Some Aspects of Climate Variability and Increasing Aridity in Central Morocco over the Last Forty Years: Case of Tensift Basin (Marrakech-Morocco)

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Abstract
Morocco, due to its location in the Mediterranean circumference, is vulnerable to present and future climate variability and climate change. Its surface water resources are becoming ever more limited and difficult to exploit. It might be expected that the warming of the hot season and drought would result in an increase in arid and semi-arid regimes of the region. In this context, we are interested in the evolution of aridity through climate indexes, including precipitation, temperature and evapotranspiration over the last 40 years in the Tensift watershed (central Morocco). As preliminary results, in the Tensift basin, the temperature became higher during the last two decades. It diminishes paradoxally towards mountainous areas. A slight decrease of precipitation has been noticed in the foothill regions of the High Atlas and near the Haouz plain. The study of aridity evolutions by the aridity index of De Martonne and aridity index of UNEP takes into account respectively the ratio between the mean annual precipitation (P) and temperature (T) and the relationship between annual precipitation and evapotranspiration. Generally, the aridity is decreasing from downstream to upstream of the study area. But during the past two decades, the region of the Tensift knew a subtantial augmentation in arid land regime may be due to global warming and reduced precipitation measured. Typically, there is a coherence between UNEP index and the index of the De Martonne from point of view of increasing aridity, which adds robustness to the result.
Keywords: Tensift watershed, De Martonne's aridity index, UNEP index, aridity, spatial variability.

1. Introduction. Introduction, problem and study area

Morocco is located in a transition zone between the arid climate of North Africa and humid climate of Central Europe. The Mediterranean basin is particularly vulnerable to present and future climate variability as well as climate change. Due to its unique geographical location. It could be that the warming of the hot season and drought result in the developpement of arid and semi-arid regimes in the region (Gao & Giorgi, 2008).
In fact, in Morocco, the growth rate of agricultural production between 1970 and 2000 was irregular in relation not only to different economic choices but also with climate change and water resources during this period. Moroccan mobilized hydraulic potential is estimated at 20 billion m3, of which 4 billion m3 of groundwater and 16 billion m3 from surface waters (Agoumi & Debbarh, 2006). These latter are becoming more and more limited and difficult to operate. They are closely related to precipitation, characterized by a highly irregular distribution in space and time (Riad & al. 2006).
Precipitation is the most important factor in the climate as it is easy to measure. Furthermore, most studies and analyzes are based on precipitation (Kouassi & al. 2010).
Over the past thirty years, most climate indices and criteria used to define the concept of aridity. Which are based on the heights precipitation of rainfall, extreme temperatures and evaporation of the air. These indices are usually calculated annually (sometimes monthly).
The study area is part of the great Tensift watershed. It occupies an area of about 18500 square kilometers upstream to the mouth of Abadla (Figure 1).

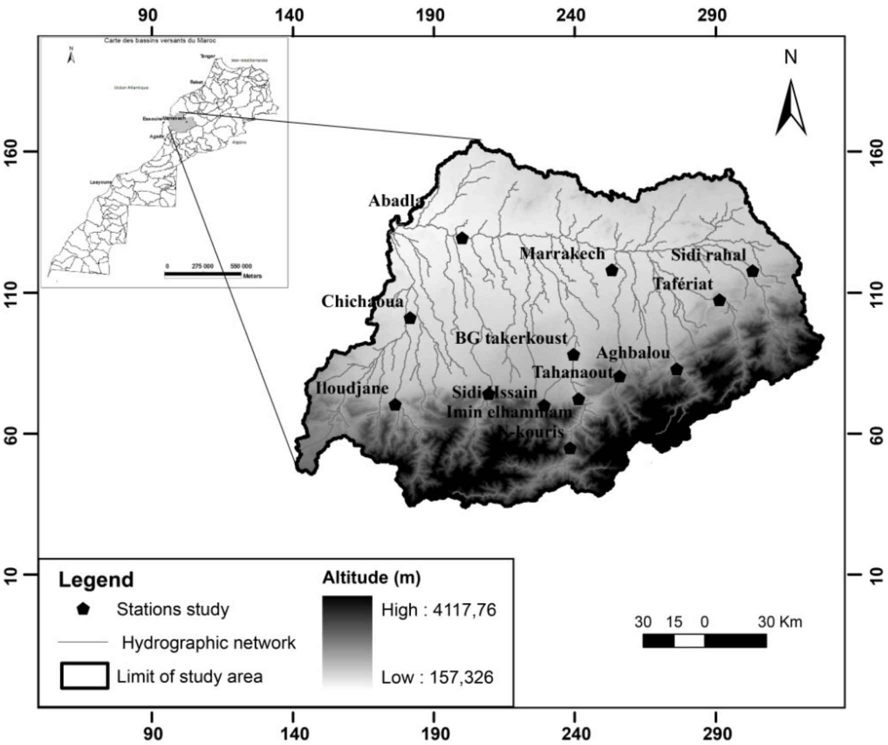


Figure 1: geographical situation of the Tensift watershed

Tensift watershed lies between latitudes 30 ° 50 'and 32 ° 10' North and longitudes 7 ° 25 'and 9 ° 25' West. It occupies an area of 18500 km2 with a perimeter of about 574 km. It is a very contrasted to the relief between 157 m and 4167 m (Figure 2). The average altitude is 1028 m, the median elevation (corresponding to the hypsometric curve at abscissa 50% of the total area) varies between 650 m and 1150 m (Figure 3) (Riad & al., 2006) .

The compaction coefficient is approximately 1.3. The basin is elongated and the time of water concentration is important.

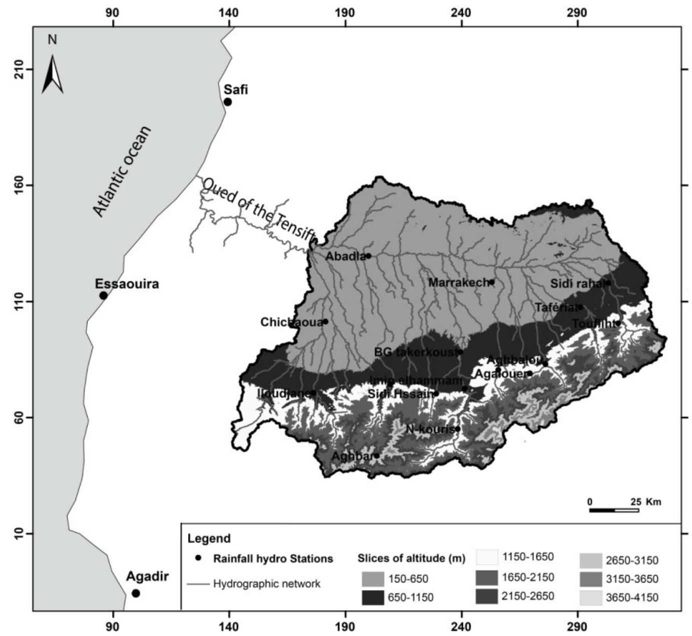


Figure 2: Distribution of slices altitude of the Tensift basin

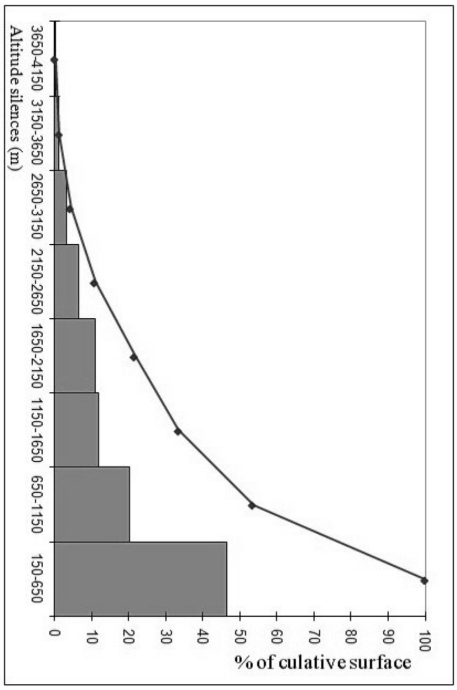


Figure 3 The hypsometric curve of the Tensift Watershed

Tensift watershed is characterized by a different climate related to its extension and its relief. The climate is semi-arid influenced by the cold ocean current of the Canaries in the coastal zone, semi-arid and warm in the Jbilet and continental arid in the Haouz.

Tensift geological formations are diverse. In addition, in the Atlas range, outcrops are dominated by abundance eruptive and metamorphic rocks of Precambrian age including granite, diorite, dolerite, andesites and rhyolites, primary schist. Its Secondary formations are strongly colored red and largely dominated by calcareous, sandstones, marls and clays (Boutateb 1988, Moukhchane 1983).

The Tensift plain is presented as form of an elongated east-west depression, which make flush detritic formations, that come from the destruction of the Atlas range and the accumulated Neogene and Quaternary. The Tensif plain is covering the Primary, Secondary and Tertiary formations (Boutateb 1988 ; Moukhchane, 1983). Schist are widespread in Jbilets with varied facies and several colors (Sinan 2000).

Bare soils dominate almost the entire basin. Specifically, the area of Jbilet and flanks of the Atlas. With annual scattered vegetation, it appears on Piedmont of the Atlas Mountains and sweet slopes south of Jbilet. The forest covers a small area on the Piedmont; rainfed and irrigated agricultural crops occupy the Tensift plain (Chaponnière 2005).

2. .Methodology, results and discussion

Oued of the Tensift is powered almost completely by its left bank affluents which drain the slopes of the northern Atlas. The right bank is devoid of perennial streams. Only flows are resulting from violent rainy events occasionally contribute to power the oued (Riad et al. 2006). Furthermore, the spatial distribution of weather stations in the Tensift watershed is heterogeneous. Also, these stations present an incomplete series and/or short time of temperature (1984 to 2010/11).

To reduce the irregularity the observated series, we have used the isohyets method to fill gaps at the level of the chronological series of weather stations. It is based on a network of isohyets curves and It is going to take account of a number of stations outside the basin (Rodier 1963). In our case, we have established annual isohyets maps since 1970/71 until 2010/11.

2.1. Aridity estimate

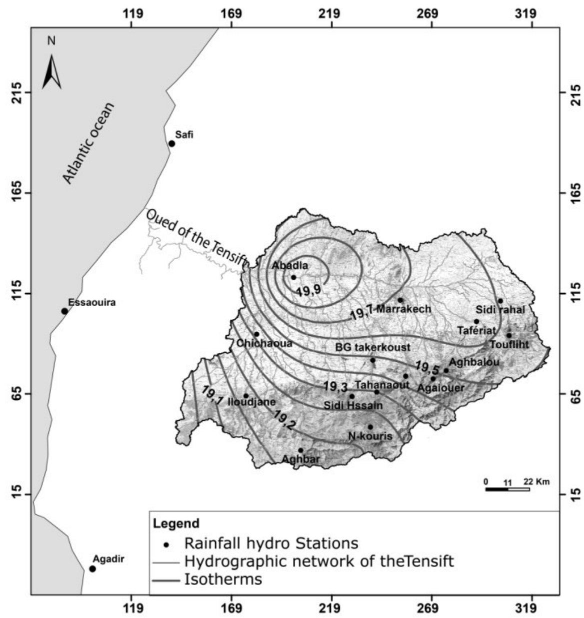
The Aridity is the consequence of the climate variability is a growing problem in many parts of the world (Wallen 1967). the identification of the different types of arid regimes is from the aridity index. Among the most used indices is the De Martonne's aridity index (IA=P/(T+10) where P is the annual rainfall and T means the average annual temperature and added the 10). Another effective measure is the difference between monthly rainfall and evapotranspiration defined and measured by Thornthwaite's formula. It's expressed through the aridity of UNEP index (United Nations Environment program, 1992), which requirse the precipitation and potential evapotranspiration, where the AUI is defined by the ratio AIU= P / PET where P is the annual precipitation and PET is the annual potential evapotranspiration (Gao & al.(, 2008).

The values of the AIU≥1, 0.65≤AIU < 1, 0.5≤AIU< 0.65, 0.2≤AIU< 0.5, 0.05≤AIU< 0.02 and AUI≤0. 05 identify respectively, the humid, dry the land, dry sub-humid, the regimes semi-arid, arid and arid (Gao et al., 2008).

2.2.Temperatures spatial distribution

According to a study carried out in Morocco in 2001 and the results of which were presented in the national communication the United nations about climate change, the average annual temperature will increase of 0.6 ° C to 1 ° C between 2000 and 2020 (CNUSED, 2001). Other studies have shown that the global warming has been powerful over the last twelve years. For exemple the average of the temperature rise exceeds 0.6 ° C for the city of Agadir for example (Stour and Agoumi, 2009). In this study, the temperature data series covers the period 1973 to 2011 artificially subdivided into two sub-periods. Also, in the Tensift basin the spatial distribution of the average interannual temperature of the period 1973 to 2011. Il is approached in our the following study shows an increase from upstream to downstream in the watershed.

Between 1973/74 and 1989/91, the temperature has experienced a slight spatial variation with a maximum 19.3 ° C at the level of the Abadla station, and a minimum18.3 ° C at N' kouris station (Figure 4). During the last twenty years (1990-2011), the annual average temperature becomes higher throughout the Tensift watershed. It reaches 20.5 ° C at the Abadla station (Figure 5).



Figur4: the spatial distribution of interannual average temperature from 1973 to 2011

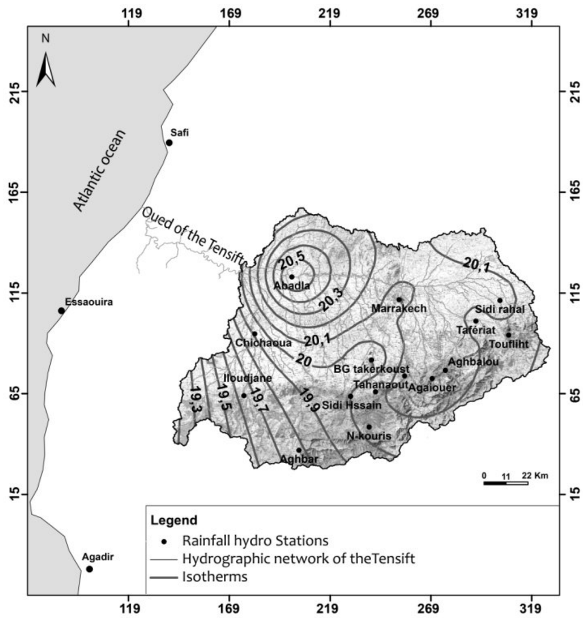


Figure5: The spatial distribution of interannual average temperature of 1991-2011

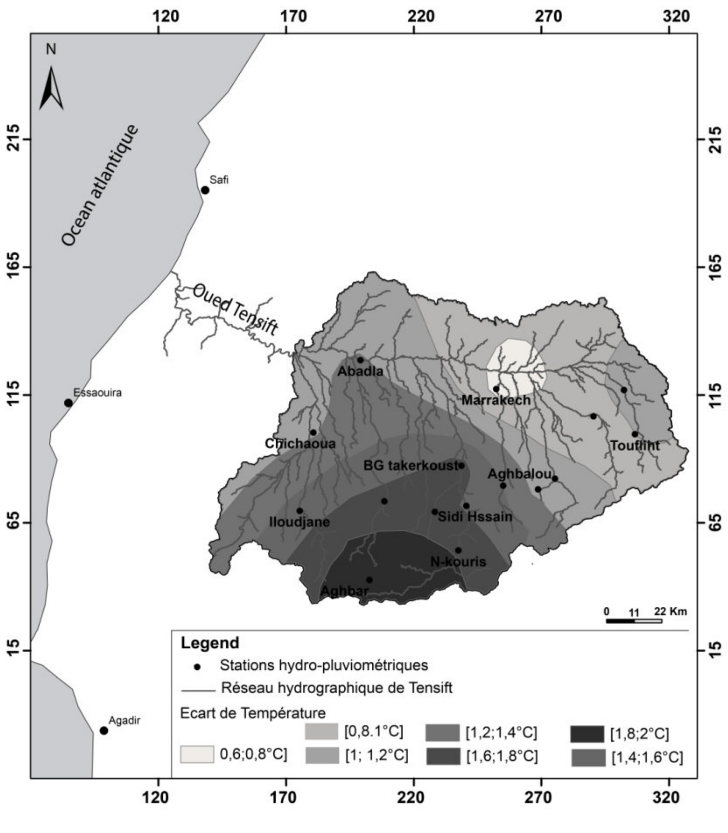


Figure 6: The spatial distribution of the differences in the interannual average temperature during the observation period (1973-2011).

The study of differences in interannual mean temperature between the second period (1991-2011) and the first (1973-1990) is represented in the figure 6 which shows an increase in temperature along the Tensift watershed. Therefore it's hot throughout the Tensift watershed. Maximum values of temperature differences have registered at the level of mountain areas, especially in the South of the watershed (superieur than 1.6 ° C). On the other hand, minor differences have been recorded North the watershed (Jbilet). This climate variability may be related to what is happening at level of the globe. Knowingly the rate of the emission of greenhouse gases strength into in the atmosphere is noticed everywhere the Earth. As a result, this has contributed to a significant increase of terrestrial temperatures (CNUSED 2001; Piervitali and al., 1996; Orderly and al., 2007; IGCC, 2002; Schair and al., 2004).

At level of the Mediterranean basin during the past 50 years, climate trends have been characterized by an augmentation in the average temperature (2-4 ° C), and a rise in the frequency and intensity of droughts (Macais et al., 2006; IGCC 2002). A study carried out in Spain, shows a significant increase of daily average temperature that characterizes the period of 1949-2000 (Brunet et al., 2005).

Mountainous areas in the Tensift watershed also know a population growth. In 2002, a study by the Regional Directorate of water and forest of the High Atlas mountains at Marrakech, the size of population user of the Ourika forest (High Atlas) expanded by 14% from 1994 to 2002 (DREF). And in Morocco, the demand for fuel wood is greater than the productivity of the forest (CNUSED 2001). This causes an over-exploitation of forests to meet the needs of population. Also, it will lead to an augmentation in emissions of carbon dioxide (main GHG) which is related to the combustion of the wood on the one hand and the low rate of absorption on the other hand.

The mountainous regions of the study area are also described by a developpement in agricultural activities. It would be another source of emission greenhouse by 25% (CNUSED 2001).

In fact, the climate consequences expected on the deforestation places are desertification, which results in the change of regional radiative conditions and the decrease of the water recycling in situ. This brings about a temperature increase on-site at the level of the ground (Norrant 2007).

2.3.Spatial distribution of precipitation

To understand more the climate variability we should go throught the rainfall analysis. These latters, their regimes and their actual geographic distributions are related to the direction of the winds, mountain systems and air masses dominances (Shepherd et al. 2004). Moreover, the TA repport of the intergovernmental expert group, concerning the climat's evolution (Houghton et al. 2001), inspired that the increase in the surface temperature is likely lead to many changes in rainfall.

Figure 7 shows the map of spatial distribution of interannual rainfall during the observation period (1973-74 to 2010/11). Precipitation decreases from upstream to downstream of Tensift watershed. They reach 600-700 mm in the mountainous areas and 190 mm in the plain.

From 1973 to 2011, the precipitation knows a temporal evolution can be divided into two periods of observation. The first extends from 1973 to 1990 and the second in 1991 to 2011(figure 8).

There over the past 20 years a decrease in the height of the rains. Less than 10 mm in the eastern part of the basin of Haouz (Sidi Rahal and Taferiat), Eastern (Chichaoua) and Southeast of Tensift. This decrease can reach less than 34 mm Aghbar station. In other areas of the basin, the height of the rains increases relatively. It can reach more than 40 mm in the region of Marrakech.

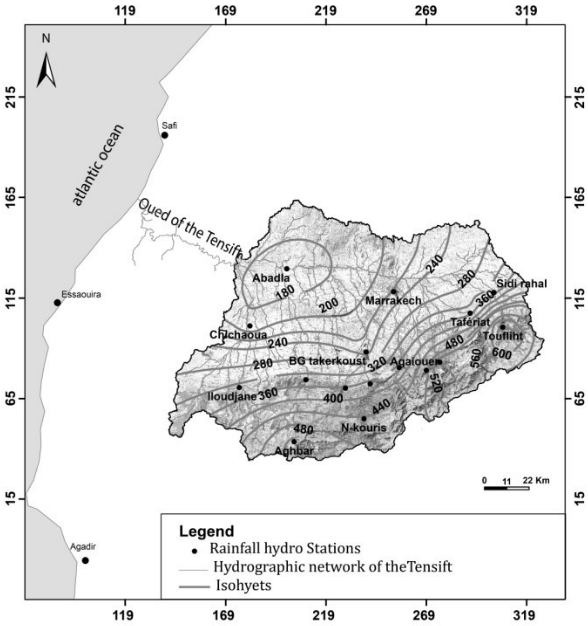


Figure 7: The spatial distribution of interannual rainfall of 1973-2010

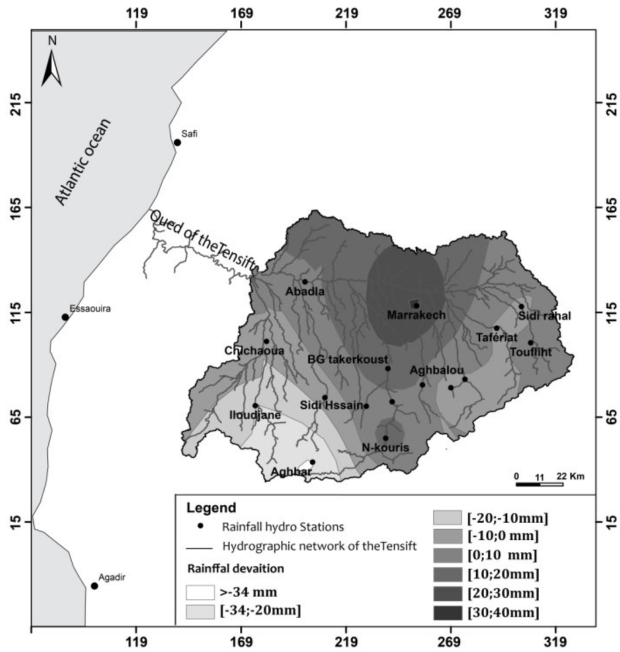


Figure 8: The spatial distribution of the differences of interannual rainfall between 1973-1990 and 1991-2011

By comparing these results with temporal variations of rainfall in some rainfall stations (table 1) during the period of observation (1973-2011), one finds that this variability is well marked. These fluctuations reflected by an alternation of dry years and wet years for example figure 9 which shows these fluctuations in the station of

Sidi Rahal. This station is characterized by a long dry period from 1998 until 2008. This implies a diminution in the average rainfall at the level of the second period.

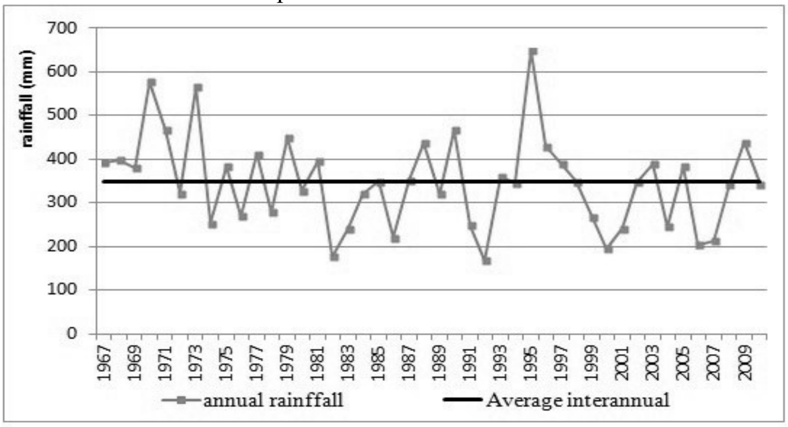


Figure 9: Variation in annual rainfall in the Sidi Rahal station

In Abadla, Imin Elhammam and Aghablou stations, there is an increase in wet years which are most important in the region of Marrakesh from 1990 to 2010. This confirms the rise in height of rain differences in these stations, which can be explained by an increase in winter-spring and autumn downpour. On the other hand, in the summer, storms cause heavy rains and violent floods as in the case of the flood of August 17, 1995 in the Ourika valley (Haut Atlas) (Saidi & al.. 2003).

2.4.Analysis of aridity maps

2.4.1.Index of De Martonne

Index of annual aridity of De Martonne (Ali and Piedallu, 2005), is a bioclimatic index that characterizes the aridity level to the level of a given region. This index takes into account average or annual amounts of precipitation and temperature. This index has been applied to the Tensift basin (Marrakesh) for a total period observation for 40 years and the results are shown below.

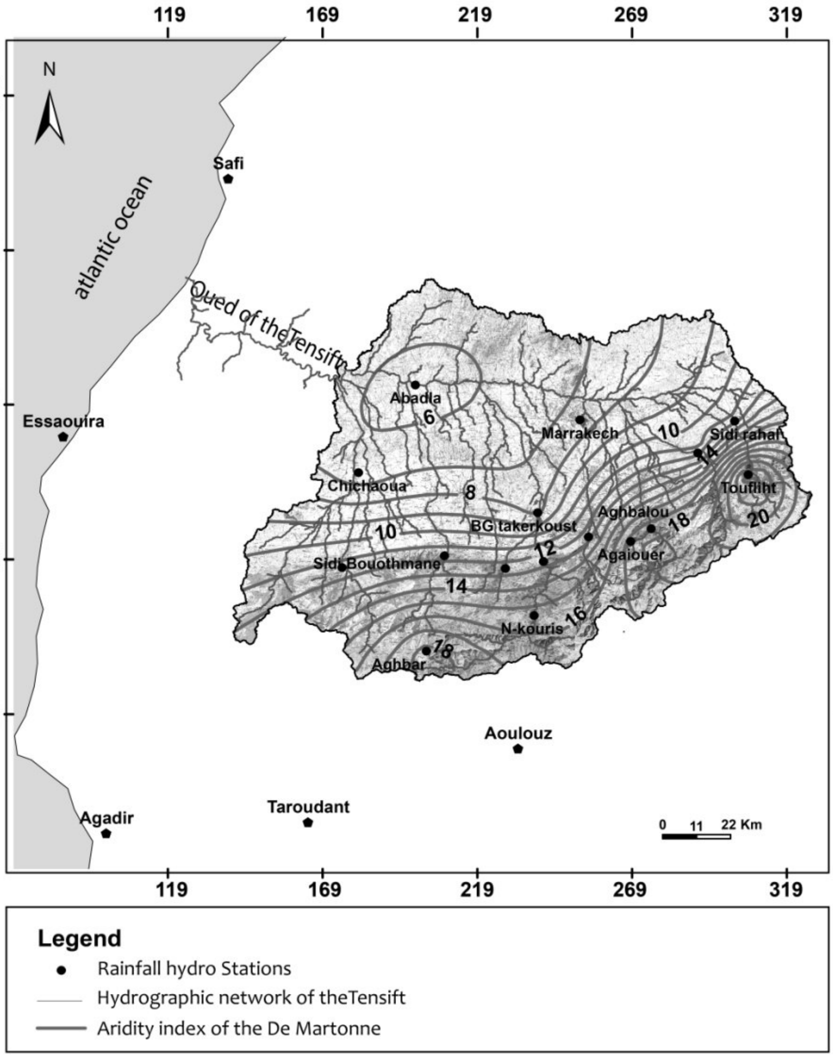
Figure 10 shows the distribution of the aridity index of De Martonne in Tensift watershed. During the observation period. We note that during the last 40 years, averages of aridity index in most areas of the basin are included between 6 and 13 which imply that these areas are classified arid to semi-arid. This index can reach 22 in some mountainous areas, so these are sub-humid areas according to the classification of De Martonne in 1926 (Lungu et al. 2011). Furthermore, the spatial distribution of the index also shows a variability with low values less than 10 are registered to the West and the North of the Tensift watershed; whish indicate a high aridity. Mountainous areas whish register more high values of this index imlpy a less pronounced aridity.

The comparison between the aridity index distribution of the second period (1990/91 to 2010/11) (Figure 11) and the first one, shows an increase in both last decades.

The map in figure 12 shows the evolution of aridity across the distribution of aridity index differences between 1973 and 2011, that differences of aridity index decreased from 2 to 0.5 in the region of the High Atlas and towards the West and South West of Tensift, which shows a slight increase in aridity. These areas are characterized by an improvement of agricultural activities. According to a study that shows the relationship between aridity and water for irrigation in Romania (Platineanu et al. 2006), the lower value of aridity index corresponds to the highest water for irrigation. This means that irrigation is generally influenced on water resources and the progress of aridity afterwards.

The differences of the index increased to the North of the watershed of Tensift. This allows to think that the degree of aridity has diminished in this direction of the basin.

The calculation of aridity index in a study on the climate of the basin watershed of Souss which limit the watershed of Tensift by South, shows that the aridity index decreased from 9.5 to 8.9, from 8.3 to 6.5 and from 14 to 10.6 respectively in the Agadir, Taroudant and Aoulouz stations (their location in figure 10) during the period from 1960 to 1990 (Saidi 1995). This shows that the process of accentuation of the aridity in recent decades is a broader geographic phenomenon. This aridity is moving dangerously close to the pre-Saharan latitudes towards Mediterranean latitudes (31 ° N and 32 ° N).



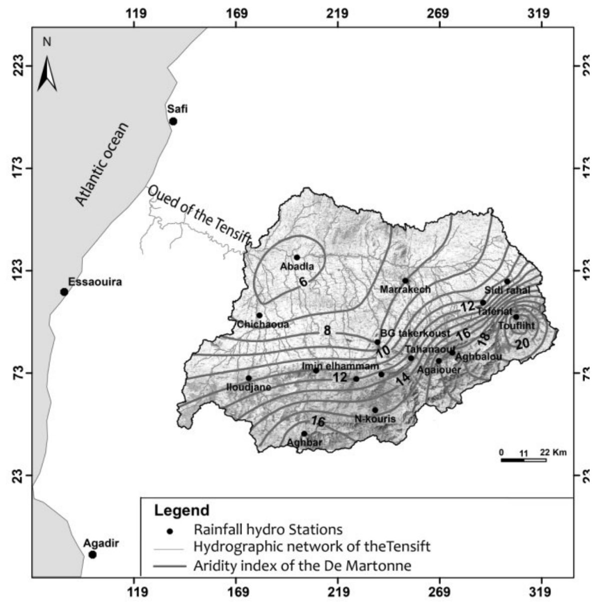


Figure 11: The spatial distribution of aridity index of the De Martonne 1990/91-2011

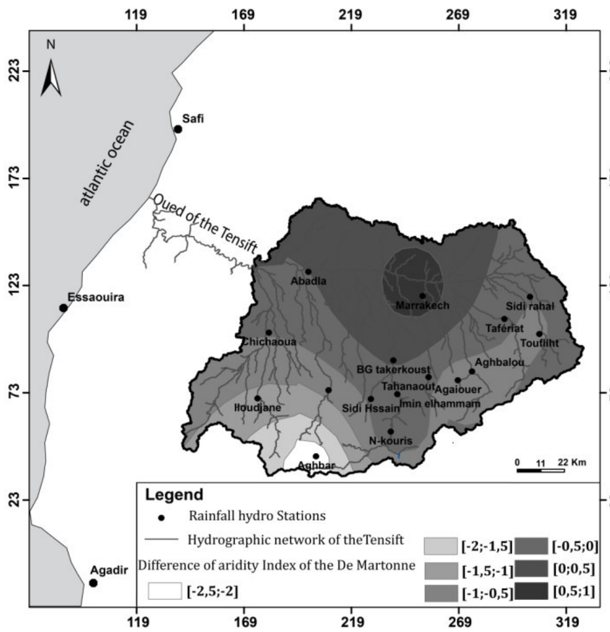


Figure 12: The spatial distribution of the differences of aridity index of De Martonne during the observation period (1973-2011)

2.4.2.UNEP aridity index

To judge the veracity of this point of view, the resort, comparatively to the UNEP aridity index, will allow seeing to what extent the findings and results of the first test are verriable. The figures below present the results of this treatment.

Figures 13 and 14 show the spatio-temporal distribution of aridity in the last 40 years. These figures show that the index of AUI increases downstream to upstream. This implies that the degree of aridity decreases from downstream to upstream. Figure 14 shows that aridity has grown to mountainous areas in the last 20 years in relation to the first period (figure 13). The expansion of the class of arid regime (0, 05≤AIU < 0.2) becomes higher with 7667 Km² in the second period compared to 4443 Km² in the first one. On the other hand, the classes arid semi (0, 2≤AIU < 0.5) and sub humid (0, 5≤AIU < 0.65) are reduced respectively with partials extensions 10291 Km² and 431 km2 in the first period compared to 7560 Km² and 138 km2 during the second part. The relative humidity in these areas (Ahgbar and Toufliht stations) may be linked to their special geographical situation. The Toufliht station is located in an area of dense plant cover (forest) while the station Aghbar is located in an area of high altitude.

The spatio-temporal evolution of the UNEP aridity index confirms the results of the index of aridity of De Martonne. In these last decades, aridity has grown and has gained ground to the mountainous regions. Another study (Gao et al. 2008)- on the accentuation of aridity in Mediterranean regions found that towards the end of 21th century, the regions of the Mediterranean area could know a sharp increase in the expansion arid zone regime under the effect of gases greenhouse estimated from simulations of high resolution with a regional climate model. In addition, the aridity increases also more in the regions of the North Africa and Middle East (Gao et al. 2008). This could increase the extent and change the positions of subtropical areas dry (Maliva et al. 2012).

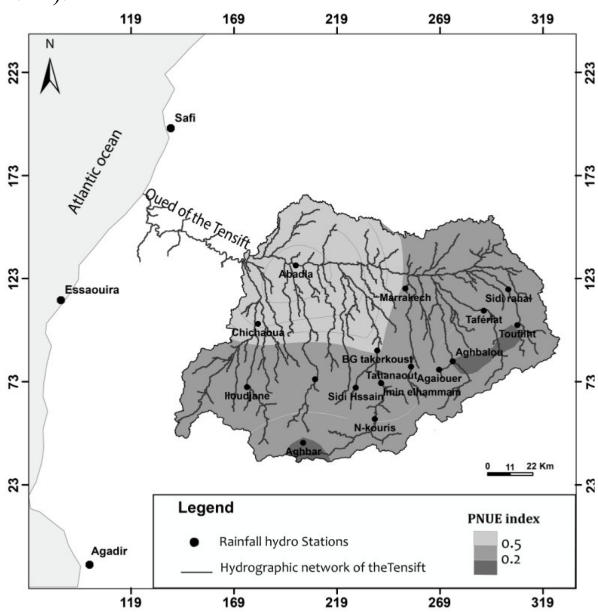


Figure 13: The spatial distribution of aridity index UNEP 1973-1991

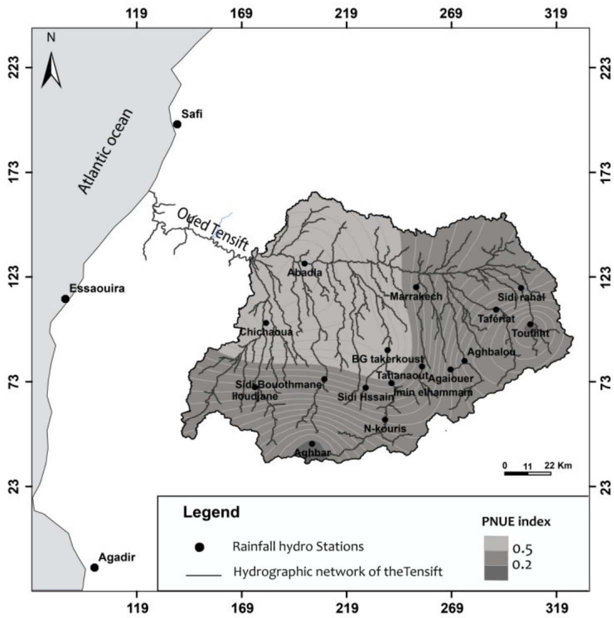


Figure 14: The spatial distribution of UNEP aridity index 1991-2011

Conclusion

The use of two different methods for the evaluation of aridity (aridity index of De Martonne, the UNEP aridity index) estimates the possible variations in climatic regimes of the Tensift watershed, during the observation period of 1973 to 2011. The variables used in calculated aridity indices are the air temperature, precipitation and potential evaporation.

Analysis of mean annual temperature shows an increase from the sides of the Ocean to the continent. On the other hand, a marked increase over the past 20 years was found. The annual average difference of the temperature gets higher towards the mountainous areas. This temporal variability is closely linked to global climate conditions and the general trend towards warming (notably under the effect of greenhouse gases).

The analysis of the annual average rainfall has shown spatial variability that is expressed by a height of precipitation which increases downstream to upstream of the basin. Analysis of their differences during the observation period reveals a decrease of approximately of 10 mm of precipitation in the eastern part of the basin of Haouz (Sidi Rahal and Taferiat) and the East of Tensift (Chichaoua) and less than 34 mm in South East areas. On the other hand, a slight elevation of these differences is recorded in the rest of the Tensift watershed areas.

Paradoxically, it reaches a height more than 40 mm at the level of the Marrakesh areas.
The application of the two indices to the Tensift region showed a substantial increase in the extent of the arid regime areas. The increase in aridity would be due to global warming and the diminution of the measured precipitation. Generally, it is an agreement between UNEP index and the index of De Martonne in the direction of increasing aridity, which strengthens the results and conclusions.
In brief, aridity has made significant progress towards the mountainous areas. This could be linked to the global advancement of desertification found south of Morocco (report at the level of the Souss watershed, in the South of the Tensift, at the Agadir, Taroudant and Aoulouz, stations where the aridity index declined between 1960 and 1990). It is therefore a significant progression in aridity that is gaining ground to Moroccan latitudes.

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