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Assessment and Future Climate Dynamics in the Bouregreg Basin, Morocco – Impacts and Adaptation Alternatives

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ABSTRACT

The hydrological regimes of all Moroccan basins are characterized by significant inter-annual variability, with alternating wet and dry years, interspersed with periods of intense hydrology or severe drought. Most watersheds are short of water. Climate change and the increasing frequency of severe events, particularly sudden drops in precipitation and widespread drought, are likely to exacerbate this situation. Like the severe drought years that hit Morocco from 1980 to 1985, 1990 to 1995, 1998 to 2002, 2011 and 2015 to 2020, the threat of drought still hangs over the country. During these years, almost all watersheds experienced water shortages, leading to overexploitation of groundwater. The aim of this research is to explain the climate of the Bouregreg watershed and the effects of climate change on its water resources. In order to preserve a more sustainable environment for future generations, it is crucial to assess the vulnerability of this area and the possible effects of climate change on hydrology. The results find after treatment of data confirmed previous research concerning the increase in temperatures and the decrease in precipitation which has been carried out in northern Morocco. RCPS scenarios (2.6; 4.5 and 8.5) shows that the research region will become dry. Getting from 0.8 to 1.3°C on an annual basis is planned for the 1920s and 2030s, as well as a modest increase in the frequency of days with summer waves.

Keywords: climate, sustainable environment, modeling, climate change, water management.

INTRODUCTION

Climate change has dramatic consequences for life on earth, hence the growing interest in it over the years. A particular interest has developed around the study of climate change and its involvement in the depletion of water resources. These variations lead to the creation and propagation of catastrophic events such as floods and drought. Morocco is particularly sensitive to these phenomena because of its geographical position. In addition to flooding phenomena, drought has been evident in the countries of the Mediterranean basin since the early 1980s, as demonstrated by climate simulations (Change, 2007). The arid to semi-arid regions of Morocco are experiencing periods of drought with deficient rainfall and low runoff from the main wadis in the catchment areas, as a result of the climatic variability observed in these regions in recent years. Indeed, these regions have experienced significant drops in the volume of surface water stored, thus causing difficulties in supplying drinking water to the regions and satisfying their agriculture. The management of this situation requires knowledge of the climatic factors and the study of their impacts.

According the IPCC, or Intergovernmental Panel on Climate Change (Change, 2007), greenhouse gases produced by humans are mostly responsible for the warming that has been witnessed over the past 50 years. The continuation of emissions would lead to an increase in mean sea level by a value between 0.09cm and 0.088cm and in temperature by a value between 1.4°C and 5.8°C between the year 1990 and the year 2100. More droughts and floods will occur in some areas due to an enhanced hydrological cycle. Le Treut et al., and Houghton (Houghton, 2009; van Ypersele de Strihou et al., 2004). In its five reports, the IPCC has consistently alerted people to the problem of global heating and its effects on climate change via temperature and precipitation changes (Benchrifa et al., 2021; Butphu and Kaewpradit, 2022; Paglia and Parker, 2021; Raju and Kumar, 2018). The fourth study (Raju and Kumar, 2018) anticipates a highly probable rise in the frequency of severe temperature events, heat waves, and bouts of heavy precipitation with a higher degree of certainty. According to the fifth report (Masson-Delmotte et al., 2022), recent developments have made human and environmental systems vulnerable and had an influence on them on every continent and in every ocean. For Morocco, the climate is experiencing a significant and intensifying drought episode, as well as a downward trend in precipitation (Falhaoui et al., 2017). Bouregreg watershed is more fragile than those around it since it continues to be a rain-fed agricultural region with significant breeding and a hot, humid continental environment all year round (El Aoula et al., 2021). Reducing susceptibility to climate change has grown in importance for poor nations in recent years. The identification of susceptible regions offers a methodical basis for focusing preventative activities to safeguard vulnerable individuals and the environment. Therefore, indicators are used by policymakers for both direct decision making and understanding vulnerability. The objective of this paper is to study the impact of climate change on the water resource then to establish reference for solutions that can enhance sustainable environment. The main contributions of the paper are:

- explain the Bouregreg watershed climate and to study the effects of climate change on its water resources;
- evaluate the risks and identify the threats and possible impacts of global warming on the hydrology of this region.

MATERIALS AND METHODS

Study location

One of the major Moroccan rivers, the Bouregreg watershed, is situated in northwest Morocco (situated between 32.8° and 34°N and 5.4° to 6.8°W) (Figure 1). It is distinguished geomorphologically by its genesis in the Middle Atlas massif at a height of 1627 m at the level of Jbel Mtourzgane (El Houssaine et al., 2021) (Figure 1). It has an approximate surface area of 1000 km^2 and a length of 240 km. The Wadi Beht watershed limits it to the north and northeast. The watershed of Oued Grou, a tributary of the large Oued Bouregreg basin, limits it to the south and southeast. It empties into the Atlantic Ocean at Rabat-Sale. It has a semi-arid climate, with 400 millimeters of annual precipitation on average in the coastal region and 760 millimeters close to Oulmes. Since 1971, it has flowed on average at a rate of 23 m^3/s, although during floods, that rate may rise to over 1500 m^3/s. In a typical year, the total volume runoff is around 660 million m^3 (Benchrifa et al., 2023c, 2023a, 2023b, 2023d, 2022; Benchrifa and Mabrouki, 2022; Mabrouki et al., 2022a, 2022c, 2022b). The Sidi Mohamed Ben Abdellah (SMBA) dam, built in 1974 and with a capacity of 1.025 billion m3 when it was enlarged in 2006, blocked the Bouregreg basin just before its outlet (Ouharba and Triqui, 2023).

The closeness of Mediterranean Sea and Atlantic Ocean to the territory of Rabat affects its climate, resulting in a Mediterranean climate with wet winter and dry summer. Advective rainfall occurs in the winter mostly because of the passage of Atlantic disturbances, which are often from the north. The region is located at the transitional zone between semi-arid climatic stage and sub-humid climatic stage according to the indicator of Martonne climate and the factor of Emberger (Change, 1990) calculated for 1961 to 2012.

Emberger's rainfall quotient Q2

It is feasible to describe the Mediterranean climate from an ecological standpoint using the Emberger quotient (Hassani et al., 2021). According to this definition, this quotient:

$$Q_2 = \frac{1000 \times P}{((M+m) \times \frac{(M-m)}{2}} \quad (1)$$

where: m – the minimum value of the average daily temperature for the warmest month (degree Kelvin), M – the maximum value of the average daily temperature for the warmest month (degree Kelvin), P – Average of precipitation per year (mm).

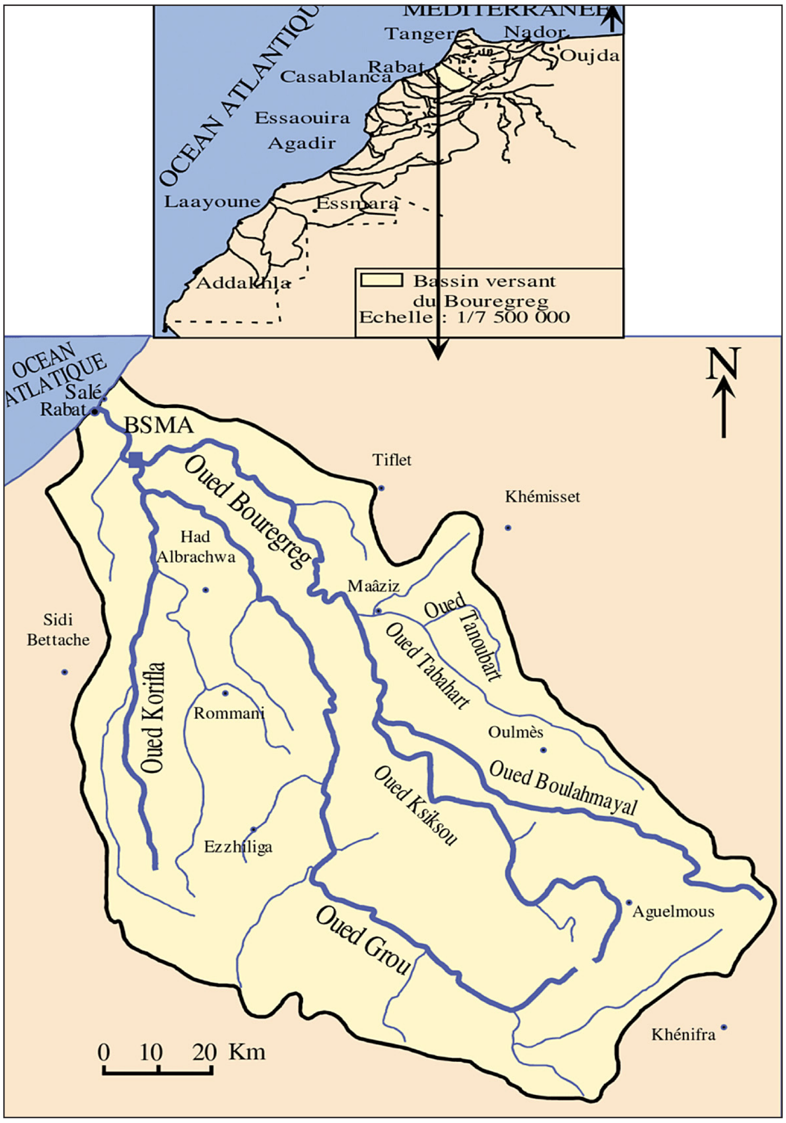

Figure 1. Bouregreg watershed location

This quotient allows for the identification of several bioclimatic phases present in the watershed. Different from a watershed are these bioclimatic phases. These bioclimatic phases come in cold to warm variations and range from semi-arid to subhumid. Table 1 shows the main bioclimates present in the basin.

Modelisation

HadCM3 model (SRES scenarios)

In this study, we used data from HadCM3 model and extracted them by using ArcGis software for visualization and display and we compared these data to the data for the year (2007–2008) for the Marchouch experimental site (center of Bouregreg watershed), and also with the future projections periods data (2030). RCP stands for 'Representative Concentration Pathway'. To understand how our climate may change in the future. The RCPs try to capture these future trends. They make predictions of how concentrations of greenhouse gases in the atmosphere will change in the future as a result of human activities. The four RCPs range from very high (RCP8.5) through to very low (RCP2.6) future concentrations. The numerical values of the RCPs (2.6, 4.5, 6.0, and 8.5) refer to the concentrations in 2100. And in the basin's upstream region, we utilized the CNRM-CM5 model's climatic forecasts for the years 2041–2060 and 2061–2080 for the RCP scenarios 2.6, the RCP 4.5, and the RCP 8.5. Finally, we used ArcGis software for extracting and visualizing data values and compare them with the reference period data.

Table 1. Basin Bio-climate (CNRF, Rabat**)**

Station	Min (°C)	Max (°C)	Q_2	Bioclimat
Rabat	8.1	28.4	83.99	Hot sub-humid.
Roummani	4.0	36.0	37.82	Semi-arid temperate
Oulmes	3.2	33.8	69.49	Temperate sub-humid
Khenifra	1.2	40.3	55.0	Semi-arid fresh
Tiflet	5.6	35.8	56.4	Semi-arid temperate
My Bouazza	3.2	33.7	67.5	Temperate sub-humid
Sidi Ahsine	3.2	35	79.6	Sub-humid temperate
Tiddas	4.5	35.1	53.4	Temperate semi-arid
Timeksaouine	4	34	64.2	Sub-temperate wet
Khemisset	5	36	62	Sub-temperate wet

-CNRM-CM5 model (RCPs scenarios)

As part of phase 5 of the intercomparing project CMIP5, the National Centre for Meteorological Research's, the National Centre for Meteorological Research-Group for the Study of the Meteorological Atmosphere and the European Centre for Advanced Research and Training created the updated version of CNRM-CM (Voldoire et al., 2013). The CNRM-CM5 comprises the ARPEGE-climate atmospheric model, the NEMO ocean model, the ISBA land surface model and the GELATO sea ice model linked by OASIS system.

RESULTS AND DISCUSSION

Data observation

Generally, the climate of the Bouregreg watershed region is a coastal climate with a mild, wet winter and a hot, dry summer. The temperatures of the region are processed from five climatological stations of the national centre of meteorology, namely the station of Tiddas, the station of Oulmes, the station of Sidi Ahsine, the station of My bouazza and the station of Khenifra. Figure 2 shows the monthly variation of minimum temperature values for these five stations and Figure 3 shows the monthly variation of maximum temperature values for these stations. From Figure 2 the coldest month's minimum temperatures were less than 2°C in Khenifra and 3.2°C in Moulay Bouazza, Oulmes and Sidi Ahsine.

From Figure 3, the hottest months are between June and August.t, with maximum temperatures that range from 30 to 40°C. The basic rainfall data was obtained from the national meteorological office. The files of these data give the measured values of the average daily rainfall of the rain gauge station located in the centre of the Bouregreg

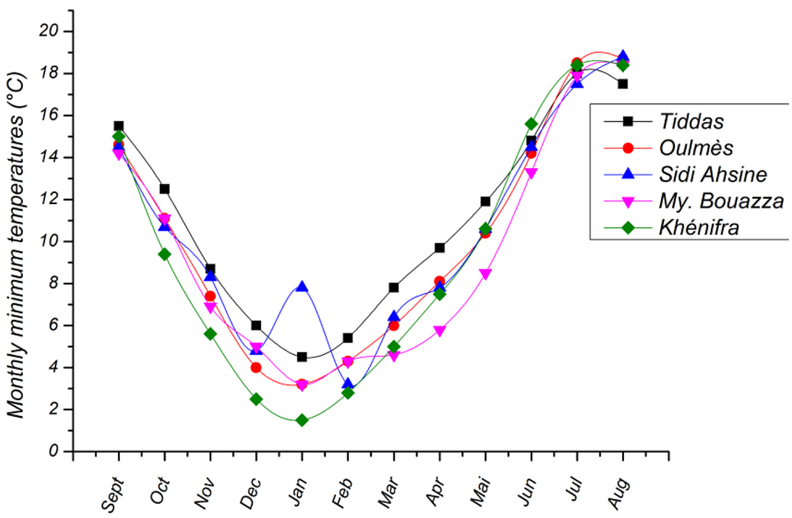

Figure 2. Monthly values of minimum temperatures of Bouregreg watershed

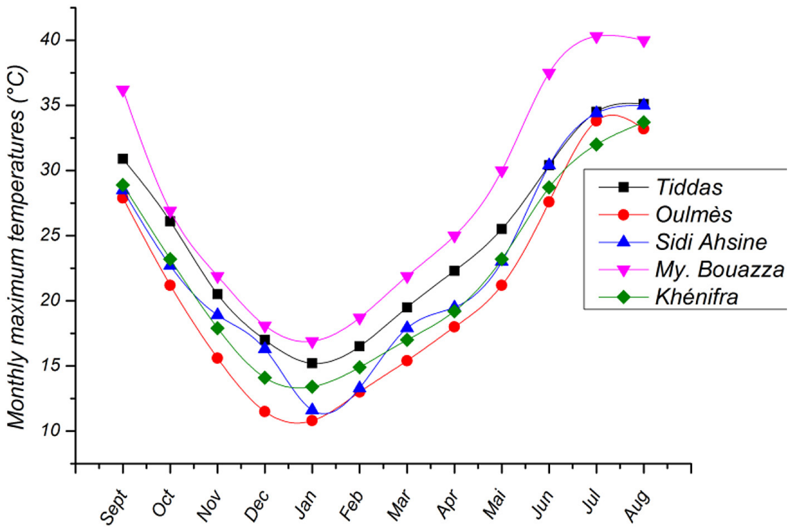

Figure 3. Maximum temperatures for every month of the upstream Bouregreg watershed

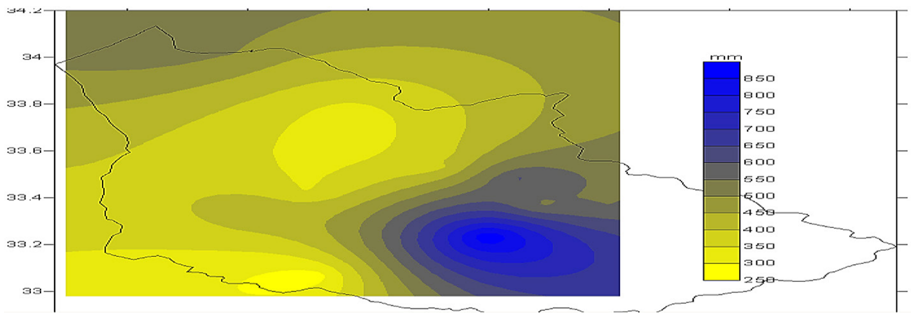

Figure 4. Bouregreg watershed's spatial distribution of annual precipitation

watershed. The main characteristics of the rainfall station studied are shown in Figure 4 and Figure 5.

The quantity of precipitation in the area is spread unevenly throughout the year, with an average annual total of 512.4 mm. A primary peak in winter and a secondary peak in spring define maximum mean rainfall. Thus, it receives 226 to 233 mm of precipitation every month throughout the winter. For the spring season, however, it ranges between 110 to 175 mm/month (Masson-Delmotte et al., 2022).

Frequent weather phenomena

In the Rabat-Salé region, climate-related risks include Dew, Storms, Chergui, Fog and Hail. Figure 6 shows the frequency of each meteorological phenomena in percent.

From the figure it can be seen that dew is the most frequent meteorological phenomena during the year with a maximum of 9.3 days in December and a normal of 63 days per year. The longest duration in the last 30 years was 175 days recorded in 1993 followed by fog with an average of of 37 days per year. The region is characterised by two types of fog: cooling fog in autumn and evaporating fog in spring. Chergui has an average of 26.2 day/year and the storm phenomenon has an annual average of 13.1 days with an average occurrence of 1.7 days of the thunderstorm event which usually occurs in December.

Bouregreg basin floods characteristics

The measurements of the average flows were carried out at the hydrometric stations of Lalla Chafia, Aguibet Ezzair, Tsalat, Sidi Amar and SMBA (Table 2). To visualize the variation of the flow during the period from 1974 to 2011, the monthly average of the flow for the region of Khenifra has been plotted (Figure 7) as well as the maximum and minimum value of each month (Figure 8). In general A seasonal hydrological regime can be used to describe the watershed. For this purpose,

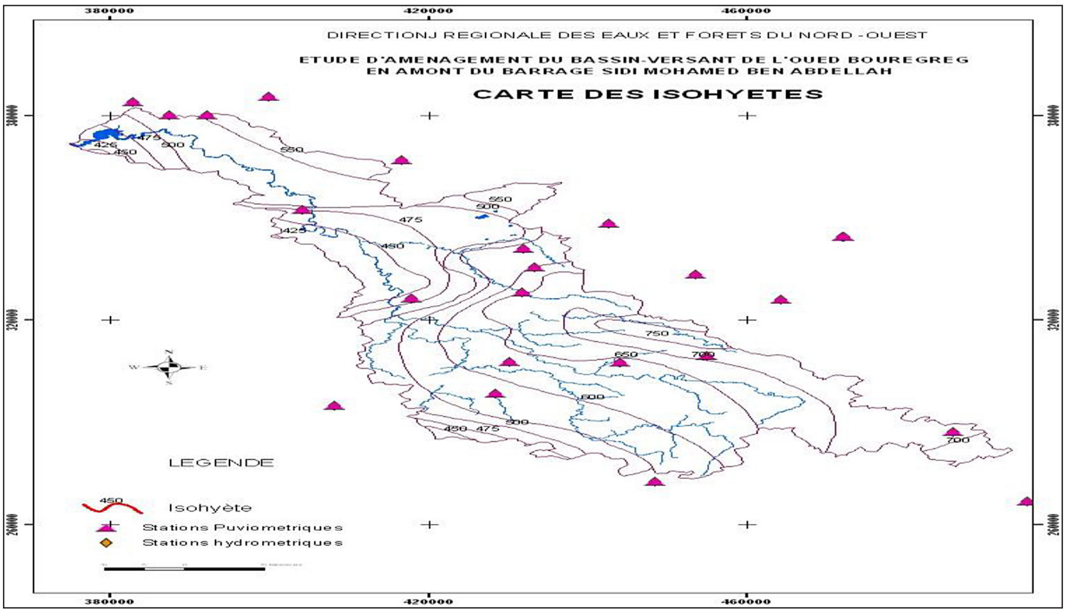

Figure 5. Isohyets map (2016)

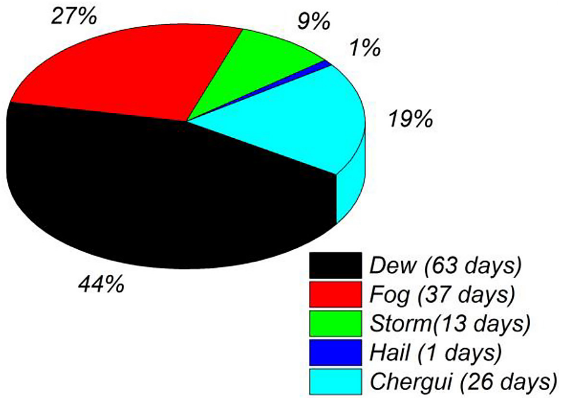

Figure 6. Percentage of the important meteorological phenomena in Rabat - sale region

Table 3 has been used to present the monthly flow values of the stations of Tsalat, Lalla Chafia and Aguibet Ezziar SMBA. The flow records its greatest during the months of January, February, and March. More than two thirds of yearly flows are made up of them. At all stations, the winter has the largest flow. August is when the lowest water levels are most severe. The majority of the time, surface water quality is rated as acceptable to exceptional. Figure 9 provides an illustration of the hydrograph floods used at the SMBA dam during the return periods T = 2 years to PMF. There is typically a wait of a few hours between the beginning of the rain and the beginning of the flood.

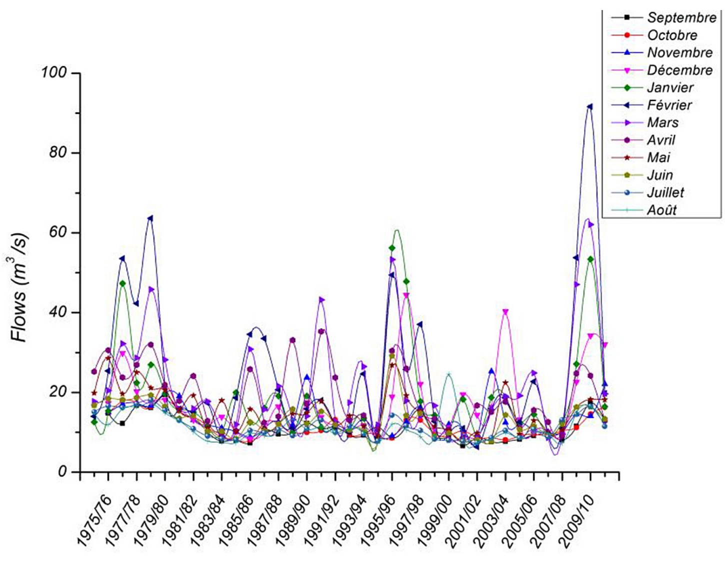

Figure 7. Monthly values of flows for Tarhat (Khenifra) during the period (1974–2011)

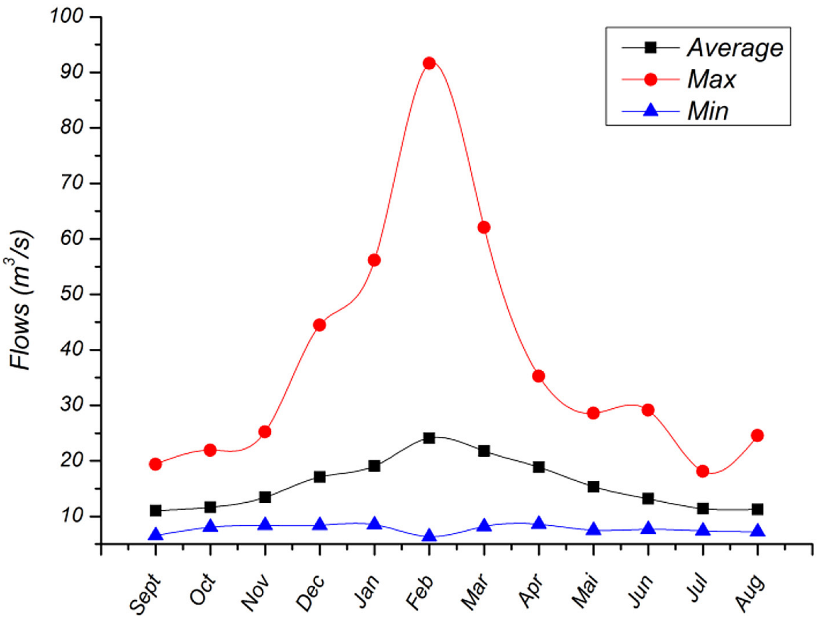

Figure 8. Average, max and min monthly values of flows for Tarhat (Khenifra) during the period (1974–2011)

Table 2. Annual average value of flows at hydrometric stations for 2012

Stations	SMBA	Lalla Chafia	Aguibet Ezzair	Tsalat	Sidi Amar
M	19.3	7.3	6.5	1.7	0.8
BV (km²)	9590	3266	3800	690	329
Cv	0.841	0.970	0.989	0.886	1.362
Max	61	27	21	5	4
Min	2	0	0	0	0

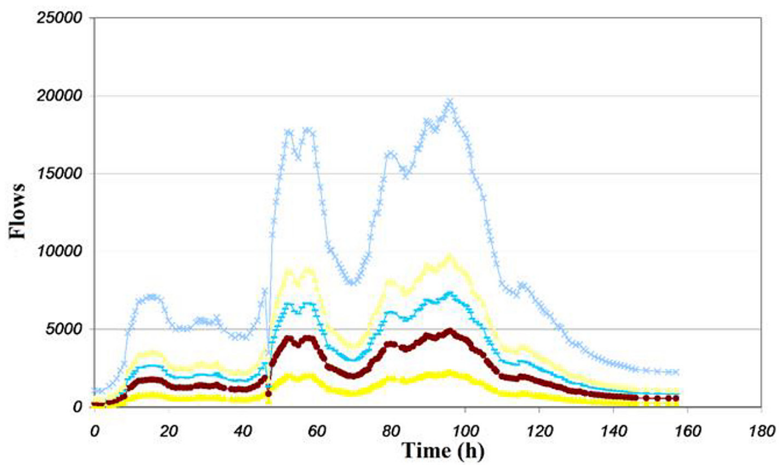

Figure 9. Floods hydro-graph observed at the SMBA dam (DRPE)

This is explained in part by the early losses from infiltration and interception and in part by the timing of the first raindrops' conveyance. After then, the flow increases until it reaches its peak flow, at which point it starts to decrease. The recession curve's slope then becomes gentler. The highly extended pelvis (compare the pelvis of Gravelius) are confirmed by this spreading. The last stage of the response may need many days. This step is the return to a stable state after the disruption caused by the flood. In this stage, the flow slowly returns to its normal level (Falhaoui et al., 2017).

Table 3. Seasonal flows (DRPE, 2012)

Stations	Minimum monthly flow (m^3/s)	Medium monthly flow (m^3/s)	Maximum monthly flow (m^3/s)	Spring flow (%)	Winter flow (%)	Autumn flow (%)	Summer flow (%)
Tsalat	0.40	2.51	7.50	29.80	62.87	6.53	2.41
Lalla Chafia	0.7	5.46	22.88	33.49	58.50	6.37	1.63
Aguibet Ezziar SMBA	0.6	4.90	17.19	33.27	57.52	7.65	1.55

Climate projections using HadCM3 model (SRES scenarios)

Observation is not always possible or sufficient to study a real phenomenon. The main causes are the lack of technical, financial or theoretical means. Experimentation on a model of the phenomenon that we want to study is then very helpful to deepen the study. In our case, using HadCM3 model (SRES scenarios) we were able to predict the monthly data of maximum temperature (Table 4), minimum temperature (Table 5) and precipitation (Table 6) for the year 2030 and to compare these values with the measurements carried out at the Experimental Domain of Marchouch, (INRA) during the period 2008–2009. According to the suggested model, there will be less rainfall in the future, approximatively less than 80%. According to the climatic scenario, a severe aridity would develop in the Rommani area of INRA Experimental Domain in Marchouch,. The climatic scenario model predicts a rise in temperature of around (+1 to 2°C) for the temperatures (T max and T min). In the future, the research area will warm up.

Table 4. Comparison between the maximum temperatures at (2008–2009) and at (2030) of the INRA Experimental Domain in Marchouch

Month	T_{max}	
	Future – 2030	2008–2009
January	15.30	14.33
Febrary	17.10	17.54
March	19.40	20.59
April	20.50	20.26
May	26.90	26.26
June	30.70	30.86
Jully	34.60	29.22
August	33.50	31.44
September	28.40	28.22
October	22.80	22.44
November	16.30	17.67
December	13.10	15.25

Table 5. Minimum temperatures comparison between (2008–2009) and (2030) for the INRA Experimental Domain in Marchouch

Month	T_{min}	
	Future – 2030	2008–2009
January	5.20	5.90
Febrary	6.20	7.40
March	7.40	9.80
April	9.30	7.00
May	12.30	11.70
June	15.90	16.10
Jully	17.60	15.40
August	17.90	16.20
September	16.60	15.70
October	13.30	12.10
November	9.50	7.60
December	6.80	6.40
Cumulated/year	11.50	10.94

Climate projections using CNRM-CM5 model (RCPs scenarios)

To deepen the study on climate variables and their evolution in the future, CNRM-CM5 model (RCPs scenarios) was used for the prediction of maximum temperature, minimum temperature and rainfall during the period 2041–2060 and 2061–2080 and these results were compared with the measurements collected at Tahrat region (Khenifra) during the period 1950–2000 Figure 10, Figure 11 and Figure 12 present the results of this study. The monthly cumulative rainfall throughout the wet season (October to April) exhibits little variation. RCPs (2.6, 4.5, and 8.5) for future periods (2041–2060 and 2061–2080) compared to the base era (1950–2000). However, the data shows that the region's wettest months – November and February – had more rain cumulatively than in the recent past. Additionally, there has been a decline in the total monthly rainfall from February to May. In terms

Table 6. Current rains comparison between (2007–08) and (2030) for the INRA Experimental Domain in Marchouch

Month	Rain	
	Future - 2030	2007–2008
January	2	52.87
Febrary	2	45.44
March	3	13.07
April	2	44.74
May	2	45.25
June	0	0.00
Jully	1	0.00
August	3	0.00
September	7	1.40
October	10	15.94
November	17	67.52
December	8	14.85
Cumulated/year	57	301

of rainfall, there is a 93.15% connection between 2050 and the past (1950–2000), a 91.27% correlation between 2070 and the past (with an average departure of -2.42), and a 93.11% correlation between 2050 and 2070. From Figure 12 the general trend is the increase in minimum temperatures in the future compared to the period between 1951–2000 taken as a reference. The RCP 2.6 scenario predicts a greater rise in all temperatures compared to the other scenarios, while the RCP 8.5 scenario projects a greater rise in minimum temperatures. This will make the wet season much warmer. According to these scenarios the study zone will become more arid.

Climate change projections for Morocco

We anticipate a rise in temperatures, a decrease in precipitation, and an increase in unpredictability based on future estimates given for Morocco. By 2030, the average temperature may rise by 1.1 to 1.6°C, 2.3 to 2.9°C, and 3.2 to 4.1°C, respectively. Precipitation might drop throughout the entire nation by 14% in 2030, 13–30% in 2050, and 21–36% in 2080 (Mabrouki et al., 2023; Ouraich and Tyner, 2018).

Situation A_2

It paints a bleak picture of a future where inequality between the North and the South is widening and the population of the planet is expanding quickly. The economy is also expanding

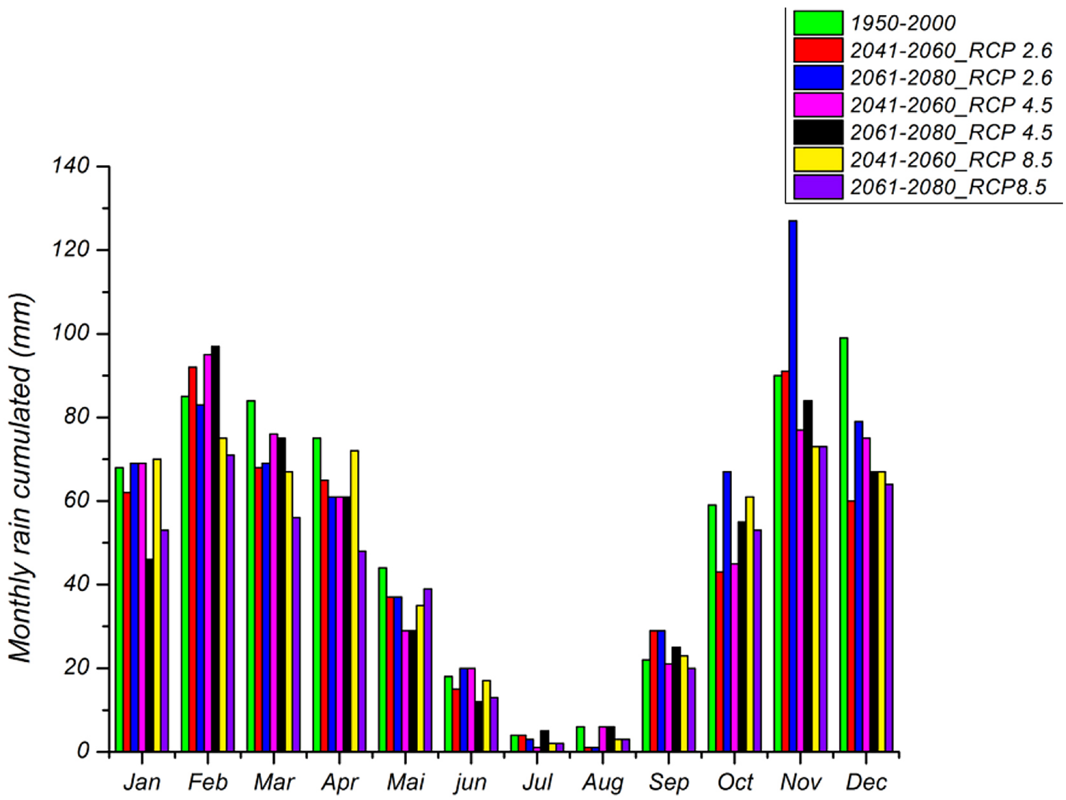

Figure 10. Monthly values of cumulated rain in Tarhat-Khenifra for period between 1950–2000 and future periods 2041–2060 and 2061–2080

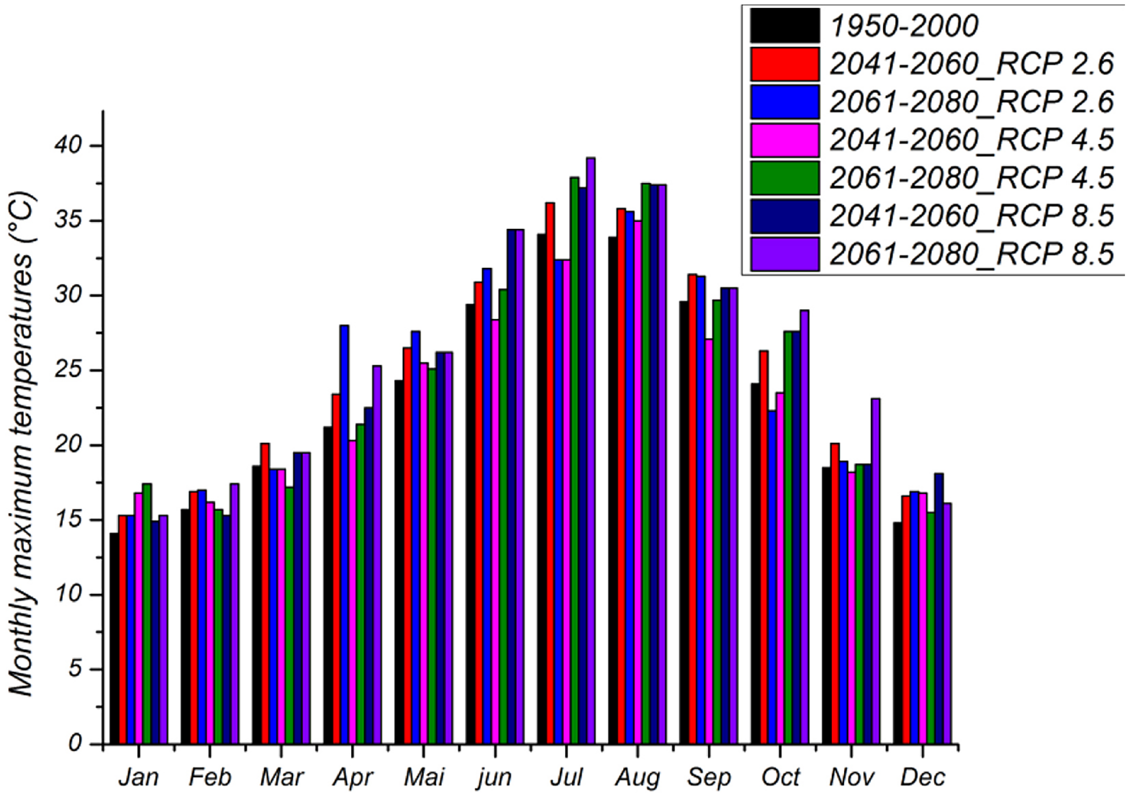

Figure 11. Maximum values of temperatures for Tarhat-Khenifra for period between 1950–2000 and period between 2041–2060 and 2061–2080

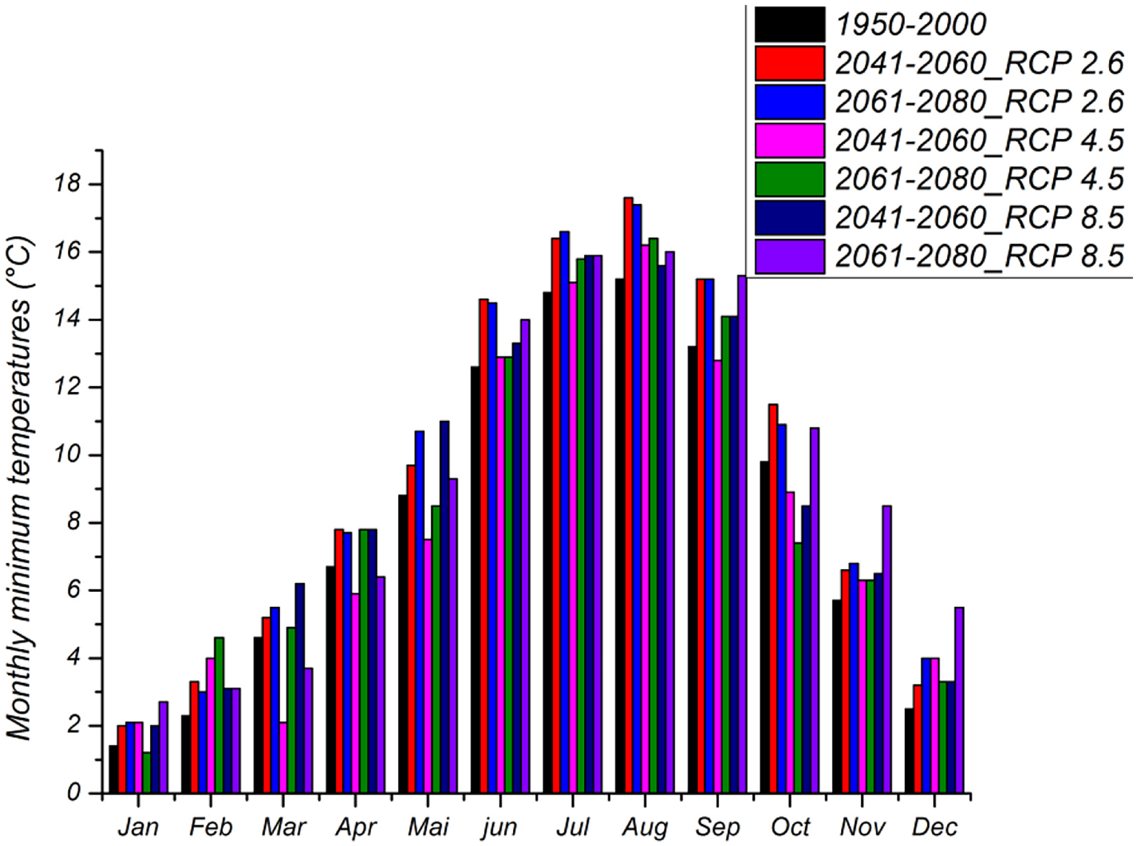

Figure 12. Minimum values of temperatures for Tarhat-Khenifra for thet period between 1950-2000 and periods between 2041–2060 and 2061–2080

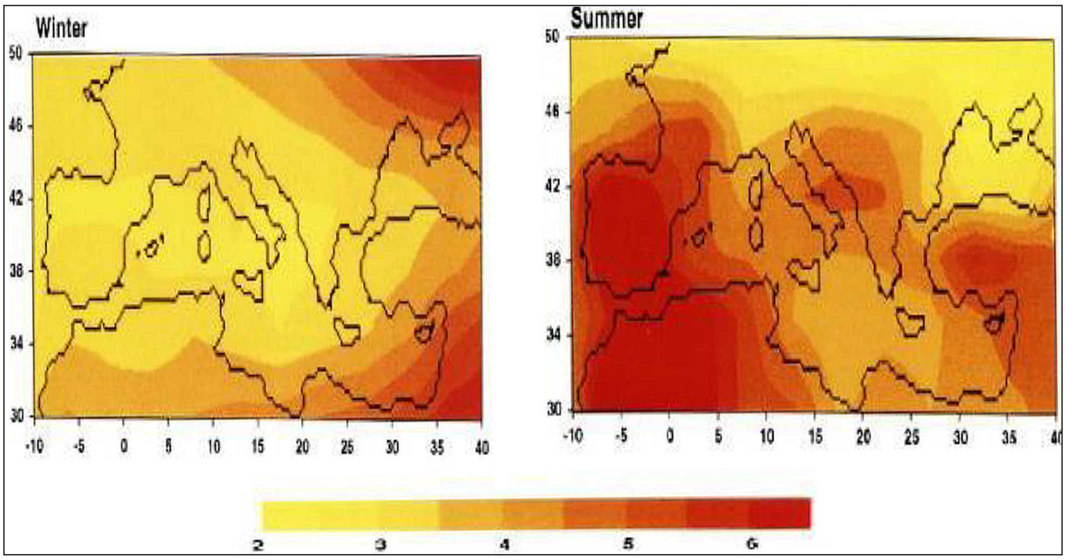

Figure 13. Variation of average seasonal temperatures in the Mediterranean region following a doubling of CO_2, as predicted by the MCG of GISS (Goddard Institute for Space Studies) during the decade 2020

quickly but is dependent on technology that produce pollution. continued reliance on fossil fuels and regionally variable economic growth.

Situation B_2

In terms of economic, social, and environmental sustainability, it paints an optimistic picture of a society where local solutions are prioritized. The population of the planet is steadily increasing, albeit more slowly than in A2. Economic development is at intermediate levels, while technical advancement is slower and more varied.

CONCLUSIONS

The Bouregreg watershed's rainfall regimes vary depending on the areas of each basin; for example, the north and south of the basin have different rainfall regimes. All areas of the Bouregreg basin show a general decline in yearly rainfall. The extensive development projects in the Bouregreg Estuary, such as the Sidi Mohammed Ben Abdellah Dam and the calibration dikes, have resulted in noticeable physical changes to the estuary that significantly influence the hydraulic and geomorphic properties associated with the watercourse.

The future climate of the Bouregreg watershed was studied by using CNRM-CM5 model's analyzing by the ArcGIS software for extracting and visualizing data values and comparing them with the reference period data. The scenarios RCP 2.6, RCP 4.5, and RCP 8.5 from the CNRM-CM5 models were selected to represent a range climatic forecast for the years 2041–2060 and 2061–2080. Generally, the research region will become drier, which will have direct consequences on vegetation and on water resources, according to the RCPs scenarios (2.6; 4.5 and 8.5). This agrees with the findings of the World Bank research on Morocco reported in the "WB/FAO/INRA/DMN" report. A warming of 0.8 to 1.3°C annually is projected for the years 2020 and 2030, along with a modest rise in the frequency of days with summer heat waves. Total Precipitation will decline between 6 and 20 percent annually and between 15 and 35 percent in the winter.

Future climate assessment outcomes will be significantly influenced by the quality of the input data and model uncertainty. Therefore, additional research employing different statistical downscaling techniques and longer time series than those utilized in this study is still needed to confirm these findings. To better predict the future climate at the full watershed scale, it will also be advised to finish this study by examining the meteorological station's projected minimum and maximum temperatures as well as the other stations' projected precipitation. Furthermore, this is merely the beginning of the evaluation of anticipated future changes in the surface water resources in the Bouregreg watershed; additional research on the effects of climate change on Bouregreg runoff through the use of hydrological models is required.

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