Impact of Climate Change on Water Resources in Morocco Case of the Bouregreg Watershed

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Abstract: ***The hydrological regime of all the basins is characterized by a inter-annual variability marked by the alternation of the wet and dry episodes, intercalated by years of high hydraulic or severe drought. Most hydraulic basins faced water deficits. This situation is likely to deteriorate as a result of climate change and extreme events, particularly the reduction in rainfall and generalized drought. The threat of drought still occurs over the country, as in the periods of 1980-1985 and 1990-1995 and 1998-2002, during which almost all the watersheds faced a water deficit leading to the overexploitation of groundwater. The aim of this work is to describe the meteorological conditions of the watershed of Bouregreg in order to characterize the effect of climate variability on water resources. This study allowed us to quantify the relationship between climate and surface water resources, through statistical analysis of climate parameters and climate projections. The result of this work will contribute to better understand water management resources, in order to develop mitigation strategies to reduce climate risks effects.***

Keywords: Water resources, climate change, Watershed, Modeling, Morocco

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) estimated in 2001 that most of the warming observed over the past 50 years is due to human-caused greenhouse gases. According to the same source, the continuation of these emissions without a serious reduction policy would increase the global temperature from 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, resulting in more droughts in some areas and flooding in others (Houghton, 2004; Le Treut et al., 2004).

Through its five reports, the IPCC has always sounded the alarm over global warming and its impact on climate disruption through changes in temperature and precipitation patterns. (IPCC,1990,1995, 2001, 2007). The report (IPCC, 2007) forecasts, with a higher degree of confidence, a very probable increase in the frequency of extreme events of temperature, heat waves and episodes of heavy precipitation. His latest report (IPCC, 2014) states that in recent decades climate change has caused vulnerability and impacts on human and natural systems on all continents and across the oceans. And quotes also that changes in weather extremes and climatic events have been observed since 1950. Some of these changes have been linked to human influences, including a decrease in extreme cold temperatures, an increase in extreme hot temperatures, Extreme high seas and an increase in the number of intense rainfall events in many areas. IPCC's statements about the extreme temperature and precipitation events have made the study of global and regional changes in these areas a focus of recent scientific research.

The Middle East and North Africa (MENA) region suffers the most from the world's water shortage: worldwide, the average amount of water available is close to 7,000 m^3 per person per year; In this region, it is only about 1,200 m3 per person per year. Half of its population is in a situation of water stress and, given the projected population growth (from some 300 million people today, this population is expected to reach about 500 million by 2025), it is expected That the amount of water available per capita is halved by 2050. By taking into account only renewable reserves corresponding to surface runoff and renewable water, it appears that by 1990 six countries were already facing shortages: Malta, occupied Palestine, Egypt, Libya, Tunisia and Algeria (Table 1). A projection over the year 2025, taking into account the average population growth rates and the resulting consumption changes, suggests a marked deterioration of the situation in these same countries but also of strong tensions on the rest of the southern shore, Cyprus , Syria, Lebanon and Morocco.

Table 1 : Water resources per habitant (d'après J. Margat, Plan bleu)

Contry	Resources *per capita* (m^3/year) in 1990	Resources *per capita* (m^3/year) in 2025
Libya	230	65
Malta	200	152
Occupied Palestine	371	230
Tunisia	490	240
Algeria	545	265
Morocco	1460	545
Syria	2963	625
Egypt	1078	640
Lebanon	1380	860
Cyprus	1286	1000
Spain	1909	1515
Turkey	5000	2210
Italy	3262	3200
Albania	15385	3500
France	5827	5400
Greece	5836	5430
Ex-Yugoslavia	28700	24200

Since the mid-1970s and early 1980s, Morocco has faced a deterioration in its climatic conditions. Studies of the temporal evolution of the climate indicate a decreasing trend of precipitation. This trend is accompanied by rising temperatures. It is noted at the national level a warming of 0.16 ° C per decade since 1960 in conjunction with a decrease in rainfall amounts.

Cette baisse est estimée à 15% de 1971 à 2000 selon Benassi (2001). En plus de la tendance baissière de la pluviométrie, le climat marocain connaît une augmentation importante d'épisodes de sécheresses. L'analyse de la dynamique temporelle de la sécheresse agricole indique que le Royaume est passé de 5 années de sécheresse sur 40 de 1940 à 1979 à 6 années sur 16 de 1980 à 1995, puis à 4 années sur 7 entre 1996 et 2002 (Barakat et Handoufe, 1998). La conséquence spatiale de cette évolution temporelle des conditions climatiques est qu'en

Parallel to this dynamic, there is an important agro-pastoral pressure on the wetlands, namely the semi-arid regions such as the Bouregreg watershed. This basin, unlike the neighboring basins, is a space that is all the more fragile because it remains an area of rainfall cultivation and extensive breeding.

The rural population estimated at 1.8 million inhabitants according to the 2004 census, constitutes the majority of the population of the territories of the provinces of Khenifra, Khouribga, Khemisset and Ben Slimane located in the area of action of the Agency ABHBC. This zone, which remains the most watered at the scale of the Agency's action zone, receiving nearly 500 mm of rain per year, enjoys a humid continental climate in winter and warm in summer. The geographic ensemble constitutes the zone of runoff by Excellence with regard to the geological nature and the hilly topography of the outcrops. However, its subsoil is devoid of potential groundwater resources.

The development of this area is highly contrasted by the absence of natural resources. This area contains a rural majority population whose main economic activity has returned to pastoral and farming.

In this article, we will study the impacts of climate change focusing on precipitation parameters and minimum and maximum temperatures as observational data. We will use and analyze the outputs of the general circulation models (GCMs) with finer spatial resolutions (~ 1km) to give some projections relative to the study area which is the khenifra region (Upstream of the Bouregreg) dominated by rainfall cereal crops and intensified farming. We will study the impact of changes in precipitation and temperature on the water resources of the Bouregreg basin.

2. Material and Methods

2.1. Study Zone

The Bourereg watershed is located in north-central Morocco. It covers an area of about 1000 km². It is characterized at the geomorphology level by a decline of the altitudes of the East (Aguelmous) towards the West of more than 1500m (Rabat-Sale) at 0m at the level of the Atlantic Ocean (Picture n ° 1). This basin consists of impermeable formations of primary age. This makes it a disadvantaged area for groundwater and consequently for agricultural irrigation. Thus agricultural activity dominated by cereals is mainly rainfall and subject to climatic variations.

Figure 1: Geographical position of the Oued Bouregreg watershed (Google Earth)

It is located in the South East of the city of Rabat and extends to the chain of the Middle Atlas. This mountain range gives it a diversified relief, and important water potential consisting essentially of runoff or surface water. Hydrology, it is limited to the North and to the Northeast by the watershed of Oued Beht, a tributary of the left bank of the Oued Sebou, to the South and to the South-East by that of the Oued Grou, tributary of Large basin of the Oued Bouregreg.

The Bouregreg watershed is part of the large basin upstream of the Sidi Mohammed Ben Abdellah dam, which is limited to the north and northeast by the Sebou basin and to the south and south-east by that of Oum Er-Rbie. Geographically, the catchment basin, elongated in direction SE-NW, is between the 33 °: 03 'and 34 °: 06' North and meridian 05 °: 31 'and 06 °: 43' (Figure 1).

Figure 2: Map of Administrative Boundaries

2.2 Observation Data

Figure 3: Geographical situation of the Bouregreg Watershed (El Agbani et al 1992)

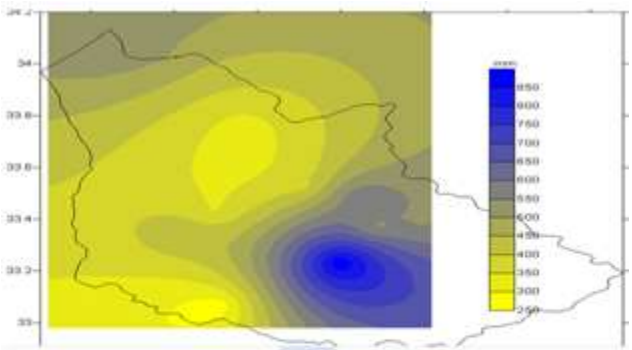

Figure 4: Spatial distribution of annual precipitation over the Bouregreg watershed (Source: Sigmed)

2.2.1. Upstream of the Basin:

Tarhat (Khenifra region)

Geographic coordinates : Latitude : 32,99 N

Longitude : -5,643 W

Altitude : 1036 m.

Figure 5: Vue de Jbel Mzourgane du point culminant le plus élevé du bassin

-Temperatures

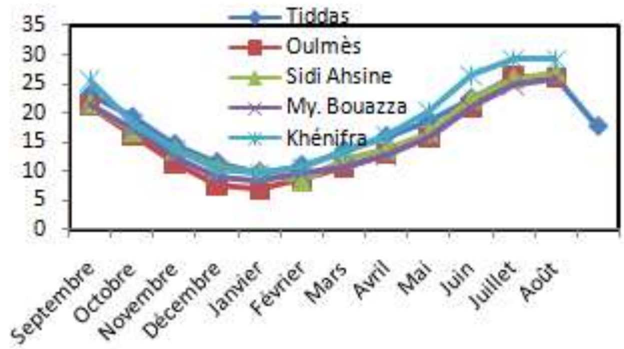

Figure 6: Mean monthly temperatures upstream of the Bouregreg watershed.

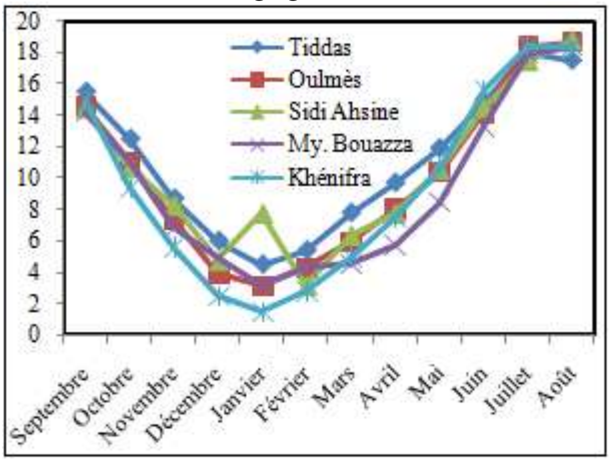

Figure 7: Monthly minimum temperatures upstream of the Bouregreg watershed.

However, the mean of the minima reached 3.2 ° C at Oulmès,, Sidi Ahsine et Moulay Bouazza And less than 2 ° C in Khénifra for the coldest month. It is 4.5 ° C in Tiddas

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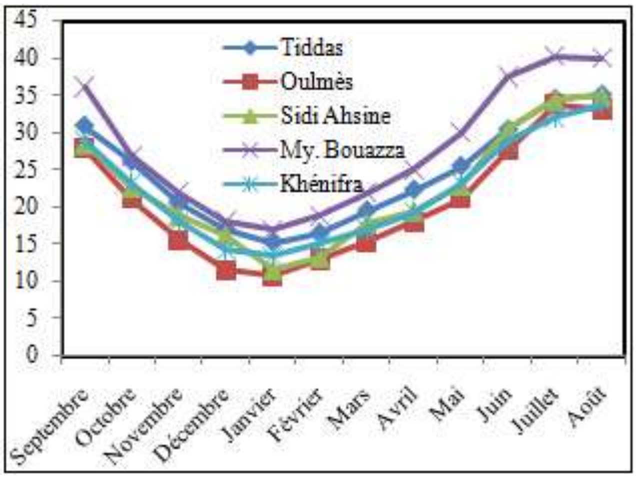

Figure 8: Maximum monthly temperatures upstream of the Bouregreg watershed.

The maximum values for the warmest months are recorded in June, July and August and reach between 30 and 40 ° C.

- Thermal regime

Minimum (m) and maximum (M) temperatures play an important role in the spatial distribution and growth of vegetation. These two parameters indirectly control the level of evapo-transpiration of plant species. The thermal amplitude determined according to the DEBRACH system (1953) is defined as the average extreme thermal amplitude obtained by the difference between the maximum mean temperature (M) of the hottest month and the minimum average temperature of the coldest month M). It makes it possible to characterize the continental climate. The thermal amplitude is determined according to the DEBRACH system (1953). The extreme thermal amplitude obtained by the difference between the maximum mean temperature (M) and the minimum temperature of the coldest month. It makes it possible to characterize the continental climate.

Based on the values of the aforementioned indicators, it appears that the thermal regime at the level of the catchment basin is characterized by a moderate semi-continental climate.

-Rains

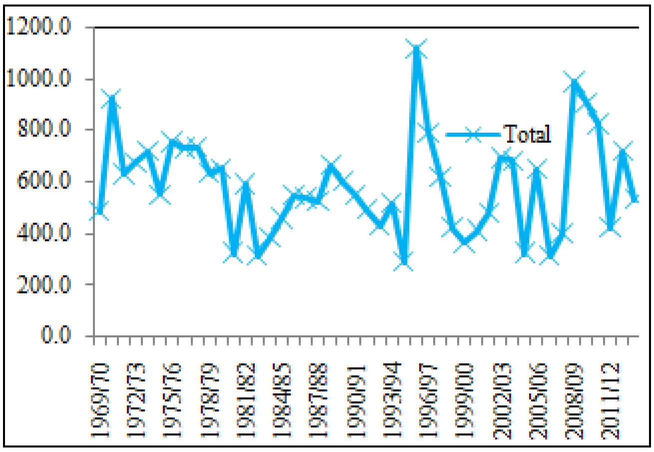

Figure 9: Annual rain of Khenifra for the period (1969-70 to 2013-14).

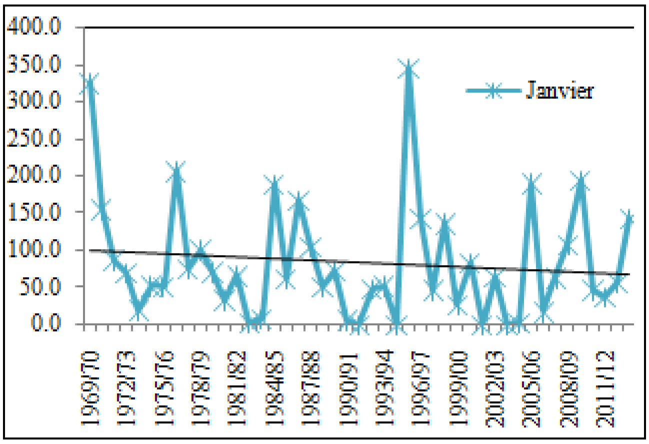

Figure 10: Rain of January of Khenifra for the period (1969-70 to 2013-14).

- Flow rates

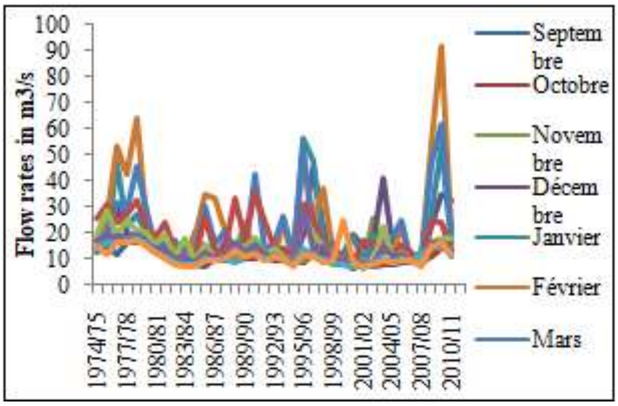

Figure 11: Monthly flows of Tarhat (khenifra region) for the period (1974/75 to 2010/2011

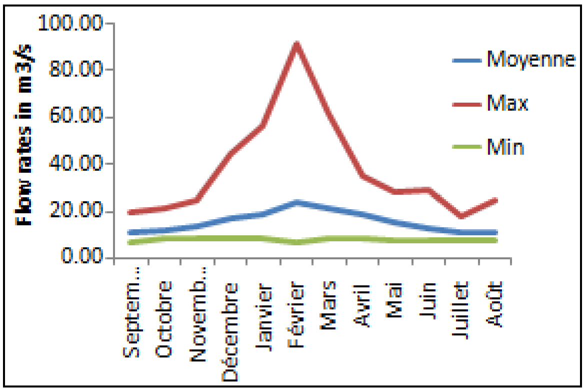

Figure 12: Monthly flows (Average, Max and Min) of Tarhat (Khenifra region) for the period (1974/75 à 2010/2011)

2.2.2. Basin Centre :

<u>Marchouch (Rommani), Rabat-region</u>

Geographical coordinates: Latitude : 33°60’41 N

Longitude : 6°71’60 W

Altitude : 339 M

Figure 13: Overview of the topography and landscape of centre Bouregreg

-Rains:

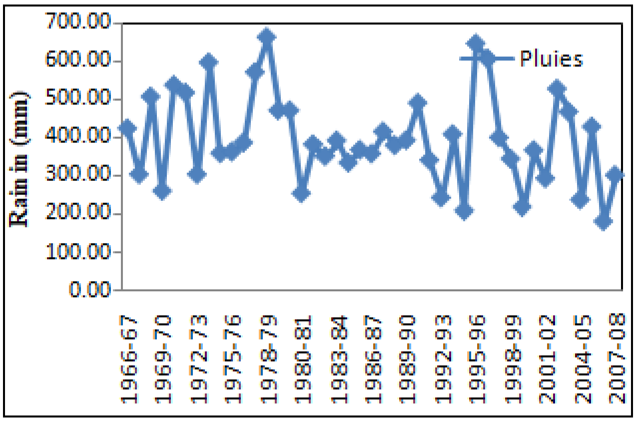

Figure 14: Evolution of rainfall in Marchouch (INRA), of the period (1966 - 67 to 2007 - 2008).

-Temperatures

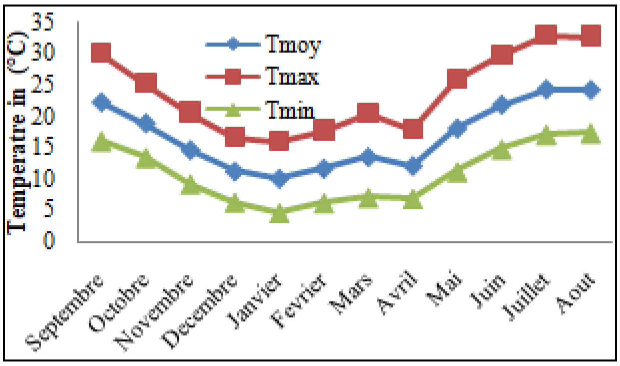

Figure 15: Evolution of Mean Monthly Temperatures moy, Tmax and Tmin) For the period (2003 to 2008), in Marchouch (INRA)

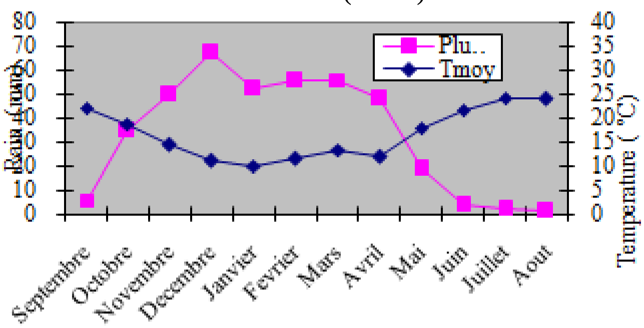

Figure 16: Ombrothermal diagram of the Experimental Domain of Marchouch (INRA).

2.2.3. Basin Aval:

Rabat-Sale and Shouls (Sale - region)

Coordinates : Latitude : 34°03'00 N
Longitude : 06°45'00 W
Altitude : 74.715 M

Figure 17: Settlement of degraded Thuja in the Shoul region (SBV)

Rains

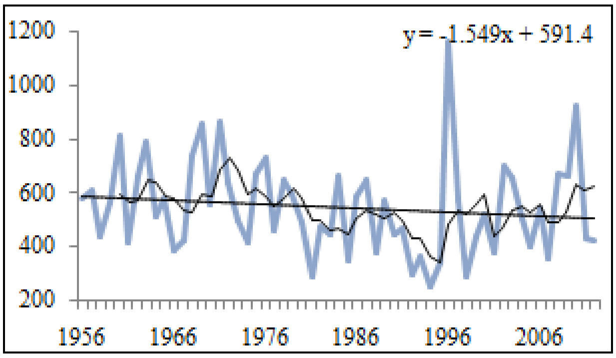

Figure 18: Evolution of annual cumulative precipitation over the period (1956-2012) (Rabat-Salé).

Temperatures

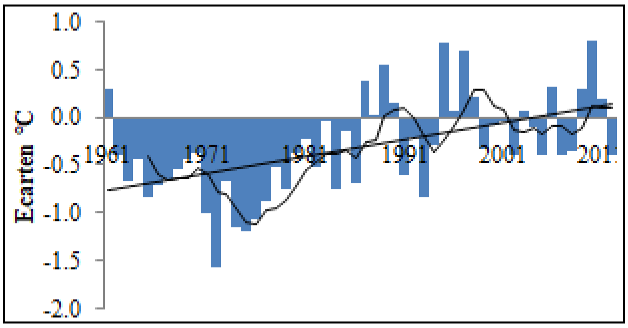

Figure 19: Evolution of the annual mean temperature deviation from normal (1961-2012) (Rabat- Salé)

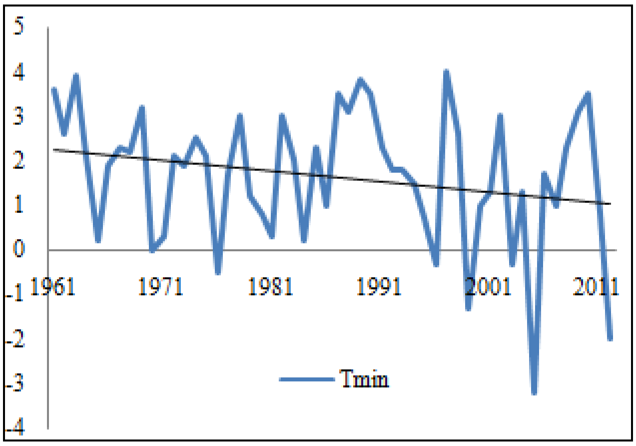

Figure 20: Evolution of annual minimum temperatures (1961-2012) (Rabat-Salé).

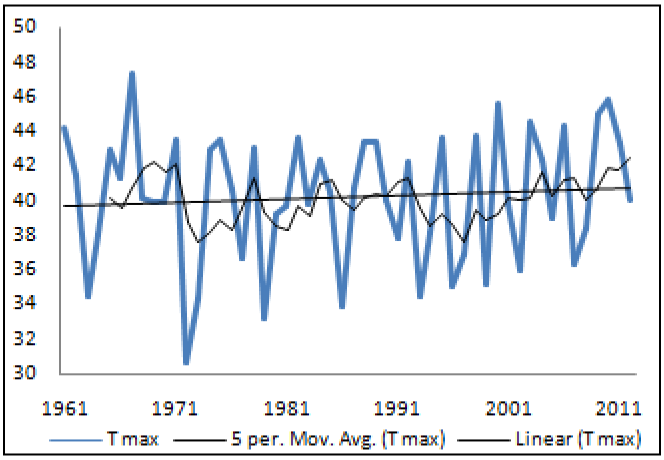

Figure 21: Evolution of annual maximum temperatures (1961-2012) (Rabat-Salé)

Figure 22: Part of the reservoir of the SMBA dam where Oued Bouregreg.

- BIOCLIMATIC SYNTHESIS
- Emberger.Q2 Pluvio-thermal quotient

Emberger's quotient makes it possible to characterize the Mediterranean climate from an ecological point of view (Sauvage C.H., 1963). This quotient is defined as follows:
Q2= 1000P/ ((M+m)*(M-m)/2)

P: average annual precipitation (mm)
M: Average daily maximum of the hottest month (degree Kelvin)
M (° K) = t ° C + 272.6
M: Average of daily minimums of the coldest month (degree kelvin)
M (° K) = t ° C + 272.6

This quotient makes it possible to distinguish a variety of bioclimatic stages prevailing in the catchment area. These bioclimatic stages vary from semi-arid to sub-humid with fresh to hot variants. The main bioclimates encountered in the basin are described in Tab. N ° 2.

Table 2: Bioclimate of the watershed

Station	Max (°C)	min (°C)	Q2	Bioclimate
Rabat	28.4	8.1	83.99	Hot subhumid.
Rommani	36.0	4.0	37.82	Semi arid temperate
Oulmes	33.8	3.2	69.49	Temerate subhumid
Khenifra	40.3	1.2	55.0	Semi arid fresh
Tiflet	35.8	5.6	56.4	Semi arid temperate

My Bouazza	33.7	3.2	67.5	Temerate subhumid
Sidi Ahsine	35	3.2	79.6	Temerate subhumid
Tiddas	35.1	4.5	53.4	Semi arid temperate
Khemisset	36	5	62,0	Temerate subhumid
Timeksaouine	34	4	64.2	Temerate subhumid

Source: CNRF, Rabat and study documents

In this study, monthly meteorological averages (Rain and Temperatures: Tmax and Tmin) and monthly flows from the Tarhat (Khenifra) hydro-meteorological station (ABH) were averaged over the reference period (1950-2000) And also for future projections periods 2050 (2041-2060) and 2070 (2061-2080) concerning the upstream of the basin.

Meteorological data (Meteorology and Temperatures: Tmax and Tmin) of the Marchouch weather station (Rommani) (INRA) were used for the periods (1966-2008) and (2003-2008), and also for the Projection period 2020 for the center of the basin.

More, meteorological data (Rains and Temperatures: Tmax and Tmin) of the meteorological station of Rabat-Sale (DMN), for the period (1961-2012), concerning the downstream of the basin

2.2.4. GCM Data

2.2.4.1. Model HadCM3
HadCM3 (Hadley Center Model 3) from *www.worldclim.org/futurdown.htm* and extracted by ArcGis software for viewing and display, then compare with current monthly climate data for the year (2007-2008) for the experimental site of Marchouch, INRA.

2.2.4.2. Model CNRM-CM5
The new version of the CNRM-CM global circulation model was developed by CNRM-GAME (National Meteorological Research Center-Meteorological Atmosphere Study Group) and Cerfacs (European Center for Advanced Research and Training) To contribute to Phase 5 of the Coupled Model Inter-comparison Project (CMIP5). The proposal of the study is to describe its main characteristics, an assessment of the preliminary demand of the average climate. CNRM-CM5.1 includes the ARPEGE-climate atmospheric model (v5.2), the NEMO Ocean model (v3.2), the ISMA earth surface and the GELATO (v5) sea ice model coupled across the OASIS system (v3).

2.2.4.3 SRES) Scenarios
Scenario B2 :
This is an optimistic scenario that describes a world where the emphasis is placed on local solutions, in a sense of economic, social and environmental viability.

The world population is growing steadily but at a slower pace than in A2. There are intermediate levels of economic development and technological change 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 the changes associated with climate indicators (Gommes et al., 2008). They are widely used at present in the modeling work carried out with the most complete coupled models.

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2.2.4.4. Scenarios RCP

In the context of the preparation of the IPCC 5th Assessment Report, an international panel of experts has defined four baseline scenarios, referred to as representative effect concentrations (RCPs) for Effect Gases (Representative Concentration Pathways) Greenhouse gases, ozone and aerosol precursors for the 21st century and beyond. These scenarios may correspond to more or less global efforts to reduce GHG emissions.

For each of these four "representative profiles", climatologists deduce the climatic conditions and impacts of the associated climate change. At the same time, sociologists and economists work on scenarios Presenting various characteristics of socio-economic developments and various adaptation and mitigation strategies. Five sets of scenarios, named SSP (for Shared Socioeconomic Pathways), have thus been defined. Such an approach allows parallel and coherent work by climatologists and economists.

The IPCC has decided to define new scenarios to better take into account this new context and allow economists and climatologists not to work in a sequential but parallel fashion.

Finally, unlike the SRES scenarios, these new scenarios are not defined by the IPCC itself, but have been established by the scientific community to meet the needs of the IPCC.

The approach followed for the definition of the scenarios for the 5th report is therefore different from the previous one. Beyond the conception of new scenarios, it is a true methodological turn that operates the scientific community

Previously, the analysis was conducted following a sequential logic. Reflection started from a bundle of "possible futures" for our societies, incorporating a wide range of determinants - changes in national economies, technological offer, energy choices, demographics, individual behavior, and so on.

To gain speed and responsiveness, the scientific community is now applying a different method. The scientists defined ex ante profiles representative of changes in concentration of greenhouse gases, ozone and precursors of aerosols representative of an increase in energy balance: the RCP (Representative concentration pathways). Based on these reference profiles, the teams work simultaneously and in parallel: climate scientists produce climate projections using CPR as input, while sociologists and economists develop scenarios leading to out-of-gas emissions Consistent with the RCPs.

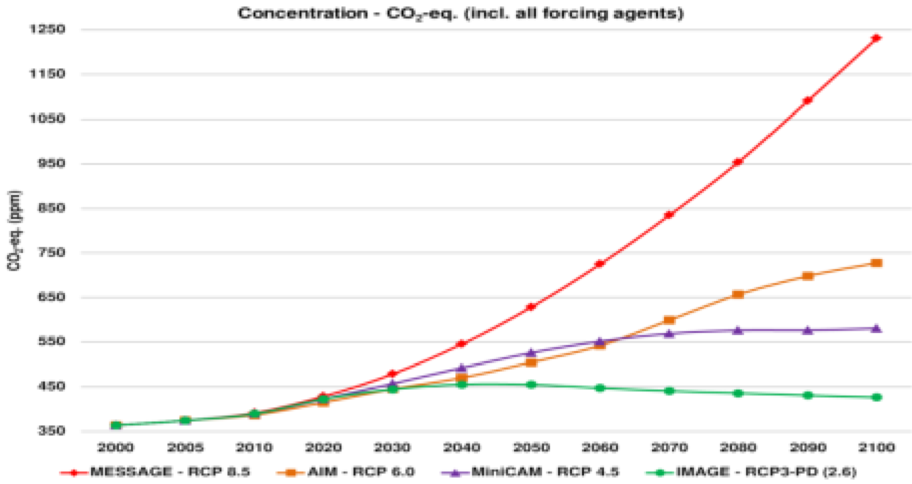

Figure 23: Estimation of CO2 concentration for different scenarios

The RCP profiles are described until 2300, while the SRES scenarios of the previous IPCC work stopped in 2100.

2.2.4.5. Downscaling

For simulations at a regional level, a "downhill" approach is used (Figure 10) using the development of regional models, with resolutions of 10 to 50 km which take into account the topography more finely. These models are themselves relayed by models of local impact or adaptation, with a horizontal resolution of the order of a kilometer.

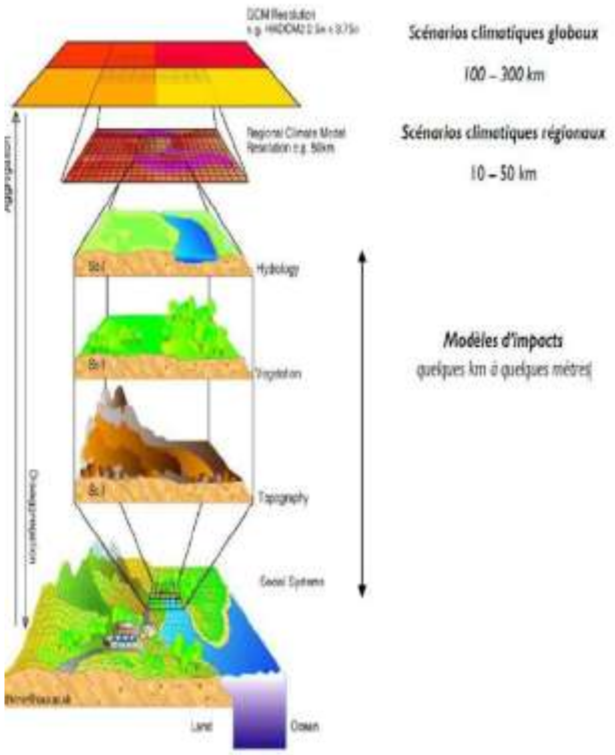

Figure 24: Scales of the various scenarios and models used in downscaling (according to S. Planton)

3. Results and discussion

Table 3: Comparison of current maximum temperatures for the 2008-09 season and future of the year (2020) of the Exp. Marchouch, INRA.

	Present	Future	Future
	2008-2009	2020	2020
Months	T max	T max	T max
September	28,22	28,40	28,40
October	22,44	22,80	22,80
November	17,67	16,30	16,30
December	15,25	13,10	13,10
January	14,33	15,30	15,30
Febrary	17,54	17,10	17,10
March	20,59	19,40	19,40
April	20,26	20,50	20,50
May	26,26	26,90	26,90
June	30,86	30,70	30,70
Jully	29,22	34,60	34,60
August	31,44	33,50	33,50
Average/year	22,84	23,22	23,22

Table 4: Comparison between the current minimum temperatures for the 2008-09 season and Future of the year (2020) of the Exp. Marchouch, INRA

	Present 2008-2009	Future 2020
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
May	11,70	12,30
June	16,10	15,90
Jully	15,40	17,60
Augustt	16,20	17,90
Average/year	10,94	11,50

For temperatures (T max and T min), depending on the model of climatic scenario B2, there will be an increase in temperature (+1 to 2 ° C). The study area will become warmer in the future

Table 5: Comparison between the current (2007-08) and future (2020) crop Field Experimental Marchouch, INRA.

Months	Present	Future
	Rain	Rain
	2007-2008	2020
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
Jully	0,00	1
August	0,00	3
Cumulative/year	301	57

For rainfall, according to the proposed B2 model for the study area, it appears that in the future there will be less rainfall (about less than 80%). It is a strong aridity that will settle in the region of the Experimental Field Marchouch, INRA, according to the climatic scenario.

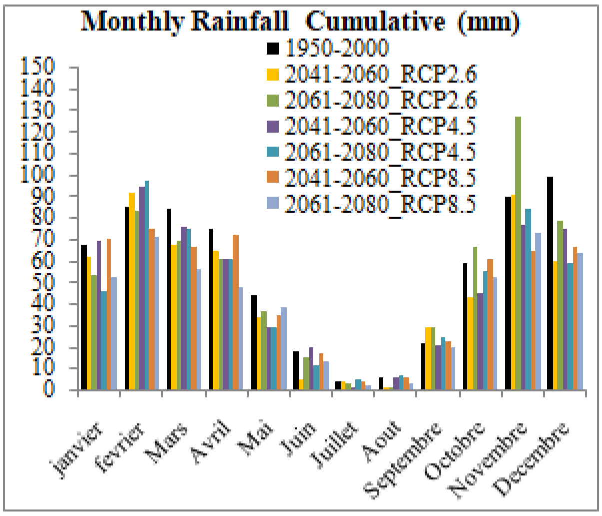

Figure 25: Monthly rains of Tarhat (Khenifra region) for the past period (1950-2000) and The periods Futures (2041-2060) and (2061-2080) for RCPs (2.6, 4.5 and 8.5).

We note that:
Trend in winter rainfall decrease (Dec-Janv) for scenario RCP2.6, while for scenarios RCP4.5 and RCP8.5 there is a decrease for December and no significant change for January. Reduced rains during the spring season (March-April-May) and the beginning of the winter season for the three scenarios except November for RCP2.6 scenarios

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where there was a clear increase in average precipitation during the Period 2061-2080.

The two months November and February are the most humid compared to the reference period, scenarios RCP2.6 and RCP4.5 provides for the retention of this property with the exception of scenario RCP8.5.

The RCP8.5 scenario predicts a decrease in precipitation during the months of November to March with the exception of the month of January. It is also found that the average precipitation for the scenario RCP4.5 Remain virtually stationary during the two projection periods 2041-2060 and 2061-2080 and this during the end of the wet season. This can be interpreted in the light of the fact that scenario RCP4.5 provides for a stabilization of CO2 concentration from the year 2050 (Figure 9).

There is a low variability in monthly rainfall for the wet season (October-April). For the future periods (2041-2060 and 2061-2080) for the RCPs (2.6, 4.5 and 8.5) by Compared with the base period (1950-2000). But the graph illustrates a cumulative rainfall higher than the future for the wettest months of the region (November and February) Compared with the previous period, and also a decrease in monthly cumulative rainfall for the critical growing months of the region's cereal crops (febrary-May).

The rainfall correlation between 2050 and the past (1950-2000) is 93.15% and the mean deviation is -8.33, the correlation between 2070 and the past is 91.27% and the mean deviation is -2.42, and the correlation between 2050-2070) is 93.01% and the mean deviation is 5.92.

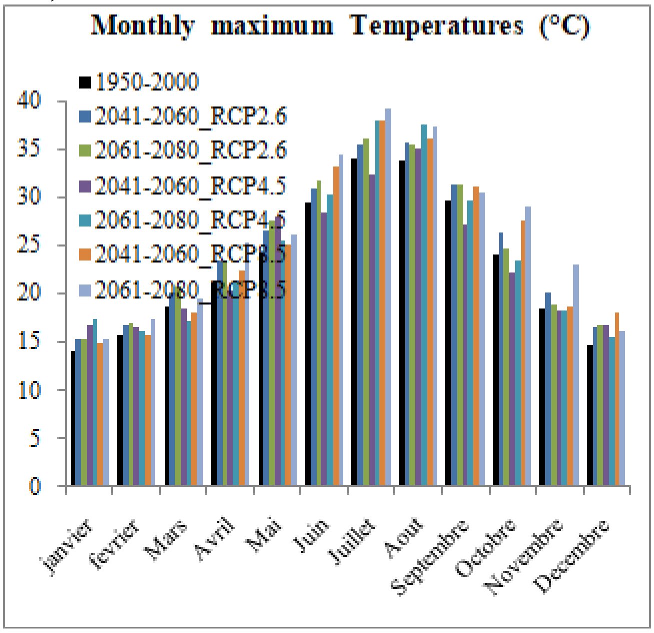

Figure 26: Maximum monthly temperatures of Tarhat (Khenifra region) for the past period (1950- 2000) and the future periods (2041-2060) and (2061-2080) for the RCPs (2.6, 4.5 and 8.5).

General tendency to increase the maximum temperatures in relation to the reference period. The increase is more marked during the summer season (June-August) and less significant during the months of November, December and February. Scenario RCP4.5 provides for lower maximum Temperatures.

Than those provided under scenario RCP2.6 during the start and end of the wet season. In most cases, RCP8.5 provides for a very marked increase in maximum temperatures, especially during the projection period 2061-2080.

The graph shows an increase in monthly maximum temperatures for periods (2041-2060 and 2061-2080) for the RCPs (2.6, 4.5 and 8.5) for the RCP 8.5 scenario compared to the reference period (1950-2000). This will give the wet period (October-April) warmer.

The correlation of maximum temperatures between 2050 and the past period (1950-2000) is 99.86% and the mean deviation is 23.36, the correlation between 2070 and the past is 99.46% and the mean deviation is 24.20, and the correlation between 2050-2070) is 23.19% and the mean deviation is 23.19.

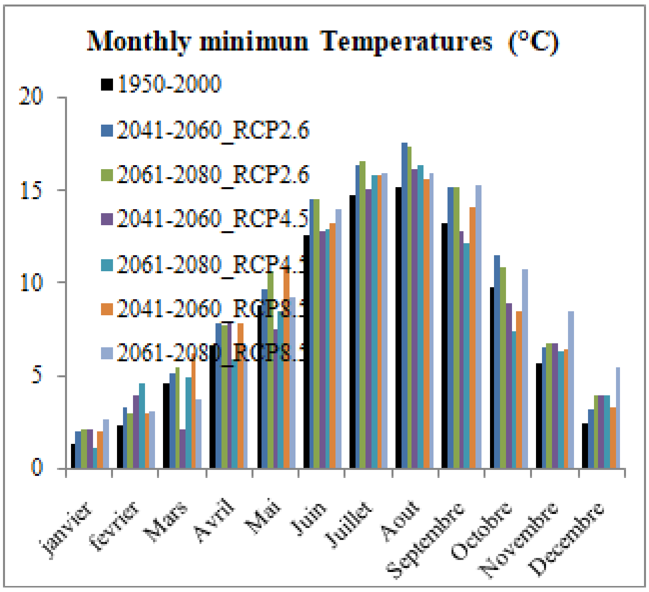

Figure 27: Monthly minimum temperatures of Tarhat (Khenifra region) for the past period (1950- 2000) and Future periods (2041-2060) and (2061- 2080) for the RCPs (2.6, 4.5 and 8.5).

General tendency to increase minimum temperatures relative to the reference period. The increase is more marked during the summer season (June-August) and less significant during the months November and January. RCP2.6 provides for a more significant (May-October) than the other scenarios. Scenario RCP8.5 provides for lower minimum temperatures during (February-March-April). Scenario RCP8.5 provides for a more marked increase in minimum temperatures during September - January. FIG. Above indicates an increase in Monthly Minimum Temperatures for periods (2041-2060 and 2061-2080) of RCPs (2.6 and 8.5) compared to the previous period (1950-2000). This will make the wet period very hot. The correlation of minimum temperatures between 2050 and the past is 99.87% and the mean deviation is 8.36, the correlation between 2070 and the past is 99.85% and the mean deviation is 8.34, and the correlation between (2050-2070) is 99.69 % and the mean deviation is 8.13.

According to the SRES (B2) and RCPs (2.6; 4.5 and 8.5) scenarios, the study area will become more arid in the future, which will have direct and negative effects on crops and especially cereal yields and also on water resources. This is consistent with the results obtained in the "WB / FAO / INRA / DMN" report prepared by the World Bank's study on Morocco (Gommes et al., 2009).

4. Conclusion

Influence on the spatial-temporal distribution of precipitation. The hydrological regime of the whole Bouregreg basin is characterized by a great inter-annual variability marked by the alternation of the wet and dry sequences, intercalated by years of high hydrology or severe drought. The Bouregreg basin has a water deficit of (8%), and is projected to have by 2020 as well. This situation is likely to deteriorate as a result of climate change and worsening extreme events, particularly the significant reduction in rainfall and generalized drought. Indeed, despite the favorable rainfall of the last two years, the threat of drought still hangs over the country as in the periods 1980-1985 and 1990-1995 and 1998-2002 during which almost all the watersheds Were in a deficit situation.

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