97) in Chichaoua. The following graph (Figure 3) shows the evolution of rainfall for the two stations located in the Chichaoua basin.

Figure 3: Evolution of annual rainfall, Chichaoua (1969-2012) and Iloujdane (1974-2013) stations Source: Statistical analysis, AHT-RESING, 2015

The province records an annual rainfall of about 187 mm in Chichaoua.

			Average rainfall (mm)												
	Altit-ude	Contact details	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Chichaoua	340	31°33;8°47	25	25	23	16	9	3	0	0	8	19	26	31	187

Table 1: Average rainfall (mm) -1933-1963
Source: Water Resources of Morocco, Volume 2 (p 404)

2. Temperatures- The average annual maximum and minimum temperatures recorded at the Chichaoua station are 27.9 and 10.6°C respectively. The average annual temperatures are about 19.3°C.

	Average maximum and minimum temperatures C°.

	Jun		Febr		Mar		Apr		May		Jun		Annual	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min		
Name of the station: Chichaoua	19	3.3	21.1	5.1	24	7.5	26.4	9.5	29.5	11.7	33	14.2		
	Jul		Aug		Sept		Oct		Nov		Dec			
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
	37.8	17.3	37.9	17.9	33.8	15.3	28.9	12.1	23.7	8.3	19.9	4.8	27.9	10.6

Table 2: Average temperatures °C -1933-1963

The lowest temperatures are generally observed in January and December with averages of 11.2 and 12.4°C respectively, while the highest temperatures are observed in July and August with averages of 27.6 and 27.9°C respectively.

	Average temperatures (°C)												
Month	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Name of the station: Chichaoua	11.2	13.1	13.8	18	20.6	23.6	27.6	27.9	24.6	20.5	16	12.4	19.3

Table 3: Average temperatures °C -1933-1963.

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

Table 3: Average TCI value during the period 1982-2021

3. Evaporation- The average annual evaporation varies between 1,800 mm on the Atlas slope and 2,600 mm in the Haouz plain. The minimum values are recorded during the month of January, while the maximum values occur in July and August, with nearly 50% of the total evaporation recorded during the four months from June to September (according to the State Secretariat in charge of water).

4. Wind- Knowledge of the prevailing wind regime is an important concept. Observations made at the level of the Chichaoua city wastewater treatment plant show that the wind blows in a West-East direction. The average annual wind speed is about 3 km/h in the mountains and 5 km/h in the plains.

5. Vegetation- In the study area, the vegetation cover is generally poor. Three quarters of the area is almost bare. The types of vegetation vary according to the altitude and the nature of the land. The evergreen oak forests (Argan, Thuja, Red Juniper, etc.) extend over the Atlas mountain range.

Agricultural land occupies 23% of the area of the zone, and 42% of the agricultural land is irrigated area. Pasture and fallow land occupy 61% of the area, which is comparatively higher than in other areas.

6. Land use- The areas of the different land use strata were determined from the land use strata map prepared by the Ministry of Agriculture in 2016 and from the GIS developed for this study (Figure 4). From these areas it can be seen that:

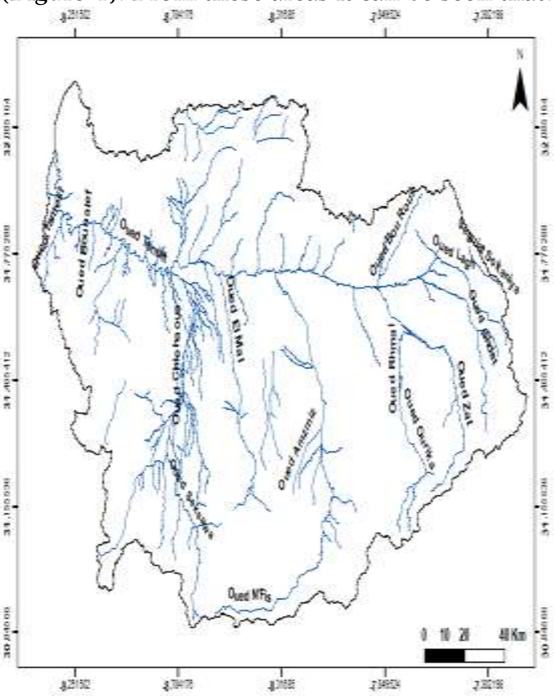


Figure 4: Map of the hydrographic network of the area

In the Chichaoua basin:

i. The land used for rain-fed agriculture is spread over the whole plain and foothills of the sub-basin because of the arid climate. Only a part of this area, mainly cereals, is cultivated each year, the rest is left fallow.

ii. The irrigated land is located mainly in the plain area (Sidi M'Hamed Dalil and Mejjat communes), and is largely cultivated for market gardening with high added value. Other irrigated lands, of lesser importance, are also located in the communes of Sidi Bouzid and Lamzoudia.

iii. The areas reserved for plantations consisting of olive trees, apricot trees, rosaceous and citrus fruits, they cover 9985 ha, located in the irrigated parts of the communes of Ait Hadi, Sidi Bouzid and Sidi M'Hamed Dalil as well as on the banks of the wadi Chichaoua in the part of the plain and in the medium and high valleys The uncultivated lands are located mainly in the communes of Saidate, Sidi MHamed Dalil and in the piedmont area.

iv. The built-up area covers 3829 ha, including the towns of Chichaoua, Imintanoute and all the douars.

v. The forest massif covers the mountainous part of the basin.

7. Hydrological framework- The province of Chichaoua is endowed with a weak but not negligible hydraulic potential. The socio-economic development of the province must necessarily involve the evaluation of available water resources and also the rational management of these resources.

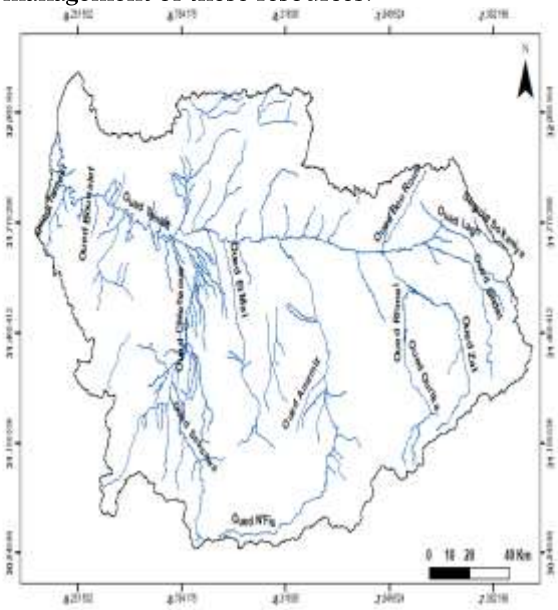


Figure 4: Map of the hydrographic network of the area

IV. METHODOLOGY

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. The system is based on satellite observations of the Earth, biophysical theory of vegetation response to the environment, 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 products such as Temperature Condition Index (TCI); Drought products.

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. This information comes from satellite sensors that offer a permanent monitoring of the vegetation cover and its spatiotemporal evolution (Iona-Toroimac, 2006). For our study, we chose to use *the Temperature Condition Index (TCI)* is based on 10.3-11.3 μm AVHRR radiation measurements converted to Brightness Temperature (BT), which was enhanced by completely removing high frequency noise. BT was expressed as an anomaly with respect to the 25-year climatology estimated on the basis of biophysical and ecosystem laws (minimum law, tolerance law and carrying capacity). TCI is a proxy for thermal condition.

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 (Unganai and Kogan, 1998; 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).

4. 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 (Kogan, 1997; Kogan *et al*, 2004).

The formula given by **Kogan** is:

i. TB max is the maximum temperature;
ii. TB min at minimum temperature
iii. TB (a) at the temperature of the period under study.

TB: 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 favorable 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.

Calculation of TCI- The TCI is an indicator derived from the brightness temperature (Band 4 of the AVHRR sensor for example). A low TCI reflects a TB that is close to the maximum TB and a high TCI reflects a TB that is close to the minimum TB. In other words, low TCI values represent water-stressed conditions while high TCI values represent conditions where there is no water stress. In the formulation of this indicator, the values of TB and TBmax. The reason is that this indicator evaluates the situation (TB) in relation to the situation that represents dry conditions. It is the maximum temperatures that indicate the conditions of hydric stress.

5. 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 TCI obtained from satellite images.

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. 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 TCI classes ranging from 0 to 100 (Kogan, 1997; Kogan, 1995). Drought conditions are met when the TCI is below 40. In order to perform this TCI classification and calculate the average drought-damaged area, we followed the following steps in GIS:

i. 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.
ii. 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.

iii. 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 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 index depends largely on the values of other 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.

V. RESULTS AND DISCUSSION

1. 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.

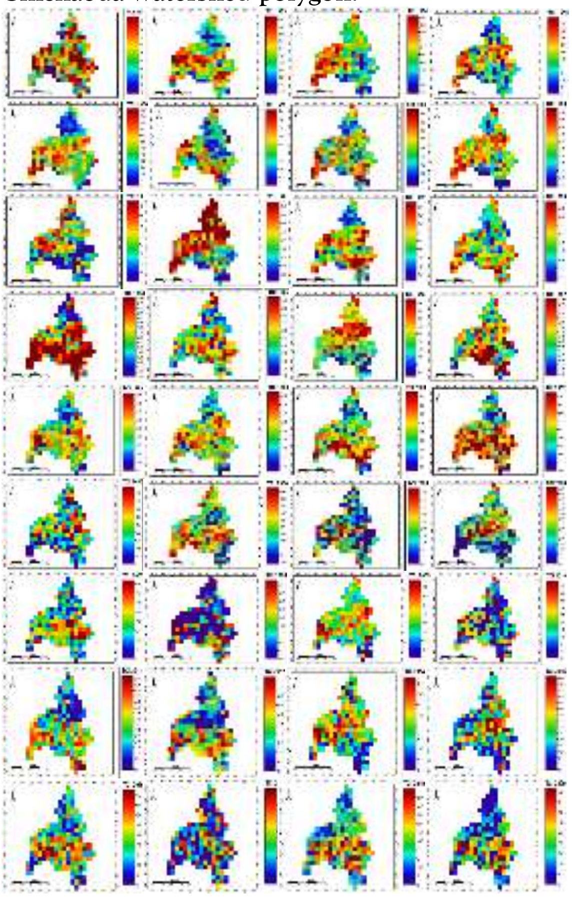


Figure 5: Distribution of drought intensity estimated by the TCI in the Chichaoua watershed, for the agricultural period 1982-2021.

Figure 5: shows the spatial distribution of the change in the TCI temperature indicator 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 colour gradient of each pixel represents the drought level. Green corresponds to the lowest value, red to the most intense.

Table 4: shows the average value of the TCI for each year between 1982-2021. 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 impacted by drought 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. 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).

Figure 6: Variation in drought intensity for the period 1982-2021- 71% to 90.5% of the study area is affected by low intensity drought (Figure 6). 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.

Figure 5: 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

VI. 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 Chichaoua watershed, reflected in the increase in temperature that could affect the plant. The analysis and monitoring of this index thus allow to identify the temperature dynamics for the vegetation and to 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 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.

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

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

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.

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 sitehttps://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.