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The Bouregreg Watershed Water Vulnerability Assessment (Morocco), in the face of Climate change

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Abstract

The hydrological regime of all the basins is characterized by a great inter-annual variability marked by the alternation of wet and dry sequences, inter-bedded by years of strong hydraulicity or severe drought. Most watersheds have water deficits. This situation is likely to deteriorate as a result of climate change and the worsening of extreme events, in particular the significant reduction in rainfall and widespread drought. the threat of drought still hangs over the country like the periods 1980-1985, 1990-1995, 1998-2002, 2011-2012 and 2015-2016 (year of severe drought during the last 30 years), and during which the almost all watersheds have been in a water deficit situation leading to the overexploitation of groundwater . The present work aims to describe the meteorological conditions of the Bouregreg watershed, in order to answer the problematic dealing with the effect of the climatic fluctuations on the water resources, the assessment of the potential impacts of climate change on hydrology and assess vulnerability in order to identify the current impacts and threats and identify strategies, policies and actions to address climate variability and change and reduce the impacts and future vulnerability of these changes. The work done is likely to further contribute to research on water management, in order to enrich and exploit water information systems and assist decision-makers in the development of the master plan for integrated water resources management of basin (IWRM), and also in the direct contribution to the Sustainable Development Goals ("2.Food Security", "6.Water Resources" and 13.Fighting Climate Change".

KEY WORDS: *Water resources; climate change; hydro-climatology; Watershed; Modeling; Morocco.*

1. Introduction

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The Intergovernmental Panel on Climate Change (IPCC) estimated in 2001that most of the warming observed over the past 50 years is due greenhouse gases of human origin. According to the same source, the pursuit of these emissions without a serious reduction policy would increase global temperature by 1.4 to 5.8 ° C between 1990 and 2100, and the average sea level from 9 cm to 88 cm during the same period, and would continue to increase for centuries. The hydrological cycle will be intensified, causing more droughts in some regions and floods in others (Houghton, 2004, Le Treut et al., 2004).

Through its five reports, the IPCC has always sounded the alarm on global warming and its impact on climate change through the changes in temperature and precipitation patterns. (IPCC, 1990, IPCC, 1995, IPCC, 2001, IPCC, 2007). The report (IPCC, 2007) predicts, with a higher degree of confidence, a very likely increase in the frequency of extreme temperature events, heat waves and episodes of heavy precipitation. The report (IPCC, 2014) states, that in recent decades, changes have caused vulnerability and impacts on human and natural systems on all continents and across the oceans. An increase in high levels extreme seas and an increase in the number of intense precipitations events in many regions. Since the mid-1970s and early 1980s, Morocco has faced deterioration of its climatic conditions. Studies of the temporal evolution of the climate indicate a downward trend in precipitation. This trend is accompanied by an increases temperatures. It is thus noted at the national level a warming of 0.16 ° C per decade since 1960 concomitant with a drop in rainfall inputs. This drop is estimated at 15% from 1971 to 2000 according to (Benassi , 2001). In addition to the trend down in rainfall, the Moroccan climate is experiencing a significant increases drought episodes. The Bouregreg watershed, unlike the basins the adjoining one, is a space all the more fragile as it remains an area of cultivation rain-fed and extensive breeding, with a humid continental climate in winter and hot in summer. In recent years, reducing vulnerability to climate change has been has become a major imperative for developing countries. Indeed not only these countries lack the means to cope with the vagaries of the climate, but still their economies are generally highly dependent on climate sensitive sectors, adaptation policies are not intended to accept the inevitable, but to reduce the vulnerability of territories to the impacts of climate change and to put them in a position to take advantage of their beneficial effects. The identification of vulnerable areas provides a systematic justification for the targeting proactive measures to protect the environment and people vulnerable. So policy makers use indicators not only to understand vulnerability, but also for direct decision making (knowledge of the action).

2. Material and methods

In this article, we will study the impacts of climate change focusing on the parameters of precipitation and minimum and maximum temperatures as observation data. We will use and analyze the outputs of the general circulation (MCG or GCM) with finer spatial resolutions (~ 1km) for give some projections relating to the study area which is the khenifra region (Upstream Bouregreg Watershed) dominated by rain-fed and livestock cereal crops intensified. To whom we will study the impact of changes in precipitation and temperatures on the water resources of the Bouregreg basin.

2.1. Study area

The Bourereg watershed is located in north-western Morocco. It covers approximately 1000 km². It is characterized geo-morphologically by a drop altitudes from the East (Aguelmous) to the West from more than 1500m (Rabat-Sale) to 0 m at level of the Atlantic Ocean (Fig. 1). Hydro-logically, it is limited to the North and Northeast by the watershed of Beht wadi,

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tributary of the left bank of Sebou wadi, at South and South-East by that of Oued Grou, tributary of the great basin of Oued Bouregreg.

Fig. 1: Geographic position of the Oued Bouregreg watershed (Google Earth).

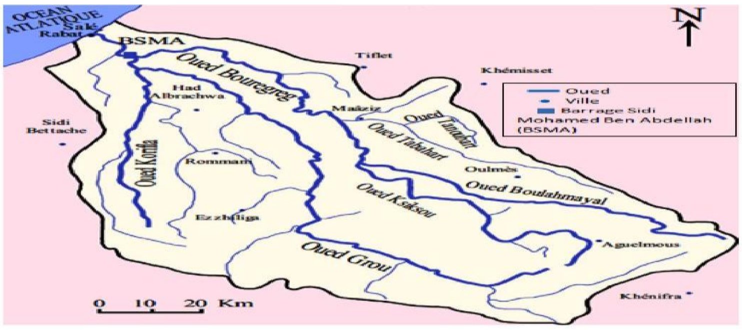

Figure III. 2 : Principaux Oueds du bassin versant du Bouregreg (Bounouira, 2007).

Fig. 2: Main wadis of the Bouregreg watershed (Bounouira, 2007)

2.2. Observation data

Fig. 3: Part of the SMBA dam reservoir where the Oued Bouregreg flows directly**.**

Rabat-Sale Coordinates:

Latitude : 34°03’00 N, Longitude : 06°45’00 W, Altitude : 74.715 M

2.2.1. Temperatures:

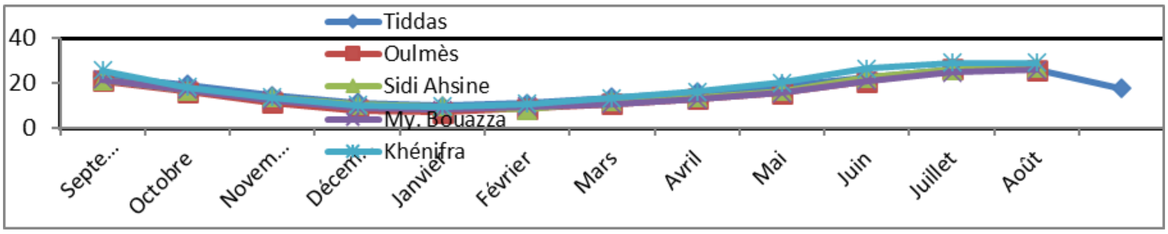

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Fig. 4: Evolution of Average Monthly Temperatures (Tmoy, Tmax and Tmin) Period (2003 to 2008), in Marchouch (INRA).

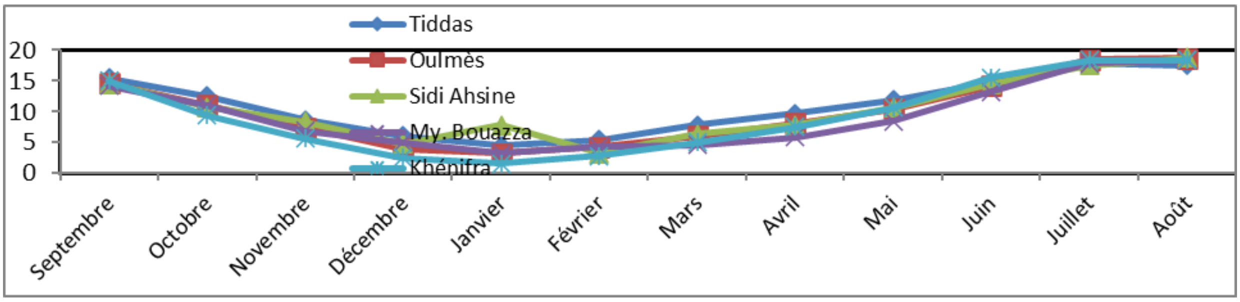

Fig. 5: Minimum monthly temperatures upstream of the Bouregreg watershed.

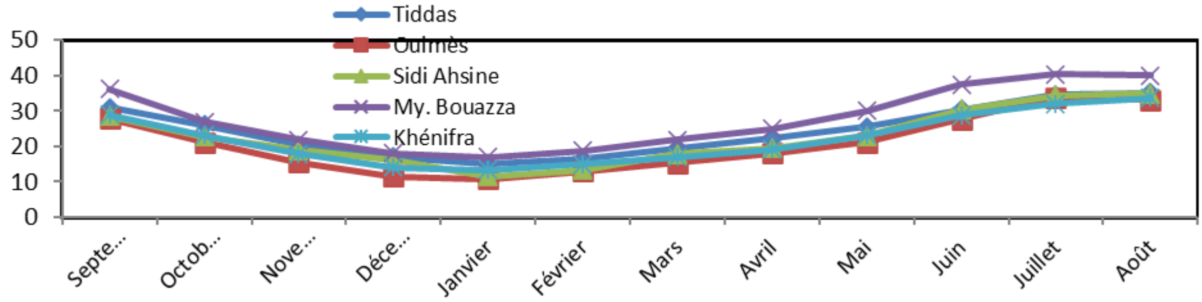

Fig. 6: Maximum monthly temperatures upstream of the Bouregreg watershed.

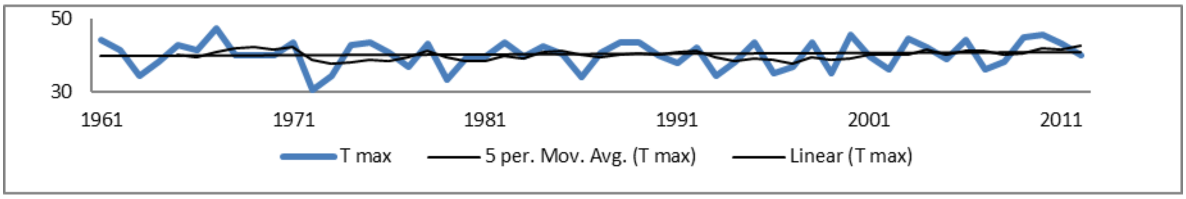

Fig. 7: Evolution of maximum annual temperatures (1961-2012) (Rabat-Sale)

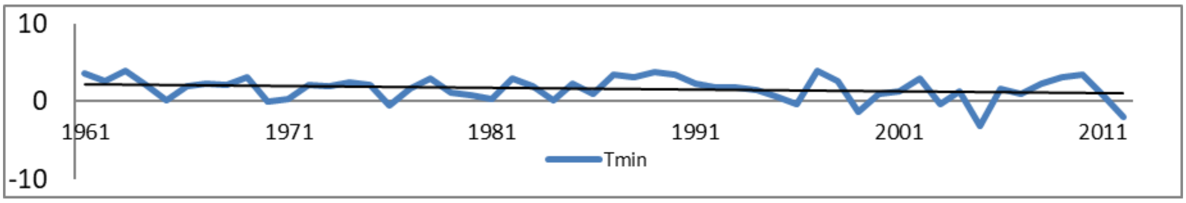

Fig. 8: Evolution of minimum annual temperatures (1961-2012) (Rabat-Sale)

2.2.1.1. Thermal regime

Minimum (m) and maximum (M) temperatures play an important role in the distribution spatial and vegetation growth. These two parameters allow control indirectly the level of evapotranspiration of plant species. The thermal amplitude determined according to the (DEBRACH system , 1953) is defined as the amplitude mean extreme thermal obtained by the difference between the mean temperature maximum (M) of hottest month and minimum average temperature of hottest month cold (m). It allows to characterize the continentality of

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the climate. The degree of continentality is expressed by (M-m) as the maximum annual amplitude. As for the type of climate, it is characterized by ((M + m) / 2) as the annual average temperature value. In se based on the values of the aforementioned indicators, it appears that the thermal regime at the level of the watershed is characterized for the most part by a semi-continental climate of the type moderate.

2.3. Rains

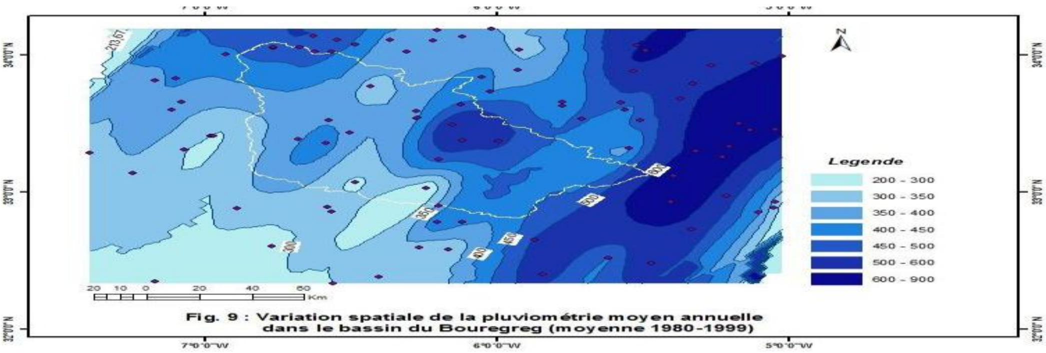

Fig. 9 Spatial variation of the average annual rainfall in the Bouregreg basin

(average from 1980 to 1999) (Source: National Meteorology Direction and FAO)

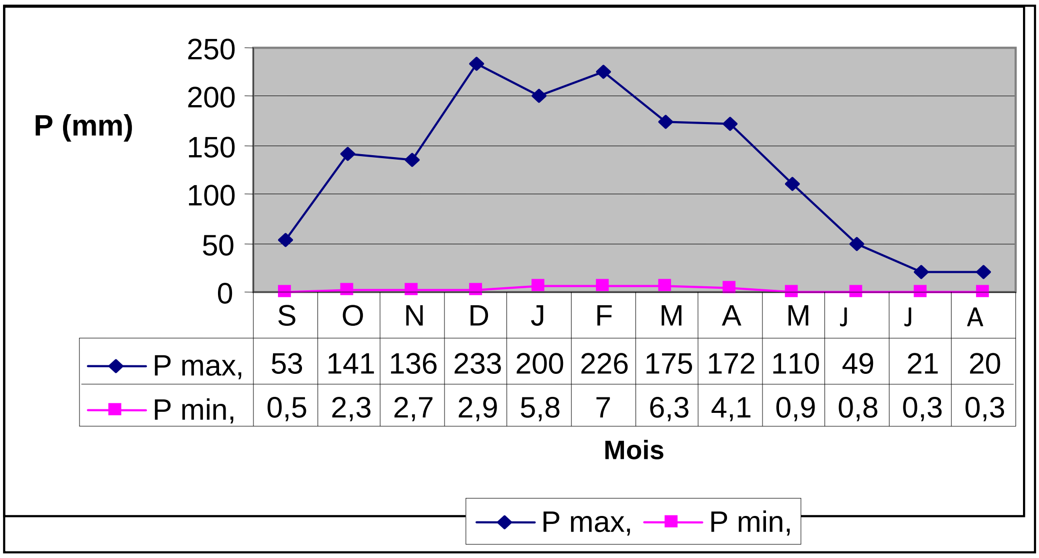

Fig. 10: Graphical representation of maximum mean monthly precipitation and minimum pelvis

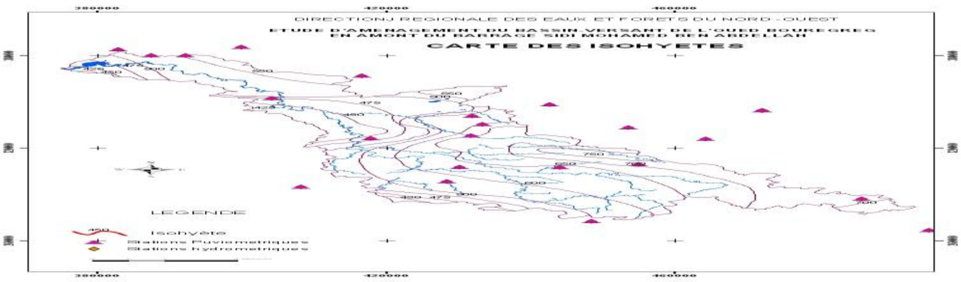

Fig. 11: Map of Isohyets.

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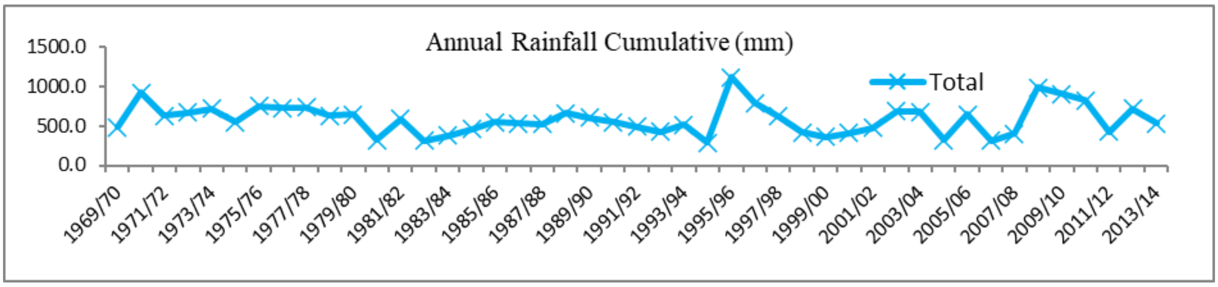

Fig. 12: Annual rain of Khenifra for the period (1969-70 to 2013-14)

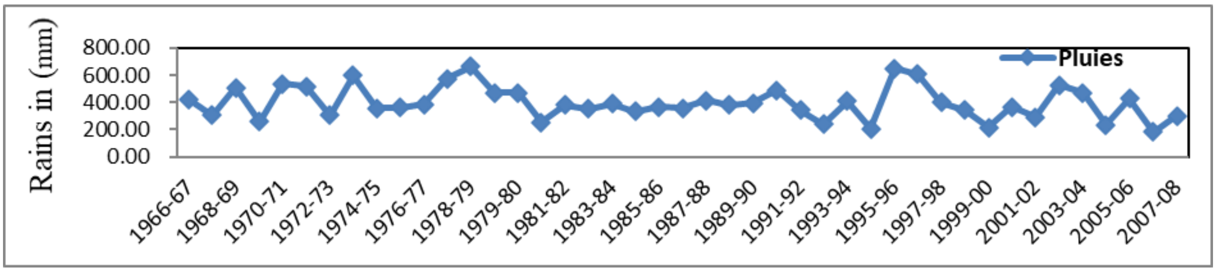

Fig. 13: Rainfall evolution at Marchouch (INRA), from the period

(1966-67 to 2007- 2008)

2.3.1. Rainfall description

The average annual rainfall in the region is 512.4 mm, this amount is distributed irregularly during the year, according to the ombro-thermal diagram, the season Wet extends from October to mid-April (Fig. 14).

-General character of the climate of the Rabat-Sale region

The climate in the region of Rabat- Sale is influenced by the proximity of the Atlantic Ocean and the Mediterranean, so the region knows a maritime climate with a cool and rainy winter and a been hot and dry. Winter precipitation is advective, mainly due at the passages of Atlantic disturbances generally coming from the North sector and the sector Where is. As for summer precipitation, it is due to convective situations caused by the infiltration of cold air at altitude associated with the Saharan thalweg bringing hot air from South. Even if the temperatures are generally mild and influenced by the ocean breeze from west during summer, the region sometimes experiences heat waves due to the phenomenon of chergui associated with the influence of the rise of the Saharan thermal depression, giving rise to a sudden increase in maximum temperatures above 40°C. The Martonne climate index and the Emberger quotient calculated over the period 1961-2012 places the region in the boundary between the sub-humid and semi-arid climatic stage.

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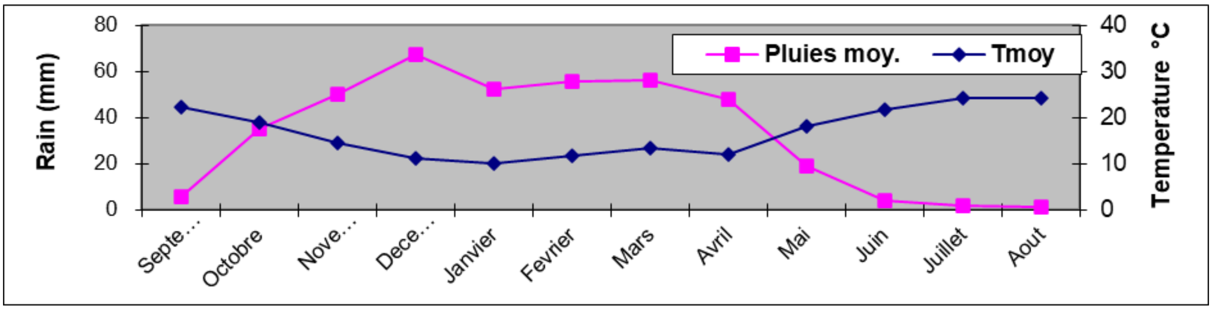

Fig. 14: Ombro-thermal diagram of the Marchouch Experimental Domain (INRA)

2.4. Ombro-thermic diagram:

According to the ombro-thermic diagrams of Bagnouls and Gaussen of the stations whose data are available, it turns out that the dry period is from June to September for all stations as shown in (Fig. 15 and 16). However for the Tiddas area, the dry period extends from the end of April to the month of October. As for the period rainy, it spreads from October to the end of May.

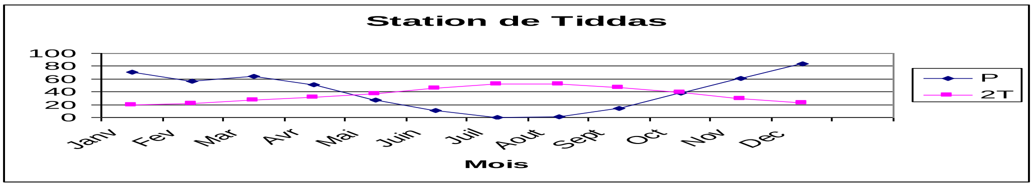

Fig. 15: Shadow curve of the Tiddas station

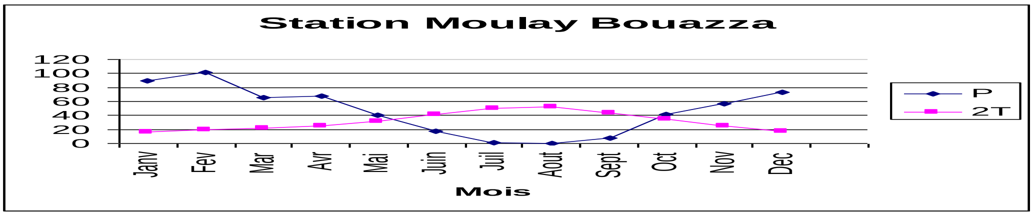

Fig. 16: Shadow curve of the Moulay Bouazza station

2.5. Other factors

2.5.1. Evaporation

Average evaporation in the region varies between 1500 and 1600mm /year. It increases considerably in summer and records the lowest values in February.

2.5.2. Snow cover

It is an important factor in restoring the water table and improving the water balance However, the absence of snow precipitations data does not allow to deepen the study on this phenomenon The snow period is between December and February without the layer of snow persists. This period also corresponds to the freezing period which extends until March However the station of Oulmes sometimes signals the presence of snow with a persistence of 10 days.

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2.5.3. Jellies

In winter, frosts are more frequent and the average number of frost days reported by the Oulmes station is 20 days a year.

2.5.4. The winds

In the study area, there are two types of winds: In summer, hot and dry winds (Chergui) In winter, the winds are cold and are responsible for the increased frost in the area and in particular the parts of the basin at high altitudes. The west winds dominate in this season. They are violent and, generally, charged with humidity, hence their influence significant on temperatures.

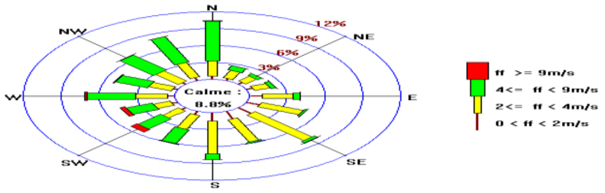

Fig. 17: Annual wind rose for period 2009-2013

2.6. Frequent weather phenomena

Among the most frequent phenomena in the region of Rabat (Fig. 18), we Benchmark:

2.6.1. Dew

With a normal of 63 days / year, the monthly maximum is 9.3 days in December. The annual maximum noted during the last thirty years was 175 days in 1993.

2.6.2. Fog

With an annual normal of 37 days, the month of March is the most exposed to this phenomenon with an average of 5.2 days / month. The annual maximum is 64 days recorded in the year 2000. The region is characterized by two types of fog: we record a dominance of cooling fog in autumn and evaporative fog in spring.

2.6.3. The Storm

With an average of 13.1 days / year. December is the month when the event thunderstorm is maximum with a normal of 1.7 days.

2.6.4. The Chergui

With an average of 26.2 days / year.

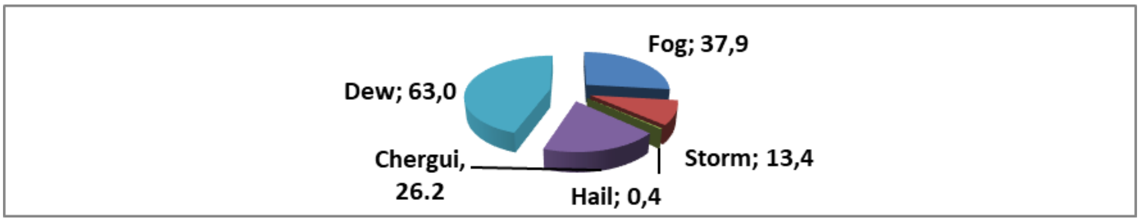

Fig. 18: Annual number of days of the most important meteorological phenomena from

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The Rabat- region.

2.7. Flow:

2.7.1. Average annual Flows

The same observations and deductions made about the average annual contributions apply to average annual flows recorded at hydrometric stations located inside the pool. The lowest average flow is observed at level of the hydrometric station of Sidi Amar which covers the sub-catchment area n°5. The under watershed n°1 corresponding to the upstream part of the basin also has a flow lesser annual means (1.7 m3 / s).

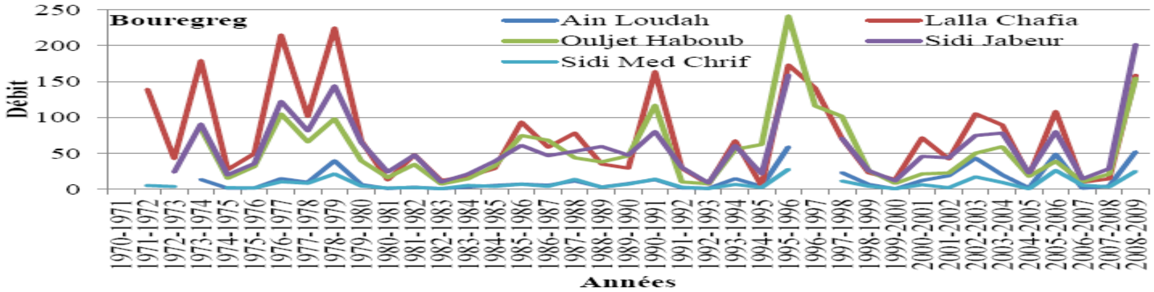

Fig. 19: Evolution of the Flow Series in the Bouregreg Watershed (m3/s).

2.8. Hydrological balance

In the absence of availability of the data necessary for calculating the hydrological balance, we will therefore limit only to the calculation of the average flow deficit at the level of the catchment area. This deficit (D) represents the losses due to evaporation and evapotranspiration from the catchment area, infiltration and water collected for irrigation. It is expressed by the difference between the actual contributions of precipitation and the runoff.

D = AP - LE

AP : apport des précipitations

LE : lame d'eau écoulée à l'exutoire

Precipitation inputs are estimated using weighted average precipitation sub watersheds. As for the average annual volume recorded at the level of withholding dam, it is estimated from the blade of water flowing out of the watershed outlet, i.e. at the SMBA dam (Table 3).

So :

AP = 2206.5 M m3

LE = runoff water layer / year * basin area

LE = 77mm * 395,600 ha = 0.077m * (395,600 * 10,000 m2) = 304.7 Mm3

Consequently :

D = 2206.5 - 304.7 = 1901.8 M m3

This result shows that the flow deficit in the watershed is around 86%.

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2.9. Characteristics of Bouregreg Watershed Floods

The flooding of a watercourse is a natural phenomenon when the rain is sustained and widespread in pelvis level. Nowadays, this phenomenon is becoming very rare and we are witnessing intense floods and amplified. Climate change and anthropogenic action are among the main factors that contribute to the appearance and amplification of floods. Stormy precipitation, degradation of natural vegetation cover and inappropriate use of sloping land are phenomena and actions that contribute to the appearance and accentuation of floods. The river basin of the wadi Bouregreg hardly escapes its facts and manifestations in addition to its hydrogeological context unfavorable consisting essentially of impermeable geological formations. Hydrographs floods adopted at the SMBA and Tiddas dam sites for the return periods T = 2 years to CMP are illustrated by (Fig. 20). Generally, between the start of the rain, and the start of the flood, there is a delay of the order of a few hours. This is explained on the one hand by the initial losses due to infiltration and interception, and on the other hand by the time of transport of the first rainwater. Thereafter the flow evolves until reaching its maximum (peak flow), then begin to decline. Then the slope of the curve recession is softer. This spreading confirms that the very elongated pelvis (Cf. Gravelius of the pelvis). The last phase of the response can take several days. It's about the return to a steady state after the disturbance due to the flood. During this phase, the flow gradually regains its normal value.

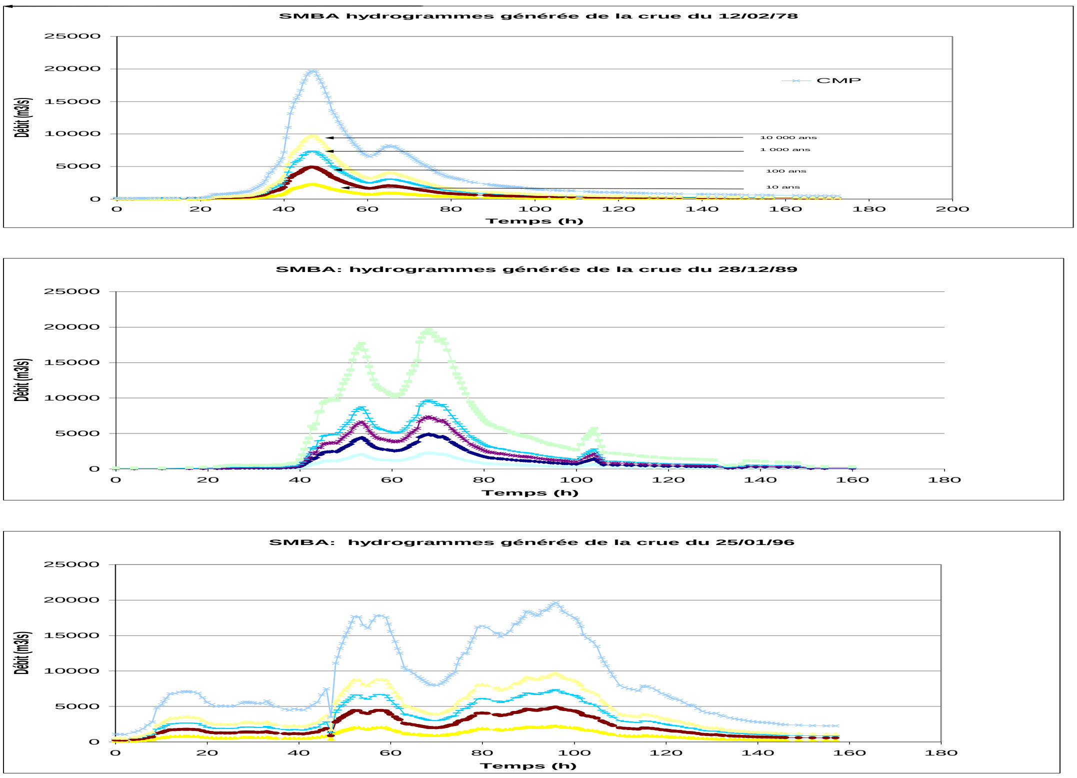

Fig. 20: Hydrograph of the floods observed at the SMBA dam (Source: DRPE)

2.10. Design of the Environmental Vulnerability Index (EVI)

2.10.1. The choice of EVI

The choice of EVI is based on the main results of the IPCC concerning the vulnerability which is geographically and socially differentiated. Any evaluation at national level must take into account regional patterns of vulnerability in the country. And the distribution of vulnerability within the national community. There is a tension inevitable that vulnerability is

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best defined in a timely manner, at a particular location in space or community, and any aggregation at the national level can result in loss of information.

The indicators chosen for use in the EVI are based on the best scientific knowledge currently available and was developed in consultation with international experts, national experts, other organizations and interest groups. The **indicators** are classified into **5 categories** (Kaly et al, 2000).

- Meteorological and Climate

- Geological

- Geographic

- Characteristics of the study area: Resources and Services

- Anthropic

***** Vulnerability, climate change and development links (IPCC, 2007b).

* Vulnerability to climate change can be exacerbated by the presence of other factors

Tensions

* Non-climate related constraints can increase vulnerability to climate change by weakening resilience and can also reduce adaptive capacity due to resources deployed to meet competing needs. Vulnerable regions suffer multiple constraints that have a negative effect on their vulnerability, sensitivity and ability adaptation. These constraints are due to various factors, including climatic hazards, poverty, difficult access to resources, food insecurity, globalization of the economy, conflicts, and the consequences of disease.

* In the future, vulnerability will not only depend on climate change, but also on development paths.

* Studies show that projections of the impacts of climate change can strongly vary according to the mode of development envisaged. For example, alternative scenarios may show considerable differences in population, income and development of a region, factors often determining the level of vulnerability to climate change.

* Sustainable development can reduce vulnerability to climate change.

* By strengthening adaptive capacity and resilience. However, at present there is little or no sustainable development programs that explicitly include adaptation to the effects of climate change or that promote adaptive capacity.

Table 1: Watershed Bioclimat

Station	**Max (°C)**	**Min (°C)**	**Q2**	**Bioclimat**
Rabat	28.4	8.1	83.99	Heat subhumid

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Rommani	36.0	4.0	37.82	Temperate semi arid
Oulmès	33.8	3.2	69.49	Temperate subhumid
Khénifra	40.3	1.2	55.0	Fresh semi arid
Tiflet	35.8	5.6	56.4	Temperate semi arid
My Bouazza	33.7	3.2	67.5	Temperate subhumid
Sidi Ahsine	35	3.2	79.6	Temperate subhumid
Tiddas	35.1	4.5	53.4	Temperate semi arid
Khémisset	36	5	62,0	Temperate subhumid
Timeksaouine	34	4	64.2	Temperate subhumid

2.11. Modelization

2.11.1. MCG model data

2.11.1.1. HadCM3 model (SRES scenarios)

The HadCM3 model (Hadley Center Model 3, British Meteorological Service) of the site www.worldclim.org/futurdown.htm and extract them by ArcGis software for viewing and display, then compare them with the current monthly climate data for the year (2007-2008) for the Marchouch experimental site, INRA. And also for the future projection periods 2050 (2041-2060) and 2070 (2061-2080) of CNRM-CM5 model (CMIP5) for RCPs scenarios (2.6, 4.5 and 8.5). Using ArcGis software to visualize and extract data in values and compare them and analyze to those of the base period.

-Scenarios (SRES), Scenario B2:

This is an optimistic scenario that describes a world where the focus is on solutions local, in a sense of economic, social and environmental sustainability. The world's population is growing steadily but at a slower rate than in A2. There are intermediate levels of economic development and evolution Technological is slower and more diverse. In our research, we have opted for scenarios A2 and B2, these two scenarios are the closest to the trajectory of the evolution of Moroccan society and changes associated with climate indicators (Gommes et al., 2008). They are widely used today in the works of modeling carried out with the most complete coupled models.

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2.11.1.2. CNRM-CM5 model (RCPs scenarios)

The new version of the CNRM-CM global circulation model was developed by CNRM-GAME (National Center for Meteorological Research-Study Group of Meteorological Atmosphere) and Cerfacs (European Center for Research and Training Advanced) in order to contribute to phase 5 of the inter-comparison project of the Coupled Model (CMIP5). The proposal of the study is to describe its main characteristics, a assessment of the preliminary demand for the average climate. CNRM-CM5.1 included model atmospheric ARPEGE-climat (v5.2), the Ocean NEMO model (v3.2), the surface of the earth ISBA scheme and the GELATO sea ice model (v5) coupled through the OASIS system (v3).

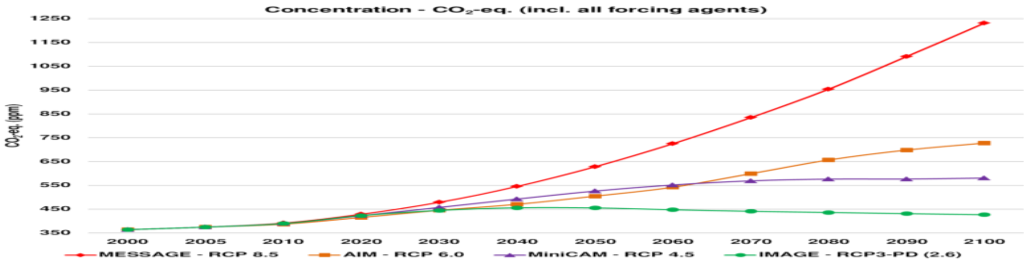

Fig. 21: CO2 concentration with all forcing agents

2.11.2. Scale reduction

For simulations at a regional level, we use a "downscale" method (Fig. 22) using the development of regional models, with resolutions of 10 to 50 km which take into account local impact or adaptation models, horizontal resolution of the order of a kilometer.

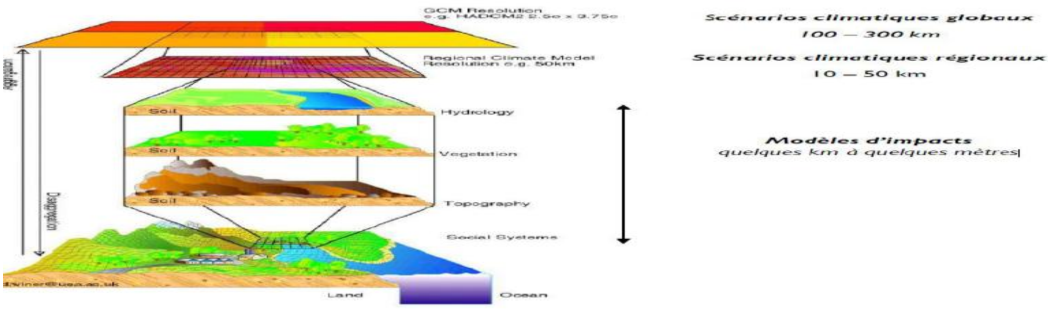

Fig. 22: Scales of the different scenarios and models used in downscaling (after S. Planton).

3. Results

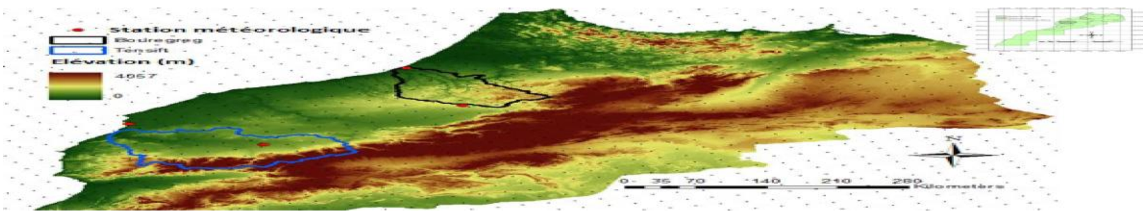

Fig. 23: Grid of regional climate models (Black dots)

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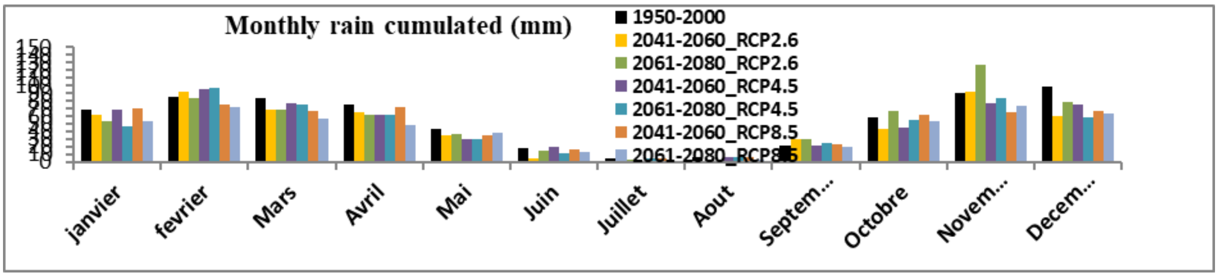

Fig. 24: Monthly rains in Tarhat (Khenifra region) for the past period (1950-2000) and The Future periods (2041-2060) and (2061-2080) for the RCPs (2.6, 4.5 and 8.5)

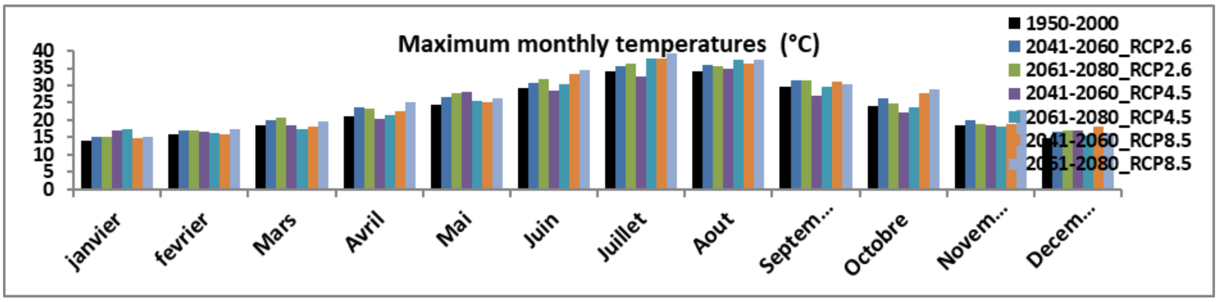

Fig. 25: Maximum monthly temperatures in Tarhat (Khenifra region) for the period past (1950-2000) and future periods (2041-2060) and (2061-2080) for RCPs (2.6, 4.5 and 8.5)

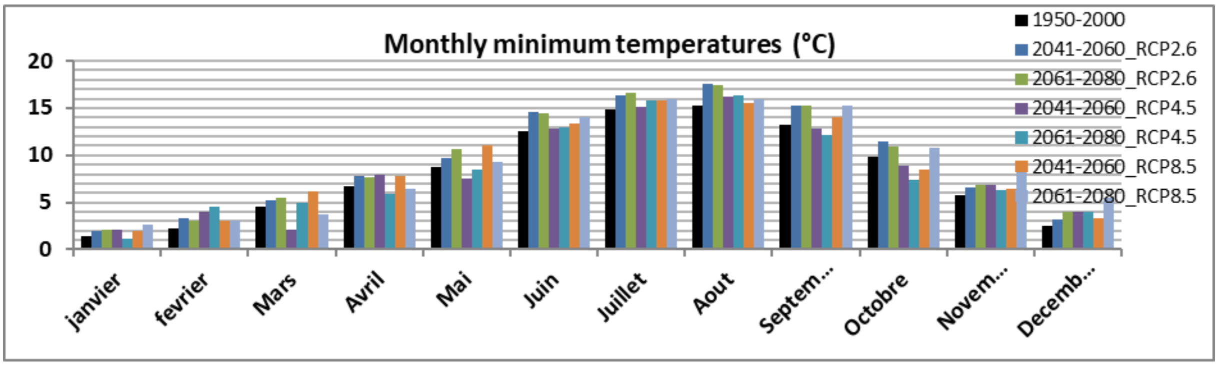

Fig. 26: Monthly minimum temperatures in Tarhat (Khenifra region) for the period past (1950-2000) and Future periods (2041-2060) and (2061-2080) for RCPs (2.6, 4.5 et 8.5)

3.1. Climate in the future according to scenario B2

-Maximum Temperatures

Table 2: Comparison between the current maximum temperatures of the campaign (2008-09) and future of the year (2030) for Domaine Exp. Marchouch, INRA

	Present	Future
	2008-2009	2030
Months	**T max**	**T max**

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September	28,22	28,40
October	22,44	22,80
November	17,67	16,30
December	15,25	13,10
January	14,33	15,30
Febrary	17,54	17,10
March	20,59	19,40
April	20,26	20,50
May	26,26	26,90
June	30,86	30,70
Juilly	29,22	34,60
August	31,44	33,50
Average/year	22,84	23,22

-Minimum Temperatures

Table 3: Comparison between current minimum campaign temperatures (2008-09) and future of the year (2030) for Domaine Exp. Marchouch, INRA

	Present	Future
	2008-2009	2030
Months	**T min**	**T min**
September	15,70	16,60
October	12,10	13,30
November	7,60	9,50
Décember	6,40	6,80
January	5,90	5,20
Febrary	7,40	6,20
March	9,80	7,40
April	7,00	9,30

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May	11,70	12,30
June	16,10	15,90
Juilly	15,40	17,60
August	16,20	17,90
Average/year	10,94	11,50

-Precipitation

Table 4: Comparison between the current rains of the campaign (2007-08) and the future of the year (2030) of the Marchouch Experimental Domain, INRA

	Present	Future
Months	**Rain**	**Rain**
	2007-2008	2030
September	1,40	7
October	15,94	10
November	67,52	17
December	14,85	8
January	52,87	2
Febrary	45,44	2
March	13,07	3
April	44,74	2
May	45,25	2
June	0,00	0
Juilly	0,00	1
August	0,00	3
Cumulated/year	301	57

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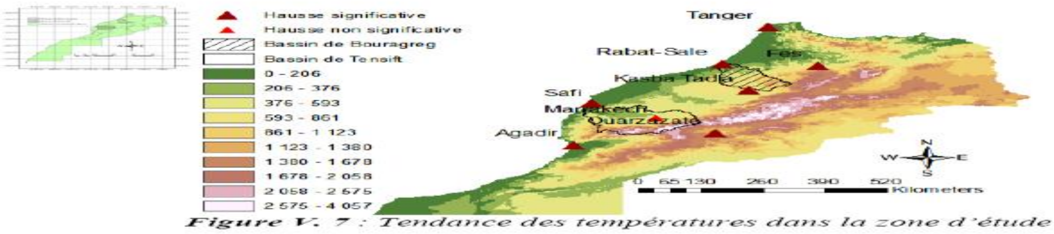

Fig. 27: Trend of temperatures in the study area

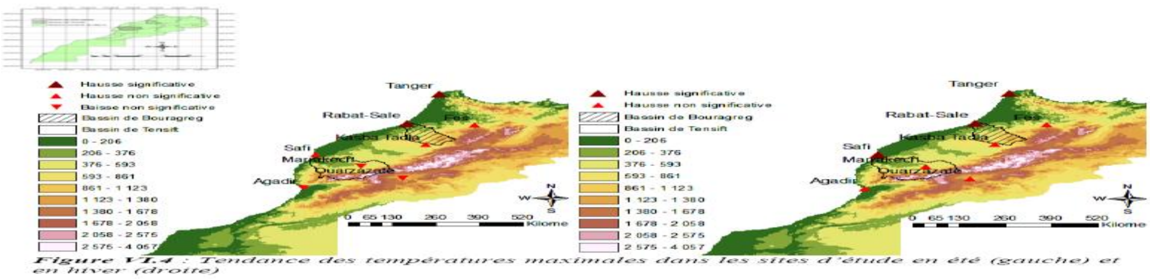

Fig. 28: Trend in maximum temperatures at study sites in summer (left)

and in winter (right)

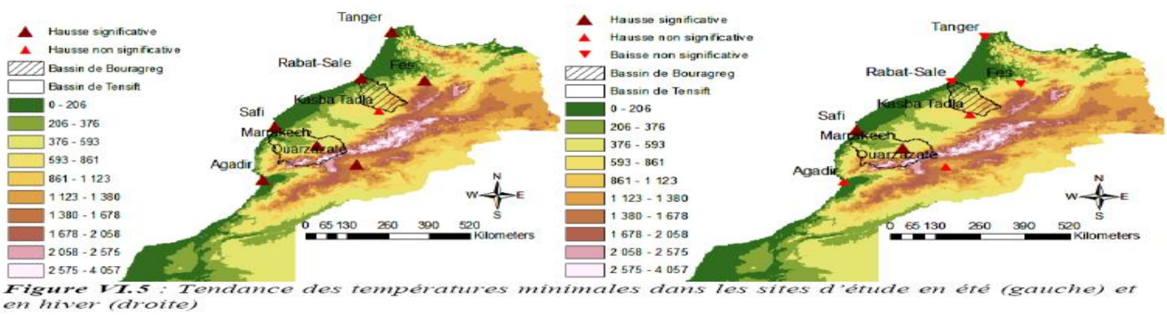

Fig. 29: Trend in minimum temperatures at study sites in summer (left) and winter (right)

4. Discussion

Influence on the Spatio-Temporal distribution of precipitation. The system of government of the entire Bouregreg basin is characterized by a very large inter-annual variability marked by the alternation of wet and dry sequences, interspersed with years of high hydraulicity or severe drought. The Bouregreg basin is experiencing a water deficit of (8%), and it is expected to also have it in 2020.This situation risk of deteriorating as a result of climate change and worsening extreme phenomena, in particular the significant reduction in rainfall and widespread droughts. Indeed, despite the favorable rainfall of the latter two years, the threat of drought still hangs over the country like the periods, 1980-1985, 1990-1995, 1998-2002, (2012 and 2016 years of severe drought over a period of 30 years), and during which almost all of the watersheds were in deficit in water supplies and for the Bouregreg watershed (-70%, - 70%, - 74%).

5. Conclusion

According to the RCPs scenarios (2.6; 4.5 and 8.5), the study area will become more arid in the future which will have direct and negative effects on crops and especially grain yields, and also on water resources. This is consistent with the results obtained in the "WB / FAO / INRA / DMN" report prepared by the Bank study on Morocco World (Gommes et al., 2009). Projections for 2030 forecast a warming from 0.8 to 1.3°C on an annual scale, accompanied by a slight increase the number of days of summer heat waves. Annual rainfall totals are assumed to decrease by 6 to 20%, those in winter from 15 to 35%. (Source: Integration Project of Climate Change in the implementation of the Green Morocco Plan).

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