PAN AFRICAN UNIVERSITY

Institute of Water and Energy Sciences (Including Climate Change)

Title:
Assessment of climate change and its impact on water resources
Case of TAFNA basin –North West of Algeria-

Name: Sarra TADLAOUI

Date: //2018

*Master In**Water Engineering***

President: ………………………………….

Supervisor: Tirusew ASEFA

External Examiner: ………………………………….

Internal Examiner: …………………………………

Academic Year: 2017-2018

Declaration

I, Sarra TADLAOUI, hereby declare that this thesis represents my personal work, realized to the best ofmy knowledge. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules andethics.

Abstract

Water resources could become scarcer in future decades worldwide. This will significantly affect semi-arid to arid climatic regions. The rapid evolution population, industrial development, and the expansion of agriculture coupled with reduced resources related to the increased frequency of extreme weather events: droughts, and transitional floods and / or linked to climate change are the main factors responsible for increasing scarcity of water resources.

Algeria and in particular the western part has experienced several periods of drought during this century (decrease in rainfall as well as significant increase in temperature). The last major drought from early 1980s to the present day was characterized by its intensity and its significant impact on water resources and crop yields. Understanding changes in key statistics of weather parameters is very important. The main contribution of this work is twofold:

First, articulating climate change through an assessment of climate data for Tafna basin, based on two parameters (precipitation and temperature)during two distinct periods (1923-1980)-(1980-2017), using different statistical methods. The most important part of this is focused on the meteorological drought defined by the Standardized Precipitation Index (SPI). A Seasonal and annual SPI was calculated for 8rainfall stations. It has been shown that the average rainfall before 80s and after 80shave decreased by about 19 % to 47% in the studied stations. The largest decrease was observed in the center of the basin.

Second, understanding the prediction of future climate of Tafna basin using downscaled climate projection from GCM product outputs of HadCM3. A Multi linear regression (MLR) was used to downscale the GCM data from A2 and B2 emissions scenarios for future climate predictions. The output generated from the statistical downscale model (precipitation and temperature) were then used to assess how these parameters may change in the future.

Key Words:

Climate change; SPI;GCM; downscaling ;HadCM3;Tafna basin

ACKNOWLEDGMENT

First and foremost, I would like to thank God Almighty for giving me the strength, knowledge, ability and opportunity to undertake this research study and to persevere and complete it satisfactorily.

I owe my deepest gratitude to my supervisor Dr. Tirusew Asefa for his continuous optimism concerning this work,enthusiasm, encouragement and support.

I offer my sincere appreciation for the learning opportunities provided by PAUWES which continue molding students to go beyond their limits and to dream for the best. I also pay my sincere thanks to all PAUWES technical staff and administrative staff for their support, tolerance and encouragement specially Fatéma and Malik.

My completion of this project could not have been accomplished without the support of my best friends Elhadi, Hakim, and Saqib. I cannot express enough thanks to my classmates for their continued support and encouragement during these two years.

I would like to acknowledge with gratitude the support and the love of my parent, thanks to my family for lending me your hands.

Finally a special thanks to my twin sister Assia,without her this study would hardly have been completed.

Table of contents

List of Tables

List of figures

Abbreviations

ANRH	NATIONAL AGENCY OF WATER RESOURCES
AOGCM	Atmospheric-Ocean General Circulation Model
CNES	Economic and Social National Council
DD	Dynamical Downscaling
SD	Statistical Downscaling
MLR	Multiple Linear Regression
RCM	Regional Climate Model
NCEP-NCAR	National Centers for Environmental Prediction–National Center for Atmospheric Research
SDSM	Statistical Down Scaling Model
GCM	Global Climate Models
HadCM3	Hadley Center Climate Model Version 3
SPI	Standardized Precipitation Index
NASA	National Aeronautics and Space Administration
ONM	National Meteorological Office
GR2M	model of the Genie Rural with two parameters for a monthly time step
ANBT	National Agency for Dams and Transfers
IPCC	Inter-Governmental Panel on Climate Change
DREWT	Water Resources Direction of TlemcenWilaya
ABHOCC	Hydrographic Basin Agency Oranie - ChottChergui
GFDL	Geophysical Fluid Dynamics Laboratory
SRES	Special Report on Emissions Scenarios

1. Introduction

1.1 Background information

Climate change refers to significant changes in global temperature, precipitation, wind patterns, and other measures of climate that occur over several decades or longer.

The Earth's climate has changed throughout history (3).Seven thousand years ago, for example, the Sahara which is largest hot desert was a landscape of lakes and forests (4).It is now widely accepted that the burning of fossil fuels and deforestation are changing our atmosphere with a speed and scope that is unprecedented in the historical record.

As science has revealed the speed and scope of climatechange, we have begun to realize that it holds potentiallyserious implications for international security. Climate change by redrawing the maps of water availability, foodsecurity, disease prevalence and coastal boundaries could increase forced migration, and raise tensions.

Climate change impacts will have direct consequences for water security.

The Intergovernmental Panel onClimate Change (IPCC) alerted the global community tothe great vulnerability of freshwater resources as are result of climate change. The principal impacts of climate change are shifts in precipitation patterns and a rise in temperature. Meanwhile, rising temperatures increase evaporation (from soil and rivers) and evapo-transpiration (from plants) and reduce the amount of available water in lakes and rivers (known as ‘blue’ water) and in the soil (‘green’ water).

Right now, the effects of climate change are already being felt by people across Africa. Evidence shows that the change in temperature has affected the health, water availability, livelihoods, food productivity, and overall security of the African people.

Africa is the world’s second-driest continent. With 15 per cent of the global population, it has only 9 per cent of global renewable water resource(5). According to the Climate Change Vulnerability Index for 2015, seven of the ten countries most at risk from climate change are in Africa.

Africa has seen a decrease in rainfall over large parts of the Sahel and Southern Africa, and an increase in parts of Central Africa. Over the past 25 years, the number of weather-related disasters, such as floods and droughts, has doubled, resulting in Africa having a higher mortality rate from droughts than any other region.

According to IPCC reports, the Mediterranean basin and particularly the North African area are amongst the most vulnerable regions to climate change. However, the information concerning the North African zone is very limited,

Algeria is the largest country in both Africa and the Mediterranean basin(6). Past analyses and GCM simulations for the next decades show that the Mediterranean region, characterized by rainy winters and dry summers, is experiencing increasing temperatures and large changes in the frequency of extreme climatic events for both temperature and rainfall (7).

Algeria,Morocco , and other Mediterranean countries, suffered from several periods of drought. In recent years, many studies have shown a declining rainfall trend in most of North West of Algeria(8).

In Algeria, a decrease on the average annual precipitation began in early 80th and it declines on the potential of rainfall, and it will continue over the next century (9).

The Territorial Management and Environment Committee of the Economic and Social National Council (CNES), on its report in 2004, mentions that Algeria needs between 15 to 20 Billion of cubic meter of water (per year) to satisfy the demand of water(reserving 70% of its to agriculture), nevertheless the actual situation shows that only 5 Billion cubic meter of water is available per year, so it becomes a serious challenge

Therefore, the answer to this delicate formula between the water resources and the satisfaction of different water sectors remains to be solved.

1.2 Problem statement

Climate is subject to significant variations in rainfall and temperature, rainfall is the most important factor of climate for both people and ecosystems. Drylands are particularly affected by recurring and prolonged droughtsand the issue of water is a real issue in this century(10).

Climate change has become, in recent decades, a real challenge for the international community. Due to the increased concentrations of greenhouse gases to levels that had not been achieved in the atmosphere for a long time, the radiative balance of the planet has become slightly positive which means that the earth warms. The latest report of the International Expert Group on Climate Change confirmed that the last three decades are the warmest ever recorded by man. Since the end of the 19th century to today, the average temperature at the earth's surface has increased by 0.85 ° C (8). This increase may seem unimpressive but it hides significant regional disparities though some areas have undergone little change, others have recorded increases of more than 2 ° C. It was from the 1820s that scientists began to see the importance of some gases in the regulation of global temperature (11).

From the end of the 1970s, Algeria experienced an intense and persistent drought (10). The rainfall deficit for 16 representative locationsin the West, Central and East regions shows a deficit of 26% in the West, 16% in the center and 11% in the East. It appears that the drought has affected the entire territory, the western regions of the country appear to beparticularly affected more so than any of the other regions

Examination of temperatures for the (1931-1960 and 1961-1990) periods by the National Meteorological Office (NOM) shows a rise in average temperatures throughout the country during the winter and autumn seasons, and a net increase in minimum and maximum temperatures at all stations in northern Algeria since the 1970s and continuing until today.

Rainfall analysis for the same periods (1931-1960 and 1961-1990) shows a decrease in rainfall in the autumn and winter in the north, while in spring, rainfall is more important in the west, the center and the south of the country, and there is less rainfall in the east (12).

The analysis of temperature data on more than 40 stations of the network of the ONM over the period (1950-2005) shows an increase in maximum annual temperatures of 1.2 ° C (0.6 to 2. 3 ° C) and seasonal temperatures of 1.6 ° C in summer (0.9 to 2.2 ° C, maximum in August) (13).

Tafna basin is one of the most important basins in Algeria, nicknamed a water tower of the west region of Algeria, Thus it has supplied water to its own population as well as to the agglomeration of the great city of Oran as well as that of neighboring wilayas, especially Ain Temouchent and Sidi Bel Abbes (14)

In this context, the Tafna basin has suffered for nearly four decades from a reduction in rainfall. This resulted in a deficit in surface runoff, a dangerous lowering of piezometric surfaces. A cute shortages in drinking water were observed nearly everywhere across the region in each existing infrastructures.

Water resources remain closely dependent on rainfall. The drought has significantly affected the level of water supply which has reached a critical threshold and does not allow for an improvement and a correct distribution (population, industry, agriculture)

Furthermore, the increases in the population as well as the socio-economical development of the region have obliged the local authorities to lookfor new water resources for Tafna basin, unfortunately its conditions under future climate change has not been investigated at the local scale. The main tasks of this research is tounderstand the evolution of Tafna climate,and to quantify future changes by the Knowldge of how Tafna Basin might respond to climate change and variability will help decision maker.

They might respond in the future if the climate conditions continue to change. Understanding these impacts would lend one a better planning approach in water resourcesmanagement.

1.3 Research objectives

The main objective of this research is to assess the potential climate change of TafnaBasin that has already occurred usingperiodsfrom observed historical record and assesspotential future changes using different statistical methods.

Assessment ofchanges in future period was done using statistically downscaled climate projection from General Circulation Models (GCM).

The specific objectives of the study are as follows:

- To understand changes those have already occurred
- To generate fine resolution climate change scenarios using statistical Downscaling Modelat Tafna basin Basin level;
- To project the variability in temperature and precipitation for selected climate changescenarios for a period of (2020s, 2050s and 2080s) at local climate station;

The relevance of our study is to find the relationship between climate change and the water resources in TAFNA, to be able to:

- Take qualitative and quantitative measures or actions,
- Perform impact assessment from regional to local scales.

1.4 Research Question

- What are the changes in mean of precipitation and temperature over the historical climate data? Is this change significant?

- What are the downscaling techniques to generate finer resolution climate data at the Basin level?

- What are the expected changes in meteorological variables (precipitation and temperature) on the Basin level?How do the water resources might respond to these changes?

2. Literature review

2.1 Climate history:

Since the formation of the Earth, the climate has been continuously changing. This climate changesthrough the modificationbiosphere, the water cycle, the shape of the continents and vegetation cover, oceans and ice, have multiple effects on all living beings (15)

The recent climatic history of our planet (during the Quaternary) is marked by a succession of cold periods, glacial and warm periods, interglacial (figureII.1).Solar Emission Variations (sunspot minimum match is cold episodes in the Earth's climate level) throughout the last thousand years of historical explain climate variability: a warm period in the Middle Ages (476-1453) Medieval optimum during the XI to XIV centuries and a cold period of the late fifteenth century to the mid-nineteenth century called Little Ice Age (1400-1850). This period is characterized, in Europe and North America, with long, harsh winters and short summers and wet, an extension of the Arctic ice and global cooling – 1°C to -2°C. This period ended in 1860 at about the same time as the industrial revolution. Since then, we entered a warm period (16)(17)

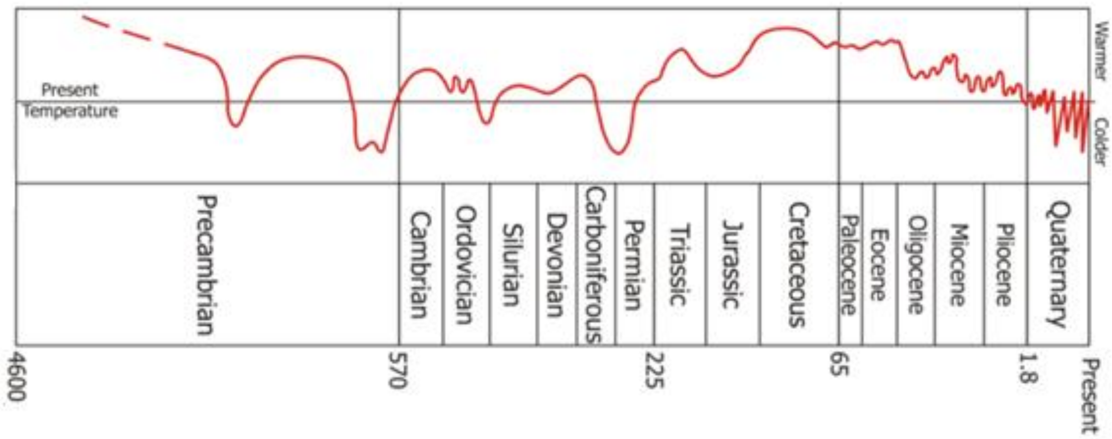

Figure II 1: Mean global temperature ((http://www.c3headlines.com).

2.2 Climate and water cycle

The water cycle contributes to the climate system to ensure the transfer of energy needed to maintain its balance. This cycle, carries water, but also energy as latent heat, mainly steam. When it evaporates, the water absorbs the energy that is subsequently released during condensation.

In fact, water vapor is the main greenhouse gas from the atmosphere, it intervenes heavily in the earth radiation budget, without neglecting the importance of the effect of clouds which reflect solar radiation to space, causing cooling, they also trap infrared radiation emitted by the Earth, causing warming. According to the optical properties of clouds, altitude and location, they can contribute to heat or cool the surface of the Earth. This feedback is a major source of uncertainty in the assessment of future climate.

The water cycle and climate are closely linked, however this relationship takes on a new significance in the context of climate change. Predicting climate change in coming decades requires an understanding of the hydrological cycle and other processes. On the other hand, climate change is certainly accompanied by changes in the water cycle (figure II.2).

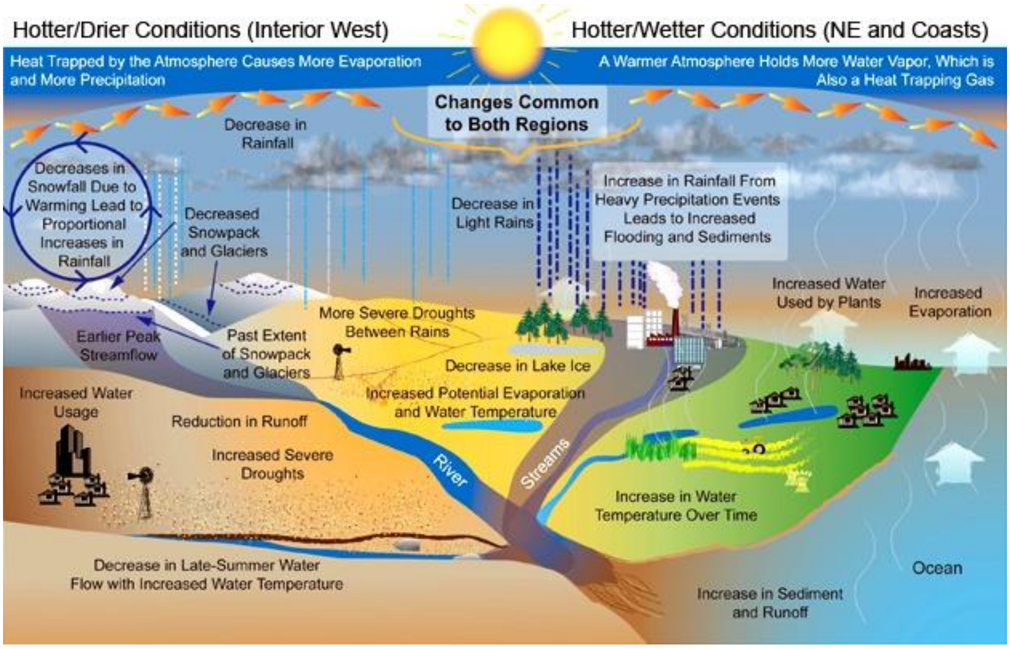

Figure II 2:projected changes in water cycle (https://nca2009.globalchange.gov)

Surface warming can lead to a decrease in snow cover and ice (15);(18)This phenomenon causes a change in the radiative properties of the Earth's surface, with a decrease in albedo, increased absorption of solar radiation and ultimately warming (feedback snow / albedo).

All these feedback plays an important role in the global mean temperature change as demonstratedby the IPCC models. These models indicate that a doubling of the atmospheric CO_2 concentration would result in a temperature increase between 2 and 4.5 ° C (average of 3 ° C) of which at least half is attributed to climate feedbacks. The main feedback is through water vapor, then clouds and finally albedo ,but there are significant uncertainties as to the precise values of these returns, especially the clouds are very strong(19).

2.3 Climatic Index

2.3.1 Standardized Precipitation Index (SPI)

The SPI is a drought index first developed by T. B. McKee, N.J. Doesken, and J. Kleist and in 1993 (20). The SPI is used to estimate wet or dry conditions based on precipitation variable. This wet or dry condition can be monitored by the

SPI on a variety of time scales from sub-seasonal to inter-annual scales. The SPI is expressed as standard deviations that the observed precipitation would deviate from the long-term mean, for a normal distribution and fitted probability distribution for the actual precipitation record. Since precipitation is not normally distributed, a transformation is first applied, followed by fitting to a normal distribution.

The SPI calculation is based on the long-term precipitation record for a particular location and long-term period (longer than 30 years is desirable). The calculationis based on a transformation of one frequency distribution (e.g., gamma) to another frequency distribution (normal). The SPI indices can be calculated eithermanually using appropriate formulas or by some softwareavailable in the literature(21).

SPI Manual calculation

The SPIis computed by fitting a probability density function to the frequency distribution of precipitation summed over the time scale of interest. This is performed separately for each month (or any other temporal basis of the raw precipitation time-series as needed) and for each location in space. Each probability density function is then transformed into a standardized normal distribution.

Thegammadistributionisdefinedbyitsprobability density functionas(21):

$$g(x) = \frac{1}{\beta^{\alpha} T(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}} \; for \; x > 0 \text{ (eqI.1)}$$

Where: α>0isashapefactor,

þ>0isascalefactor,

Andx>0istheamountofprecipitation.

T (a) is the gamma function which is definedas:

$$T(\alpha) = \int_0^{\alpha} y^{\alpha-1} e^{-y} dy \text{ (eqI.2)}$$

Fittingthedistributiontothedatarequiresthatα andþbeestimated.Forthis one method suggested in literature a methodis to useanapproximationformaximumlikelihoodas follows:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \text{ (eqI.3)}$$

$$\beta = \frac{\bar{x}}{\alpha} \text{ (eqI.4)}$$

With:

$$\bar{x}: averageof\, x_i$$

Where:

$$A = \ln(\bar{x}) - \frac{1}{n}\sum_{i=1}^{n} \ln(x_i) \text{ (eqI.5)}$$

For n observations, the resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month or any other time scale:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^\alpha T(\alpha)} \int_0^x x^{\alpha-1} e^{-\frac{x}{\beta}} dx \text{ (eqI.6)}$$

Substituting t for x/ þ reduces Eq. (6) to incomplete gamma function

$$G(x) = \frac{1}{T(\alpha)} \int_0^x t^{\alpha-1} e^{-t} dt \text{ (eqI.7)}$$

Since the gamma function is undefined for x = 0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1-q)G(X) \text{ (eqI.8)}$$

Where:

q Is the probability of zero precipitation.

The cumulative probability H(x) is then transformed to the standard normal random variable Z with mean zero and variance one, which is the value of SPI. An approximate conversion is used as an alternative:

$$Z = SPI = -\left(t - \frac{C_0 + C_1 t + C_2 t^2}{1 + d_1 t + d_2 t_1^2 + d_3 t^3}\right) for 0 < H(X) < 0.5 \text{ (eqI.9)}$$

$$Z = SPI = -\left(t - \frac{C_0 + C_1 t + C_2 t^2}{1 + d_1 t + d_2 t_1^2 + d_3 t^3}\right) for 0.5 < H(X) < 1 \text{ (eqI.10)}$$

Where:

$$t = \sqrt{\ln\left(\frac{1}{H(X)^2}\right)} for\ 0 < H(X) < 0.5$$

$$t = \sqrt{\ln\left(\frac{1}{1 - H(X)^2}\right)} for\ 0.5 < H(X) < 1$$

And:

C_0=2.515517; C_1=0.802853; C_2=0.010328; d_1=1.432788; d_2=0.189269; d_3=0.001308.

Table II 1:Drought classification based on the SPI values (20)

SPI Values	Drought severity categories	Symbol
≥2	Extremely wet	EW
1.99 to 1.50	Severely wet	SW
1.4 to 1.00	Moderately wet	MW
0.99 to 0	Mildly wet	MiW
0 to -0.99	Mild drought	MiD
-1 to -1.49	Moderate drought	MD
-1.50 to -1.99	Severe drought	SD
≤-2	Extreme drought	ED

2.3.2 OmbrothermicDiagrams

OmbrothermicDiagrams are climatic diagrams that summarize trends in temperature and precipitation for at least 30 years in a certain location, they allow one to establish the relationship between temperature and precipitation and determine the length of dry, wet, and extremely wet periods. In 1926 Marcel-Henri Gaussen developedOmbrothermic diagram where he was able to plot months of the X(axis),average monthly temperature in one Y(axis) graph (Y1) and total monthly precipitation in the other Y-axis(Y2). The precipitation is usually shown using a bar graph and temperature is usually shown as a line graph.

2.4 Climate change and global warming

2.4.1 Global scale

Since 1850, when the instrumental record of temperature at the earth's surface began, the climate has warmed significantly, especially over the past 30 years (figure II.3). Between 1905 and 2006, the average warming is estimated at 0.74°C (0.56 ± 0.92 ° C) (22).However, this warming presents disparities locally where continental regions are warming faster than the oceans, and this warming is largest at high latitudes in the Northern hemisphere.The period between 1995 and 2006 seems the hottest since 1850 (16).

Figure II 3: View a global warming; a representation of the temperature change by region (1976-2000) (16)

In 1896, "Svante Arrhenius" Swedish chemist was the first to hypothesize that the concentrations of carbon dioxide (CO_2) atmosphere could impact on climate. This hypothesis was tested extensively since that time. The various reports of the IPCC and particularly in the fourth report of 2007 provide numerous illustrations of the warming trend.

The warming of the atmosphere and found a large majority of regions of the globe, in the vicinity of the surface as at the tropopause (~ 10 km altitude) , for the temperature continental scale and the heat content of the ocean(23).

From a paleoclimate perspective, the recent warming is unusual for at least the last 1300 years, while the climate model projections indicate that this trend will persist for many centuries (22);(24)

In connection with the change, other climate notable changes were observed during the 20th century (figure II.4) includes:

a: the average sea level is indeed high of 1.8 mm / year.

b: The areas covered with snow or ice are reduced.

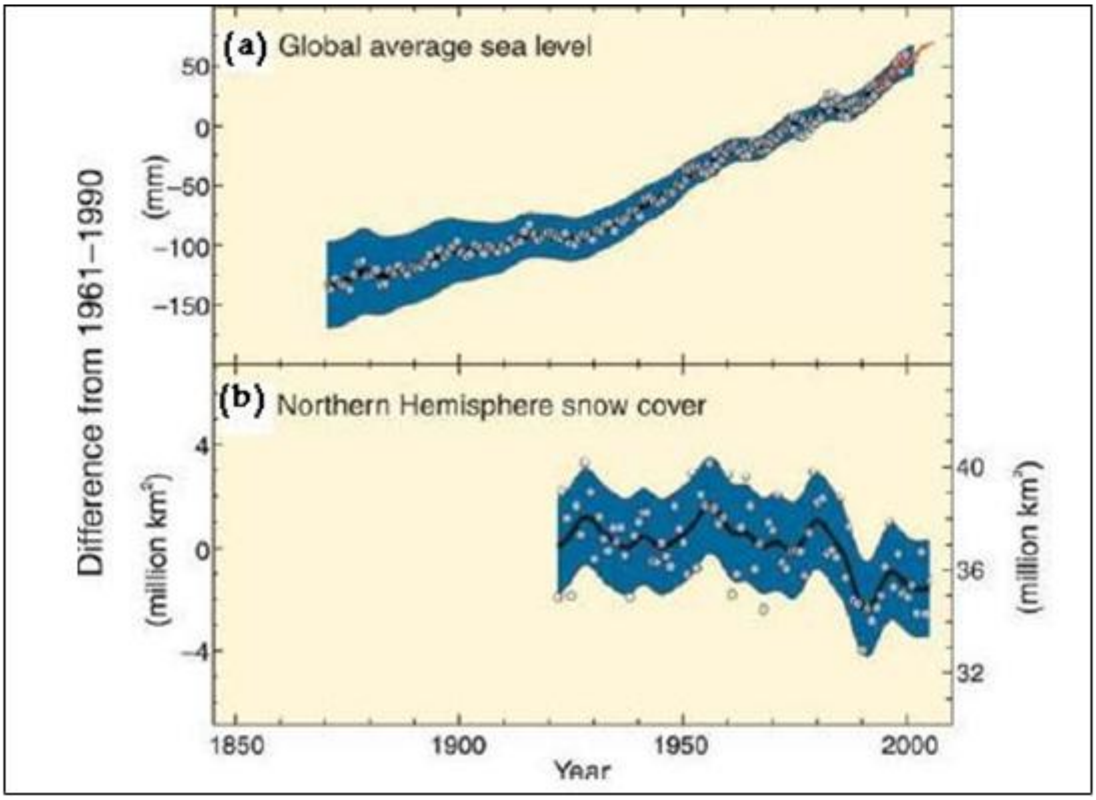

Figure II 4:Observes changes (a) the average sea level across the globe, (b) of snow cover in the Northern Hemisphere in March-April. All differences are calculated from the average for the period (1961-1990) (22)

A significant increase in rainfall duringsummer is observed on the northern hemisphere, for land surface at increased latitudes(30 ° to 60 ° North latitude) at a rate of 0.5 to 1% per decade. By contrast, in the subtropics (10 ° to 30 ° north latitude), rains in the land surface have probably decreased on average by about 0.3% per decade (22);(24). There was a significant decrease in rainfall in the Mediterranean, the Sahel, South Africa and Australia (figure II.5).

:

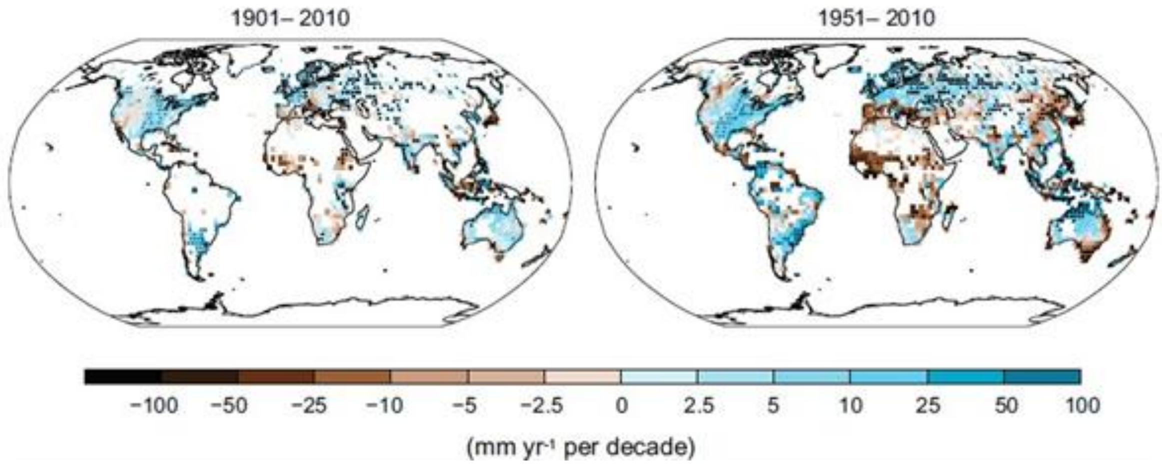

Figure II 5: Spatial distribution of linear trends in the volume of annual precipitation on land areas during the period 1901-2005 and 1901-2001 (24)

According to projections for 2050, water stress decrease on 20-29% of the total area and increase of 62-76% of the total area. The decrease is mainly due to higher rainfall while the increase would come from higher quantities of water extracted (3).

2.4.2 Mediterranean scale

The Mediterranean basin provides a good case study for analyzing regional differences in vulnerability to climate change. The basin couldbe particularly affected by climate change in the twenty-first century. The temperature rose by 0.8 ° C depending on the region. The increase is especially noticeable before 1940 and after 1970. It is particularly sensitive in North Africa with around 2 ° C. During the 1980s and 1990s, warming was more pronounced in the Mediterranean basin, with a significant increase in winter, especially regarding the minimum temperatures.

Precipitation decreased with a decrease of 20% in some areas. At North Africa, the trend is more contrasted (25);(26).

The Rising temperatures and accentuation periods of drought alter the spatial and temporal distribution of rainfall and, consequently, of the water resources. This, combined with strong human pressure on the environment and water demands ever increasing, will make meeting water needs for different uses increasingly difficult to ensure. Trends in declining rainfall were detected at different spatial and temporal scales, recording a decrease of about 20% in some areas(19).

The increased temperatures and lower precipitation simulated for the Mediterranean region by the NASA GISS global climate model driven by a scenario with rapidly increasing greenhouse gases would adversely affect crops and water availability, critically influencing the patterns of future agricultural production.

Summer seasonal mean precipitation and temperature changes for the Mediterranean region corresponding to a doubling of CO_2 as simulated by the GISS GCM (figure II.6). This climate might occur in 2050^{th,} if greenhouse gases increase varies rapidly (NASA)

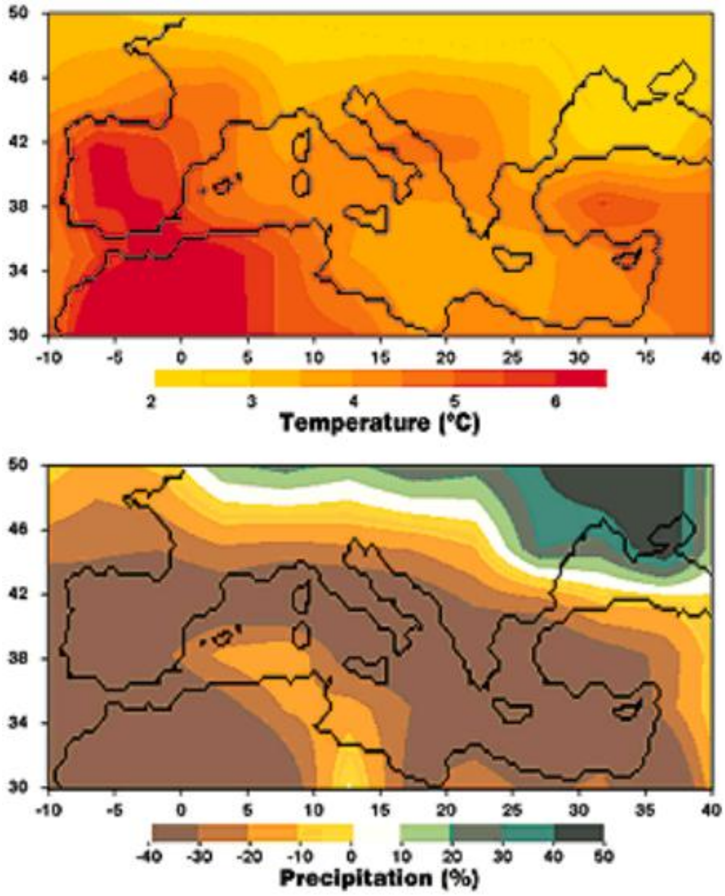

Figure II 6:Summer seasonal mean (precipitation and temperature) changes for the Mediterranean region (3)

2.4.3 Maghreb scale

In North Africa, Climate recent developments show that the warming is larger than average. Indeed, if the global temperature rise in the 20th century was of 0.74 ° C, that on the Maghreb was between 1.5 and 2 ° C in region (26), more than double the global average increase. As for the decrease in rainfall, it varies between 10 and 20%. On the other hand, many studies show that climate projections, developed by general circulation models (GCMs) currently underestimate rising temperatures and declining rainfall on the Maghreb(23). This shows that the Maghreb countries will suffer more than others. The effects of climate change are now a major concern for the region.

Projections developed for the Maghreb region (national communications of Algeria, Morocco, and Tunisia) depict trends of a decrease in rainfall and a gradual increase in the monthly average temperature in the Maghreb area. The results in (figureII.7)of the models RCP2.6 (2 °C world, left) and RC8.5 (4 °C world, right) show the evolution of average Temperature (°C) for June–July and August during the period 2071–2099 relative to the 1951–1980 period. These results show that average temperature will increase by 2–8 °C during 2071–2099 within the region (27).

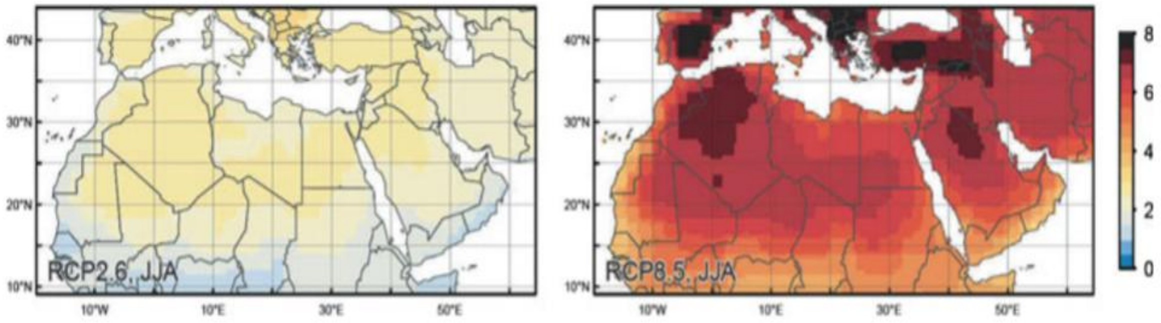

Figure II 7:Evolution of the average temperature (C°) of June-July and August during the period 2071-2099 relative t the 1951-198 period, results of the mdels RCP2.6 (2°C world, left) and RC8.5 (4°C world, right) (24)

2.4.4 Algerian scale

Algeria, the largest country in Africa, located in the southern Mediterranean, has a vulnerability to the impacts of global climate change due to its geographical location.

The climate has changed during the 20th century and the climate change signal appears to showbreaks in the rainfall pattern. Climate scenarios for this century indicate a risk of rain up to 20% reduction. Despite the uncertainties, these projections may affect strategic sectors, such as agriculture. Climate risk is in addition to other vulnerability factors related to social and economic development mode in a fragile natural environment and sometimes on the verge of an advanced degradation.

There is an increasevariability following the increase in the longitude and latitude decreased. Altitude appears to mitigate the increase. In Algeria, approximately 13% of land has a Mediterranean climate, the rest being dominated by a semi-arid desert climate.

As is the case in many Mediterranean countries, Algeria's climate is characterized by annual variability and inter-annual, [with very dry, dry years], [normal or - rarely – wet], responsible for a significant decrease in agricultural production. Rainfall occurs mainly from October to April, and the rains are often concentrated on a few days or hours. The temperatures are relatively high, causing significant evapotranspiration(23).

Since 1970, the minimum and maximum average temperatures are rising across the country, and this trend continues. Over the past two decades, the maximum temperatures rise faster than the minimum temperatures, and temperature rise reaches 2 ° C. The consequence of this temperature increase is clearly reflected by the decrease in the number of days of snow, which in some areas has decreasedfrom 26 days a year on average in the years 1971 to 1980 for 6 days during the period 1981- 1990.

Between 1923 and 1938, Algeria has experienced an excess in rainfall. This extrais about (17.6% in the East, 12.3% in the Center and 9% in the West) in the stations respectively. These are stations Constantine, Algiersand Oran (figure II.8).

From 1939, a dry period has begun and which lasted until 1946 to reach a deficit of 10.2% in the Center and 14.5% in the West. By contrast, in the east a surplus of 6.7% was recorded. The period 1947-1973 was characterized by a wet period with an excess of 13.1% at the center.

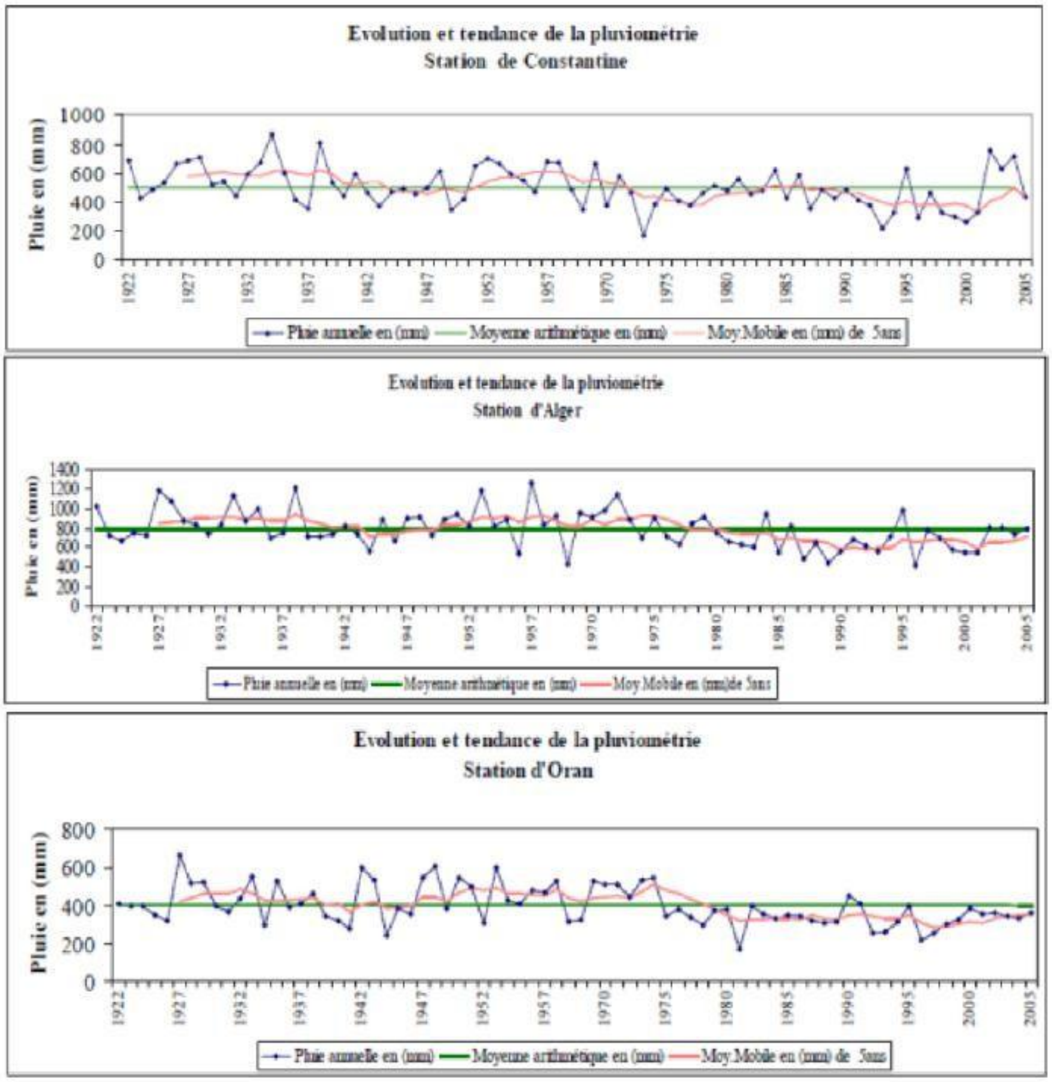

Figure II 8Evolution of annual precipitation in the resorts: Constantine, Algiers and Oran for the period 1922-2005 (3)

The drier periods were observed during 1949-1956 and 1960. Starting in 1974, changes in precipitation highlights a decrease of 13% in the East, 13.6% in Central and 16.1% in the West. Since 2000, rainfall remained in deficit in all region.

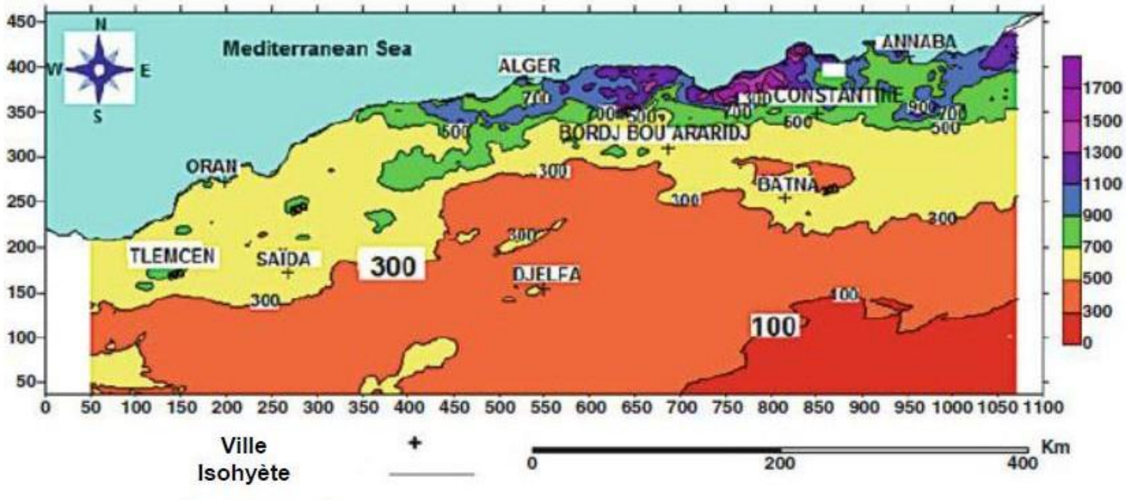

Figure II 9:Rainfall map according to ANRH for the period 1922-1989(28)

Figure II.9 and Figure II 10 show that isohyets 100 and 300mm evolve significantly in the north. This development is an indicator of climate change in Algeria. Indeed, examination of isohyets 100 and 300 mm shows that the northward shift can reach distances of over 100 km.

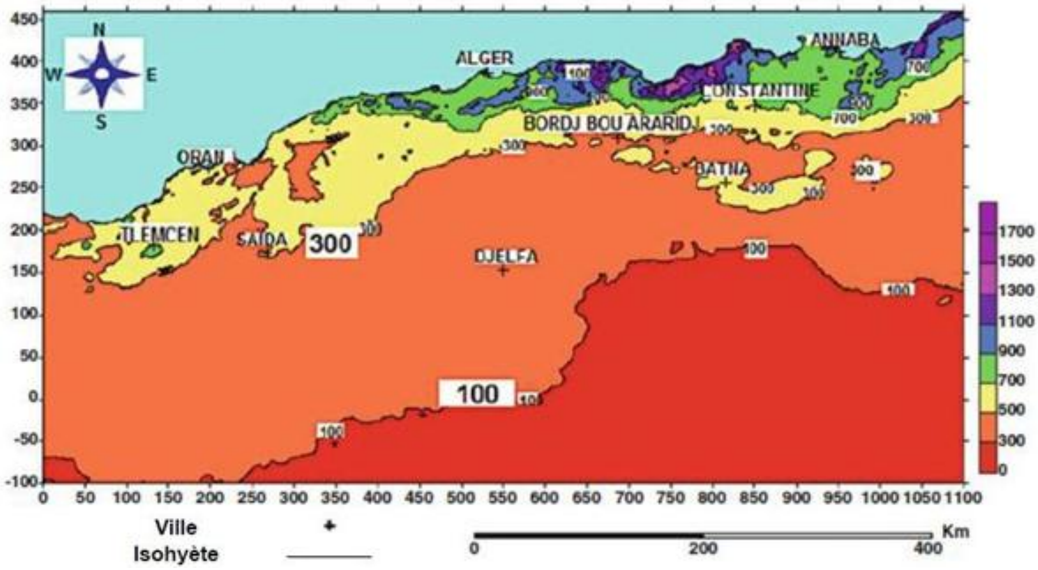

Figure II 10:Rainfall map for the period of 1965-2004 (28)

The general trend in the north is the decrease in rainfall that has become more pronounced since the mid-1970s. This phenomenon is even more pronounced in the western part of the country than in other regions (23).

2.4.5 The projected climate change in Algeria

Several sources can be used to obtain a consensus picture of climate projections on Algeria at various time horizons. The climate change in Algeria was analyzed on the basis of GCM UKHI and ECHAM3TR and IS92a IPCC greenhouse gas emissions. The UKHI model (United Kingdom Meteorological Office High Resolution) was developed in England in 1989 by English Weather Service. The ECHAM3TR model was developed in Germany in 1995 by the Max Planck Institute. Climate projections on Algeria, in 2020 and 2050 are provided in the form of cards at the annual and seasonal scale.

By 2020, projections indicate seasonal climate variations summarized in Table II.2(27). A warming of about 0.8 to 1.1 ° C is estimated for 2020 in the autumn together with a fluctuation in rainfall with a tendency to decline, about 5 to 8% in the short term. By cons in the long term, a reduction in rainfall has been envisaged which varies between 10 to 15% by 2050. In winter, the temperature increase is of the order of 0.6 to 0.8 ° C by 2020 and 0.9 to 1.6 ° C for 2050, against rainfall decreases from 10% to 20% from 2020 to 2050 (figure II.11).

Almost the same trends were observed in spring. In summer, the warming is estimated to 0.8 to 1 ° C to 2020 and from 1.3 to 2.1 ° C in 2050 with a precipitation fluctuation of the order of 8 to 13% in 2020 and 15 to 22% for 2050.

Table II 2:Seasonal climate forecasts of temperature and rainfall on Algeria in 2020 and 2050 for the 2020 model UKHU for ECHAM3TR IPCC models (13)

The same observation is recorded by using the ECHAM3TR model for an

<table>
<tr><th colspan="2">Model</th><th>Parameter</th><th>fall</th><th>Winter</th><th>Spring</th><th>Summer</th></tr>
<tr><td rowspan="4">UKHI model</td><td rowspan="2">2020</td><td>Temperature (° C)</td><td>0.8 - 1.1</td><td>0.65 - 0.8</td><td>0.85 - 0.95</td><td>0.85 - 1.05</td></tr>
<tr><td>Rain (%)</td><td>-6 to -8</td><td>-10</td><td>-5 to -9</td><td>-8 to -13</td></tr>
<tr><td rowspan="2">2050</td><td>Temperature (° C)</td><td>1.2 - 2.2</td><td>0.95 - 1.6</td><td>1.25 -1.9</td><td>1.25 - 2.1</td></tr>
<tr><td>Rain (%)</td><td>-10 to -15</td><td>-16</td><td>-10 to -20</td><td>-15 to -22</td></tr>
<tr><td colspan="2">Model
ECHAM3TR</td><td>Temperature (° C)</td><td>0.8 - 1.3</td><td>0.9 - 1</td><td>0.95 - 1.1</td><td>0.95 - 1.45</td></tr>
<tr><td colspan="2"></td><td>Rain (%)</td><td>No change</td><td>-5</td><td>-7 to -10</td><td>-5</td></tr>
</table>

average scenario, which provides an increase in temperature from 0.8 to 1.45 ° C to 2020 and a decrease precipitation of 5 to 10% (29)

The work of Giorgi and Lionello (2008) are a summary of the major results of climate simulations applied to the Mediterranean region. Several conclusions can be deducted for Algeria provide some useful guidance for precipitation projections (Table II.3). On the horizon: 2011-2040 and 2041- 2070, precipitation reductions range from 0% to 30% and 1% to 40% for B1 and A1B respectively. These projections provide, for Algeria, a decrease about 25% to 40% by the 2071-2100 periods for the A2 scenario. This decline is marked in the West region of Algeria

Table II 3:Climate projections for rainfall in Algeria on the horizon 2071-2100 under three scenarios of the IPCC (30)

Season	scenario A1B	scenario B1	A2 scenario
Winter	-20 to -30% West Center and Algeria	From -10 to -20%	-20 to -30%
(DJF)	-1 to -20% eastern Algeria		
Spring	-30 40% off western Algeria	-20 to -30% western Algeria	-30 until 40% (Greater than 40% on the West Algerian)
(MMA)	-20 to -30% in Algeria Center	-10 to -20% East and Algeria Center	
Summer	-30 40% off western and eastern Algeria	-10 to -20 West and East of Algeria	-30 until 40%
(JJA)	-20 to -30% in Algeria Center	0 to -10% Algeria's Center	
fall (HIS)	-10 to -20% Northern Algeria	-10 to -20% Northern Algeria	-20 to -30%

Moreover, an increase is expected in the frequency of droughts and a lack of contribution to the water surface by 15%, resulting in lower groundwater from 4.4% in 2020 and 6.6% in 2050 (23). So the region is moving towards a much more severe water scarcity in the coming decades.

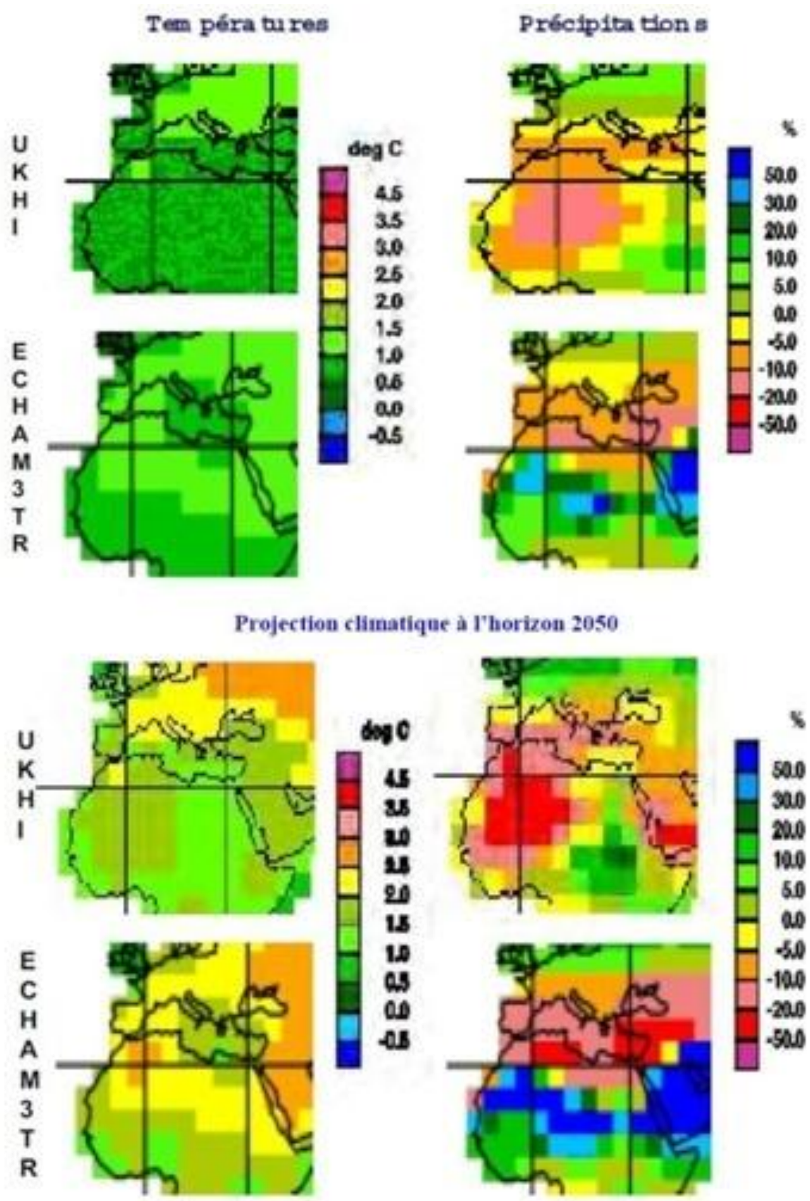

Figure II 11:Projected climate for 2020 and 2050 by the model and UKHI ECHAM3TR (31)

2.5 Climate change and water resources in Algeria

In Algeria, in recent decades, climatic conditions negatively influence the water resources (32).For example, the North-West of Algeria, a region known for its low rainfall regime, had a law 40% reduction in annual rainfall from the first half of the 1970s.

The river flows from this region are affected. During the period 1976-2002, average annual water slides decreased 28 to 36% lower than in the period 1949-1976 (32).

The sensitivity of water resources to climate change in 2020 was analyzed as part of the initial communication of Algeria (31).

Based on an assumption of doubling the allocation for drinking water and industry in 1997, and the doubling of the population in 2020, the analysis estimated water requirements to 8.3 billion m^3 / year in 2020, almost double the volume currently mobilized. The estimated impacts due to climate change on water resources is about 1.0 billion m3 by 2020 in the case of medium scenario and 1.9 billion m^3 in if the last scenario. In other words, the volume of water mobilized is at the limit of the country's needs in the case of medium scenario. It is less than 0.8 billion m^3 to the needs of the country in the case of high scenario (31). However, Algeria is already experiencing water scarcity(figure II.12).

These projections require several adjustment options including desalination of sea water, recovery of waste water, or injection of surface water into groundwater. The use of desalination of sea water is one of the possible answers to alleviate the water shortage due to a combination of increased demand and reduced supply. The orientations of the country focused on the strategy to free the country from dependence on rainfall for drinking water supply and particularly the western region of Algeria suffers from a persistent deficit in rainfall. But this approach cannot be a viable solution in the long term.

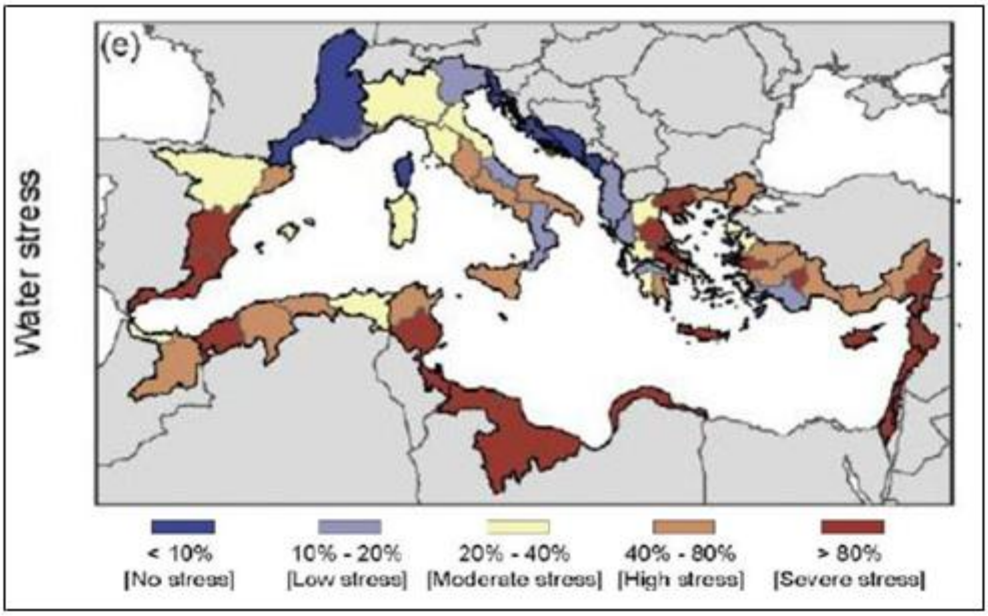

Figure II 12:Stress Screening and shortage of fresh water in 2050 (33).

2.6 Climate change scenarios

The use of climate models is made necessary by the complexity of the climate system. The process implemented by the IPCC to assess the consequences of human activities on the climate involves many disciplines. To this end, various development scenarios have been proposed, correspondingdifferent assumptions of evolution of our societies, including economic views, demographics and technology. In these scenarios are associated some programs for the next century.

The first scenarios were built in 1992 (IS92a). In its special report on the 2000 emission scenarios, the IPCC has proposed a new family of emission scenarios of greenhouse gas SRES (Special Report on Evolution Scenario), grouped into four large families (A1, B1, A2 and B2). These scenarios are summarized in Table I.1 (17).

2.6.1 Emission Scenarios

A1 scenarios:

Globalization, emphasis on human wealth Globalized, intensive (market forces). The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system:

- A1F1 in the world mainly continues to operate with fossil fuels,
- in A1T with non-fossil fuels,
- A1B in with a mixture of both.

The A2 scenario:

Regionalization, emphasis on human wealth Regional, intensive (clash of civilizations).The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.

The B1 scenario:

Globalization, emphasis on sustainability and equity Globalized, extensive (sustainable development) follows the A1 scenario, but the world turns quickly towards a service-based economy with a rapid introduction of clean and sustainable technologies.

The B1 storyline and scenario family describes a convergent world with the same global population that peaks in midcentury and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

The B2 scenario:

Regionalization, emphasis on sustainability and equity Regional, extensive (mixed green bag).

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

Table II 4:Summary of the main six SRES scenarios (24)

The groups Scenarios	A1FI	A1B	A1T	A2	B1	B2
Population growth	Low	Low	Low	Strong	Low	Average
Growth of GNP	Very strong	Very strong	Very strong	Average	Strong	Average
Energy consumption	Very strong	Very strong	Strong	Strong	Low	Average
Changing land use	low average	Low	Low	average high	Strong	Average
Availability of oil resources / gas development res	Strong	Average	Average	Low	Low	Average
Technological advances	rapid	rapid	rapid	Lents	Means	Means
Promotion of change	Coal, oil and gas	balanced	Non-fossil fuel s	regional	Efficiency and demalisation	regional

The SRES team defined four narrative storylines (figure II.13), labeled A1, A2, B1 and B2, describing the relationships between the forces driving greenhouse gas and aerosol emissions and their evolution during the 21st century for large world regions and globally. Each storyline represents different demographic, social, economic, technological, and environmental developments that diverge in increasingly irreversible ways.

Figure II 13:The IPCC SRES scenarios (28)

2.7 Global CirculationModel

From the early 20th century, despite the difficulty to account for all climate components and the interactions and feedbacks in the atmosphere, an English researcher had the idea of using the equations of fluid mechanics predict the evolution of the atmosphere. Indeed, in the years 1920-1922, LF Richardson tried first to numerically solve differential equations appropriate to produce a weather forecast six hours. For lack of means of calculation, the result was disappointing but the experience was beneficial to future generations. More than forty years, when the first computers were invented (34). In 1950the work of Richardson took up to a numerically solve equations simplified weather. Then, in 1960, two teams approached the study of the atmospheric flow in its global dimension.

The GFDL team (Geophysical Fluid Dynamics Laboratory) with Smagorinski J. and S. Manabe, and the UCLA (University of California at Los Angeles) with Y. Arakawa and A. Mintz worked on more sophisticated physical parameterizations and suppressed some approximations to use atmospheric models at all latitudes (www.gfdl.noaa.gov). But it was only in the seventies and eighties, the development of general circulation models (GCM) of the atmosphere spreads.

These first generation GCMs incorporate the most essential processes in the maintenance of general circulation of the atmosphere. They are based on mathematical equations that describe the dynamic processes related to atmospheric flow, and physical processes related to mass exchanges, energy and momentum in the atmosphere and the atmosphere interface / ocean, atmosphere / sea ice and atmosphere / biosphere. These equations are derived from the basic laws of fluid mechanics and thermodynamics and empirical formulations to represent certain physical processes.

One of the main reasons were behind the rapid development of climate models (GCM and RCM) is to determine the effect of the increase in greenhouse gases on climate change during the 21st century. There is currently a consensus among the majority of scientists on the global warming expected by MCG (IPCC report, 1996), due to the increase of gases such as CO2 or CH4. This consensus, however, accompanied by a large uncertainty about the magnitude of the temperature increase by 2100. On the one hand, the scenarios proposed by the MCG depend intrinsically, assumptions as to the increase of these gases in the future, according to forecasts by economic and population growth in the world

There are a wide range of global models and products recognized throughout the world, those are consistent simulation tools that give a good assessment of the general trends of future climate. However, they are much less appropriate when it comes to refine the results to a specific region. These models do not include enough small meshes to represent properly for example a watershed.

Climate models use scenarios for the future evolution of forcing agents (such as greenhouse gases and aerosols) to establish a set of projections describing what could happen in the future in terms of climate change. The outputs of the MCG are simulated chronic climatic parameters (temperature, precipitation, etc.)

Data from GCM outputs are used with caution. Several approximations in modeling the climate system explain the uncertainty of the results and the gap between simulation and real climate as the problems of scale (spatial resolution of GCMs)(35).

However, global climate models are not designed to study the local change impacts and do not allow to obtain a good estimate of climate parameters for example in a watershed. To enable this regional modeling, researchers have developed various procedures that can solve these problems and represent the best of their ability distinct climates locally.

The downscaling technique in space (downscaling) contributes to the achievement of climate data in finer resolution results from global models. To do this, it is hypothesized that there are strong links between regional climates and larger scales, and that these relationships remain valid under a future climate. The use of this tool can improve the information provided by the script and even incorporate some regional climate controls, but its effectiveness will depend greatly on the study area and the availability of climate data (36).

The approach implemented for the production of climate simulations usable by the impact study on the hydrological cycle mobilizes a series of steps summarized as follows (figure II.14).

Step 1: Emission scenario construction and / or gas concentration greenhouse. These scenarios are the result of socio-economic factors to consider across the globe: demography, energy choices, economic growth, agricultural, ...

Step 2: Modeling of climate change with global models wide mesh. These models simulate global atmospheric circulation system (with its oceans / atmosphere interactions) and the impact of greenhouse gases on the system.

Step 3: Descent scale. This is to obtain, from the data output from global models, for various possible methods, results of climate projections to a no finer space compatible with the objects on which we will study the impacts of change climate (the case of our watershed).

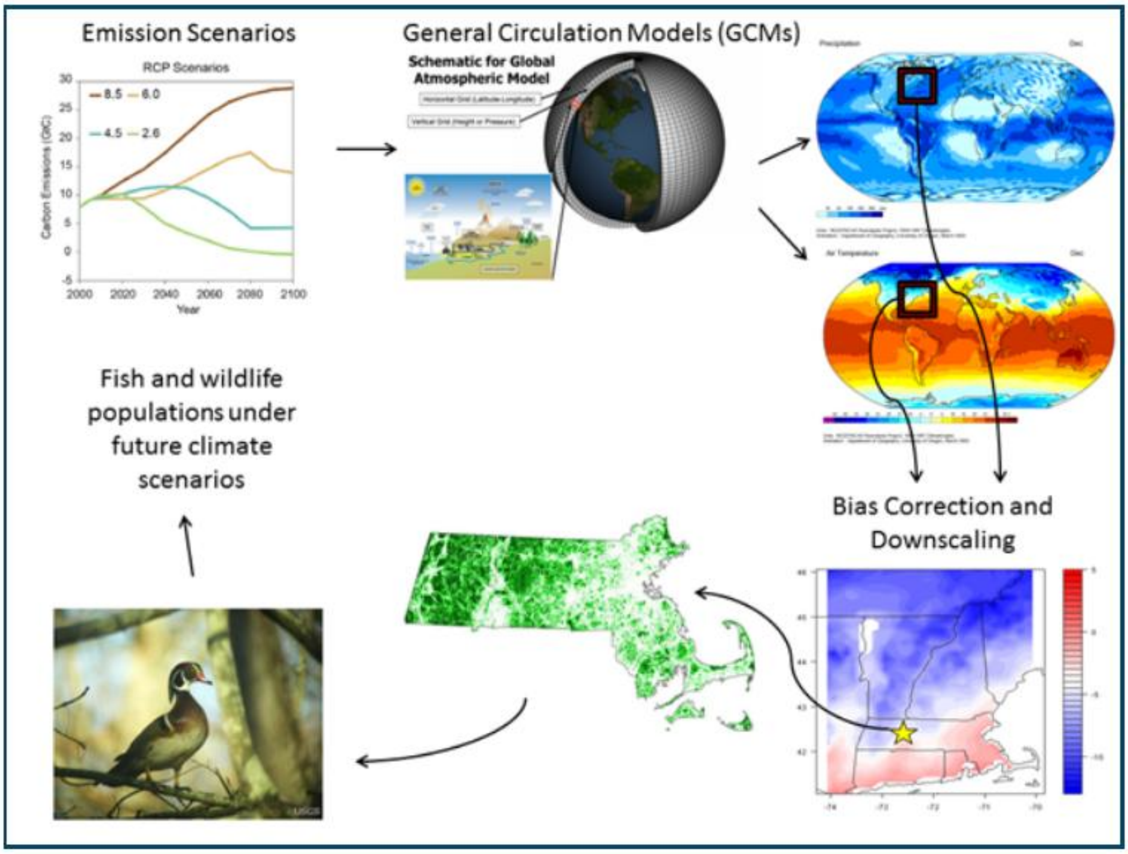

Figure II 14:Overview of climate modeling steps

2.7.1 HadCM3

AOGCMs are the main component of global climate models (GCMs) which are the primary tools used to quantify and assess climate change impacts.

HadCM3 (abbreviation for Hadley Centre Coupled Model, version 3) is a coupled atmosphere-ocean general circulation model (AOGCM) developed at the Hadley Centre in the United Kingdom.It was developed in 1999 and was the first unified model climate which does not need flux adjustment (artificial adjustments applied to climate model simulations to prevent them drifting into unrealistic climate states). HadCM3 is composed of two components: the atmospheric model HadAM3 and the ocean model HadOM3 (which includes a sea ice model). Simulations use a 360-day calendar, where each month is 30 days.

The highly quality of current climate simulation using HadCM3 model, made it one of the most efficient and reliable model in climate change studies. HadCM3 ranks highly compared to other models and was usedin the IPCC Third and Fourth Assessments report, and also contributes to the Fifth Assessment.

The Geographic coverage of HadCM3 model is shown below (figure II.15)

Figure II 15:HadCM3 geographical coverage

<u>Spatial coordinates</u> :

N: 90.0 **S:** -90.0 **E:** 180.0 **W:** -180.0

Min Altitude: 0 KM **Max Altitude:** 50 PA

Min Depth: 0 KM **Max Depth:** 5.2 KM

Temporal Coverage:

Start Date: 1989-12-01

Stop Date: 2099-12-01

The HadCM3 data can be downloaded from IPCC and also the Canadian Climate Impact Scenarios and CCIS provides all the NCEP and HadCM3 data in the grid box based on the value of latitude /longitude of the study area so that the grid box provides a zip file contains three directories: NCEP-1961-2001, H3A2a-1961-2099 and H3B2a- 1961-2099.

NCEP-1961-2001: It contains all the observed predictor data produced from NCEP/NCAR. There is a difference in the resolution in grid cells of NCEP and HadCM3, all the 41 years of daily observed predictor data were interpolated to the same grid as HadCM3 and then the data were normalized.

H3A2a-1961-2099: it contains 139 years of daily GCM predictor data assuming a characteristic of scenarios with higher rate of GHG emissions in combination with higher sulphate and other aerosol emissions. HadCM3 A2a data was normalized over the 1961-1990 period.

H3B2a-1961-2099: this directory contains 139 years of daily GCM predictor data assuming a characteristic of scenarios with higher rates of GHG emissions in combination with lower rate of sulphate and other aerosol emissions. HadCM3 B2a data normalized over the 1961-1990 period.

The normalization is done by dividing each time slice of future (2011-2040, 2041-2070 and 2071-2099) to the current period (1961-1990).

HadAM3 is a grid point model (figure II.16) that has a horizontal resolution 2.5° latitude × 3.75° longitude for the atmospheric component and 1.25° × 1.25° in the oceans. There are 19 levels in the atmosphere and 20 vertical levels in the ocean (37).This corresponds to a spacing between points of approximately 300 km. There are 96 × 73 grid points on the scalar (pressure, temperature and moisture) grid; the vector (wind velocity) grid is offset by 1/2 a grid box.

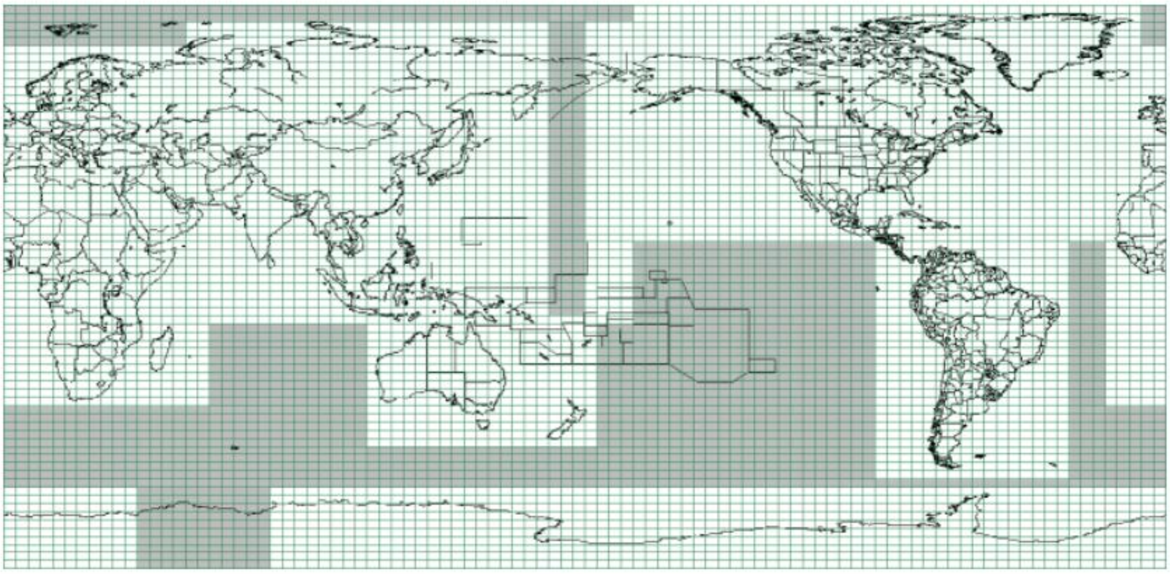

Figure II 16: Data grid box for HadCM3 model (http://climate-scenarios.canada.ca/?page=pred-hadcm3)

2.8 Predictors (large scale atmospheric variables)

Both the observed and GCM-derived predictor variables have been normalized with respect to their 1961-1990 means and standard deviations. That is, the mean and standard deviation for the 1961-1990 period were calculated and the mean subtracted from each daily value before dividing by the standard deviation.

The predictor variables supplied below have been normalized over the complete 1961-1990 period. Other options include normalization by season, which may improve the performance of the statistical downscaling model, particularly in regions where there is a distinct seasonal climate pattern. The volume of data involved means that it is not possible to supply a number of predictor datasets which have been prepared using a number of different normalization options. However, by obtaining the raw observed and raw GCM output, it is possible for you to construct your own predictor datasets using different normalization options.

The observed large-scale predictors have been derived from the NCEP reanalysis dataset. The source data were provided by the NOAA-CIRES Climate Diagnostics Center, from where you can obtain a full description of the data(http://climate-scenarios.canada.ca/?page=pred-help).

VARIABLE	DESCRIPTION	ADDITIONAL NOTES
temp	Mean temperature at 2m	
mslp	Mean sea level pressure	
p500	500 hPa geopotential height	The height of this surface will vary depending on the temperature of the atmospheric column: warmer=higher; cooler=lower
p850	850 hPa geopotential height	The height of this surface will vary depending on the temperature of the atmospheric column: warmer=higher; cooler=lower
rhum	Near surface relative humidity	The vapour content of air as a percentage of the vapour content needed to saturate air at the same temperature
r500	Relative humidity at 500 hPa height	
r850	Relative humidity at 850 hPa height	
shum	Near surface specific humidity	The mass of water vapour as a proportion of the total mass of moist air of which it is a part; can be used for tracking air masses
s500	Specific humidity at 500 hPa height	
s850	Specific humidity at 850 hPa height	

Figure II 17:(GCM predictions **http://climate-scenarios.canada.ca/?page=pred-help)**

DERIVED VARIABLES	**The following variables have been derived using the geostrophic approximation**	
**–_f	Geostrophic air flow velocity	
**–_z	Vorticity	A measure of the rotation of the air
**–_u	Zonal velocity component	Velocity component along a line of latitude (i.e. east-west)
**–_v	Meridional velocity component	Velocity component along a line of longitude (i.e. north-south)
**–zh	Divergence[1]	Relates to the stretching of a fluid, and usually refers to the outflow of air from the base of an anticyclone in meteorology
**–th	Wind direction	This is the only variable which is **NOT** normalised

Figure II 18:GCM predictors (http://climate-scenarios.canada.ca/?page=pred-help)

2.9 Downscaling

Downscaling is the general name for a procedure to take information known at large scales to make predictions at local scales. General circulation models used for climate simulations across the globe typically have a resolution of the order of several hundred kilometers. Similarly, with this resolution, these models do not provide enough accurate data (spatially) for all climate change impact studies, such as the impact of climate change on runoff, on glaciers; on coastal ocean ... These areas need more simulations at high spatial resolution. The downscaling is thus necessary when climate simulations are used as input data hydrological models that simulate the transformation of the rain flow across watersheds.

Several solutions exist to obtain information at a finer resolution. The method used to downscale large to fine-scale climate can be done at temporal and spatial features of climate projections. Spatial downscaling refers to the derivation of climate information at finer spatial resolution from coarser spatial resolution GCM output (e.g., 20 km resolution from 500 km grid cell GCM output). Temporal downscaling refers to the derivation of fine-scale temporal data from coarser-scale temporal GCM output information (e.g., daily data from monthly or seasonal information) (38). Downscaling procedures can be grouped in to two approaches Dynamical downscaling (DD) and Statistical downscaling (SD).

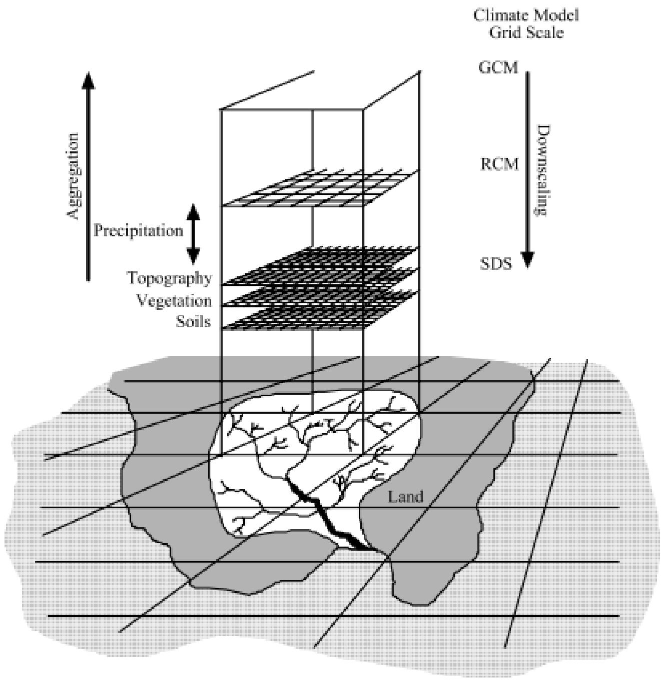

Figure II 19: Schematic illustrating the general approach to downscaling(39)

2.9.1 Dynamic Downscaling

Dynamic downscaling (DD) approach is a computationally-intensive technique which makes use of the lateral boundary conditions combined with regional-scale forcings such as land-sea contrast, vegetation cover, etc., to produce regional climate models (RCMs) from a GCM. RCM outputs are typically produced over regular geographic grids with scales in the tens of kilometers.

2.9.2 Statistical downscaling

Statistical downscaling (SD) is a computationally less demanding alternative that may be applied to achieve a variety of results. Essentially, statistical downscaling is a two-step process consisting of:

1. The development of statistical relationships between local climate variables and large-scale predictors.

2. The application of such relationships to the output of large-scale output to simulate local climate characteristics in the future (39).

Statistical downscaling is a realistic approach to develop a specific, local-level climate prediction. Typically, SD methods are applied to GCM projections, but may also be applied to RCM output as these results may not be representative for the local climate (40). Furthermore, RCM output may simply have inadequate spatial resolution for some impact studies, and hence additional statistical downscaling must be applied to the dynamical model results (38).

Statistical downscaling can produce site specific climate projections, which RCMs cannotprovide because computationally limited to a 20-50 km spatial resolution (41). Theseapproaches require less computational effort than dynamic downscaling, it tests scenarios forlonger timeframes (decades or centuries) rather than the brief (shorter timeframes) of thedownscaling approach (42). This allows the users to develop a large number ofdifferent climate simulations and thus investigate the statistical characteristics of downscaledvariable.

Moreover, SD methods allow talking weather data available at the study site intoaccount. However, this approach relies on the critical assumption that the relationship betweenpresent large scale atmospheric circulation and local climate remains valid under differentforcing conditions of possible future climates.

2.9.3 Statistical downscaling Model (SDSM)

Large-scale atmospheric variable data need to be preprocessed before using them for training the downscaling models. Standardization is carried out prior to statistical downscaling to reduce systematic biases in the mean and variances of GCM outputs relative to the observations or NCEP–NCAR data. The procedure typically involves subtraction of the mean and division by the standard deviation of the predictor variable for a predefined baseline period for both NCEP–NCAR and GCM output. The period 1961–90 is used as a baseline because it is of sufficient duration to establish a reliable climatology, but it is not too long or too contemporary to include a strong global change signal (43). A major limitation of standardization is that it considers the bias in only mean and variance. There is a possibility that the reanalysis data and GCM output may deviate from the Gaussian distribution, and bias may exist in other parameters, such as skewness and kurtosis. Thus, multidimensionality of the predictors may lead to a computational intractability and large-sized model with high multicollinearity. To reduce the dimensionality of the explanatory dataset, methods such as principal component analysis (PCA), independent component analysis (ICA), multidimensional scaling (MDS), factor analysis, and maximum variance unfolding (MVU) can be used critically reviewed and compared different dimensionality reduction methods and concluded that PCA is the best among all the methods.

SDSM developed by Wilby is a hybrid of multiple linear regressions (MLR) and the stochastic weather generator (SWG)(44). MLR establishes astatistical/empirical relationship between NCEP, large-scale variables, and local scalevariables, and produces some regression parameters.

The Statistical DownScaling Model (SDSM) is a freely available tool that produces high resolution climate change scenarios. DSM began life in summer 2000 as a crudely interfaced Visual Basic programme designed to teach five elemental steps in statistical downscaling:

Selection of predictor variables,Calibration of the model (using observed predictors), Validation of the model, Generation of future scenarios (using climate model predictors),Analysis of outputs (using a range of climate diagnostics).

2.9.4 Multiple Linear Regressions(MLR)

Multiplelinearregressionusingprincipal components MLR is a statistical downscaling technique that consists of finding a linearrelationshipbetweenadependent(observed)variableandmore than one independent variable (outputs of the general circulation models (GCMs). MLR is used to model the relationship between large-scale predictor variablesand a regional-scale hydrologic variable by fitting a linear equation to the observed data. Each value of the predictor variables is associated with avalue of the hydrologic variable. Thus, MLR is used to predict thevalues of a hydrologic variable Y given a set of p predictor variables (X1, X2,...,Xp). Regression analysis is performed using principal components and membership values obtainedfrom the fuzzy c-means clustering method. The following equations involvingthe seasonal components are used for regression analysis(45).

$$Y_i = a + b_1X_1 + b_2X_2 + \cdots + b_mX_m + C, \quad (1)$$

Where

Yi is the dependent variable; X1, X2, ...,

Xm are the independent variables;

a is the intercept; b1, b2, and bm arethe multiple regression coefficients, to be estimated by theleast-squares method andC is the error term (46).

In spite of their obvious success in many applications, MLRs present multicollinearity when employed with climaticvariables. In this regard, the parameter estimation errorscan be incorrectly interpreted (47).To resolve this problem, we used principal components (PCs).This method seeks to reduce the number of variables throughorthogonal transformations and to remove the multicollinearityof the independent variables. The PCs of the explanatory variables are therefore a new set of variables with the sameinformation as the original variables, but uncorrelated.

2.9.5 NCEP/NCAR Predictor Data

The National Centers for Atmospheric Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) have accomplished different re-analysis projects which aim on the generation of global data sets for a long time period for different atmospheric parameters.

- NCEP/NCAR has all the gridded predictor variables to use in calibration and validation in SDSM. It has:
- Spatial resolution: about 2.5° x 2.5°, Gaussian grid
- Geographic longitude: 0.0°E to 358.125°E
- Geographic latitude: -88.542°N to 88.542°N
- Dimension: 192 columns x 94 rows

NCEP/NCAR provided a 40-year record of global analysis of atmospheric predictors. The 26 predictor variables are produced by state-of-art assimilation of all available observed weather data into a global climate forecasting model that produces interpolated grid output of many weather variables (Reza, 2014). The data can be obtained from (http://www.cics.uvic.ca/scenarios/sdsm/select.cgi).This free data set is updated continuously and has therefore many users worldwide.

Predictor code	Description
p500	500 h Pa Geopotential height
p8_v	850 h Pa Meridional velocity
s500	500 h Pa Specific humidity
shum	1000 h Pa Specific humidity
p5_u	500 h Pa Zonal velocity
p_u	1000 h Pa Zonal velocity
p5_v	500 h Pa Meridional velocity
s850	850 h Pa Specific humidity
p–v	1000 h Pa Meridional velocity
p8_u	850 h Pa Zonal velocity
mslp	Mean sea level pressure
p850	850 h Pa Geopotential height
p5th	500 h Pa Wind direction
p_th	1000 h Pa Wind direction
p5_f	500 h Pa Wind speed
p5_z	500 h Pa Vorticity
p8_f	850 h Pa Wind speed
p5zh	500 h Pa Divergence
p8_z	85 0 h Pa Vorticity
p_f	1000 h Pa Wind speed
temp	Screen (2 m) air temperature
p8zh	850 h Pa Divergence
p__z	1000 h Pa Vorticity
p8th	850 h Pa Wind direction
p_zh	1000 h Pa Divergence

Figure II 20: List of predictor variables from NCEP (48)

2.9.6 SDMS Software

The SDSM software is a hybrid of multiple linear regressions (MLR) and the stochastic weather generator (SWG). MLR establishes astatistical/empirical relationship between NCEP, large-scale variables, and localscalevariables, and produces some regression parameters. SDSM Software reduces the task of statistically downscaling daily weather series into sevendiscrete steps (43):

1. Quality control and data transformation: Few metrological stations have 100% complete and fully accurate data sets. Handling of missing and imperfect data is

necessary for most practical situations. Simple quality control checks enable the identification of the gross data error, specification of missing data codes and outliers prior to model calibration.

2. Screening of the predictor variables: Identifying empirical relationships between gridded predictors (such as mean sea level pressure) and single site predict and (such as station precipitation) is central to all statistical downscaling methods. The main purpose of screening variables operation is to assist the user in the section of appropriate downscaling predictor variables.

3. Model calibration: The "Calibrate" model operation takes a user-specified predictand along with a set of predictor variables, and components the parameters of multiple regression equation.

4. Weather generator: The weather generator operation generates ensembles of synthetic daily weather series given observed or National Center for Environmental Prediction (NCEP) re-analysis atmospheric predictor variables. The procedure enables the verification of calibrated models (using independent data) and the synthesis of artificial time series for present climate conditions.

5. Data analysis: SDSM provides means of interrogating both downscaled scenarios and observed climate data with the Summery Statistics and Frequency Analysis screens.

6. Graphical analysis: Three options for graphical analysis are provided by SDSM 5.2 through the Frequency Analysis, Compare Results and the Time Series Analysis screens.

7. Scenario generations: the scenario generator operation produces ensembles of synthetic daily weather series given atmospheric variables supplied by a climate model.

Advantage of using SDSM in downscaling climate parameters as stated by :

It has been widely used in many watershed scales over arrange of different climaticcondition in the world by producing reliable results.It is user friendly and freely available software which can be downloaded from (http://co-public.lboor.ac.uk/cocwd/SDSM/).It generates ensembles which enable the user to implement uncertainty analyses(49).

2.10 Review of previous study

Several authors have studied the rainfall deficit in Tafna region, which could contribute to the planning of water resource management and mobilization strategies.

Agricultural production, drinking water supply, recreation, economy… depends mainly on rainfall and water potential. Indeed climate change has influenced Tafnarainfall in the region so it has riddled extreme events such as drought intense rain, violent floods(50).

Tafna suffered a significant reduction in rainfall, which resulted in a runoff deficit and caused a serious shortage of drinking water. This break in the chronological evolution of rainfall, which began in the mid-1970s and early 1980s of water drained by rivers; Benibahdel 69% and Meffrouche 60% .(51) The rate of precipitation decrease is 23% to more than 36%. The sudden ruptures occurred during the winter and spring. Interannuel precipitation varies greatly from year to year and from station to station; a wet year can suddenly be replaced by a dry year without transition (10). This is the case of the main Tafna stations, the number of dry years after 1975 is greater than 62%.

Given the seriousness of the water situation in the basin, the water needs are considerably increased, the different planners and manager wondered about the extent and the extension of the phenomenon, its causes and its consequences and the strategies to be implemented to mitigate its effect.

Kamini, evaluated the rainfall deficit of Tafna basin between 1941-2006, in order to model and regionalize the relationship (rainfall-runoff) to climate change, using statistical methods for the evaluation of rainfall and GR2M model for modeling (rainfall-runoff) (19). The results of the different statistical methods applied to the series of rainfall and hydrometric variables shows a decrease from the mid-1970s to early 1980s. The annual rainfall deficit reached average valuesof 38, 11% during the period of 1941-2006 and 29, 39% during the period of 1970 to 2010. The average annual runoff of the Wadis has average deficits of 61, 10% between 1912 and 2000 and 53, 13% between 1973 and 2009. The GR2M conceptual model has simulated the observed hydrographs in an acceptable manner by giving calculated flow, in calibration as in validation, by values greater or less than the observed runoff.

The regionalization of the calibration parameters of the GR2M model using the information contained in the descriptors of the subgauged sub-basins and using the linear regression method gave predetermination equations allowing the transfer to the ungauged sub-basin. The result ofthe regionalization of the model is considered satisfactory.

Description of study area

The watershed of Tafna is a hydrographic basin located in the north western Algeria, it carries the code 16 of the 17 basins of Algeria and belongs to the region Oran hydro-ChottChergui.

3.1 Geographic location

Located in the extreme northwestern Algeria, Tafnawatershedis a transboundary basin with an area of 7245 km^2, less than a third of its area is located on Moroccan territory. It is bounded by 1 ° and 2 ° west longitude and 34° 5'at 35 ° 3 'north latitude (51). With an area of 5340 km^2 on the Algerian territory, Tafna watershed is for the most part, occupied by the municipalities of the province of Tlemcen (35/53 municipalities) and some municipalities in the wilaya of Ain Temouchent (03/28 Municipalities)(52)

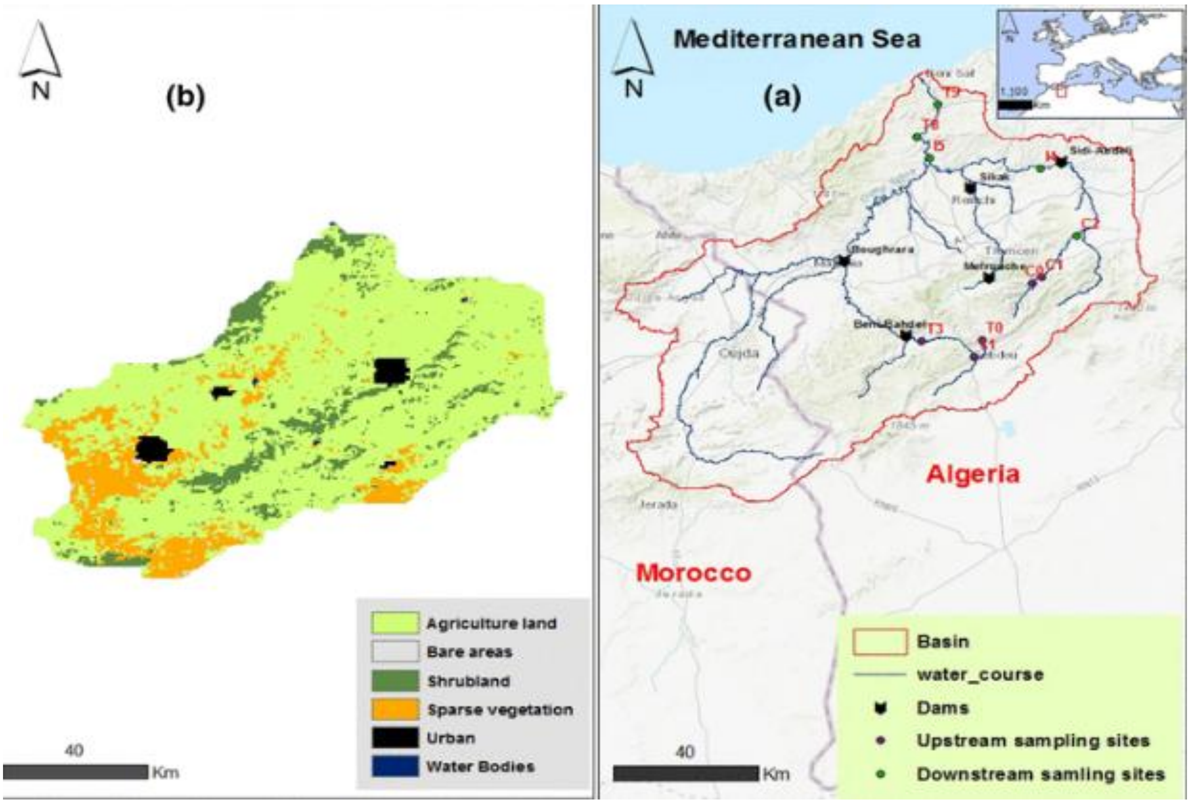

Figure III 1:Geographic location of Tafna catchment

The catchement is divided into different sub-basins which are:

Table III 1:Tafna sub-basins (53)

Sub-Basin code	Sub-Basin	wadis
1601	Mouilah upstream	Mouilah
1602	Mouilah downstream	Mouilah
1603	Boughrara	Mehaguéne
1604	Tafna upstream	Tafna
1605	Boukiou	Boukiou
1606	IsserCedra	Cedra
1607	IsserSikkak	Sikkak
1608	Maritime Tafna	Tafna

Most of OuedMouillah sub-basin covers the plain of Angad in the Moroccan territory and the plain of Zriga in the Algerian territory.

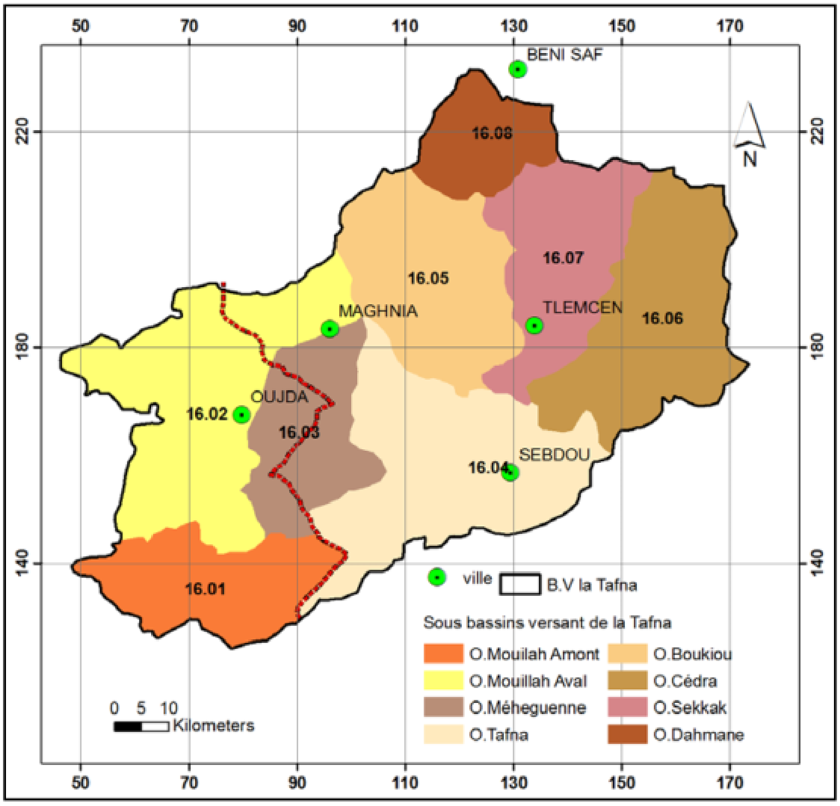

Figure III 2:Tafna sub-basins (54)

3.2 Characteristic of the catchment

The sub-basins of the Tafna generally have a fairly compact form, favoring a priori, time of concentration of runoff but the influence of the relief is even more crucial.

Table III 2:Tafna hydrological unit's characteristic (49)

Basin	Area (Km²)	Perimeter (Km²)	Compactness index	Equivalent rectangle	
				Length	Width
WadiKhemis	350	93	1.39	37.23	9.4
WadiSebdou	255.5	78	1.37	30.70	8.32
WadiMouilah	2650	230	1.25	82.96	31.94
WadiZitoun	140	65	1.54	24	5.83
WadiBoumessaoud	118	59	1.52	24.53	4.81
WadiEnnchef	86	46.7	1.41	9.04	9.51
WadiSekkak	46.3	116	1.5	48.49	9.55
WadiChouly	288.9	115	1.28	21.7	13.31
WadiIsser	1139.74	180	1.49	85.26	13.37
WadiBoukio	117.3	58	1.5	23.91	4.9

The values of the compactness index (Table) show that the Wadi of Mouilah and Chouly are the most compact wadis of the bassin (Kc <1.3) while the longest basin corresponds to Boumessaoudwadi (Kc = 1.52). Besides these extreme data all other values are very close, the forms of the corresponding basins are therefore more or less similar(55).

3.3 Hydrographic network

The river system is organized around two main wadis, the Isser east and Tafna. The west hydrology stream is Mediterranean. It includes a period of wet winter with a relatively high flow during heavy rainfall, and a period of dry summer, with a reduced rate until the complete drying of the wadis from the piedmont area, especially in recent decades. Like all Mediterranean wadi, Tafna'swadi is characterized by violent floods.

In any season, severe storms can cause flooding morphogens capable of destroying bridges and redoing or move wadi beds, erode the banks and move huge amounts of sediment.

The upper parts of wadis fed by springs are often perennial, This is no longer the case of downstream parties, which have a strong drayning accentuated by the establishment of reservoirs (BeniBahdel, HammamBoughrara).

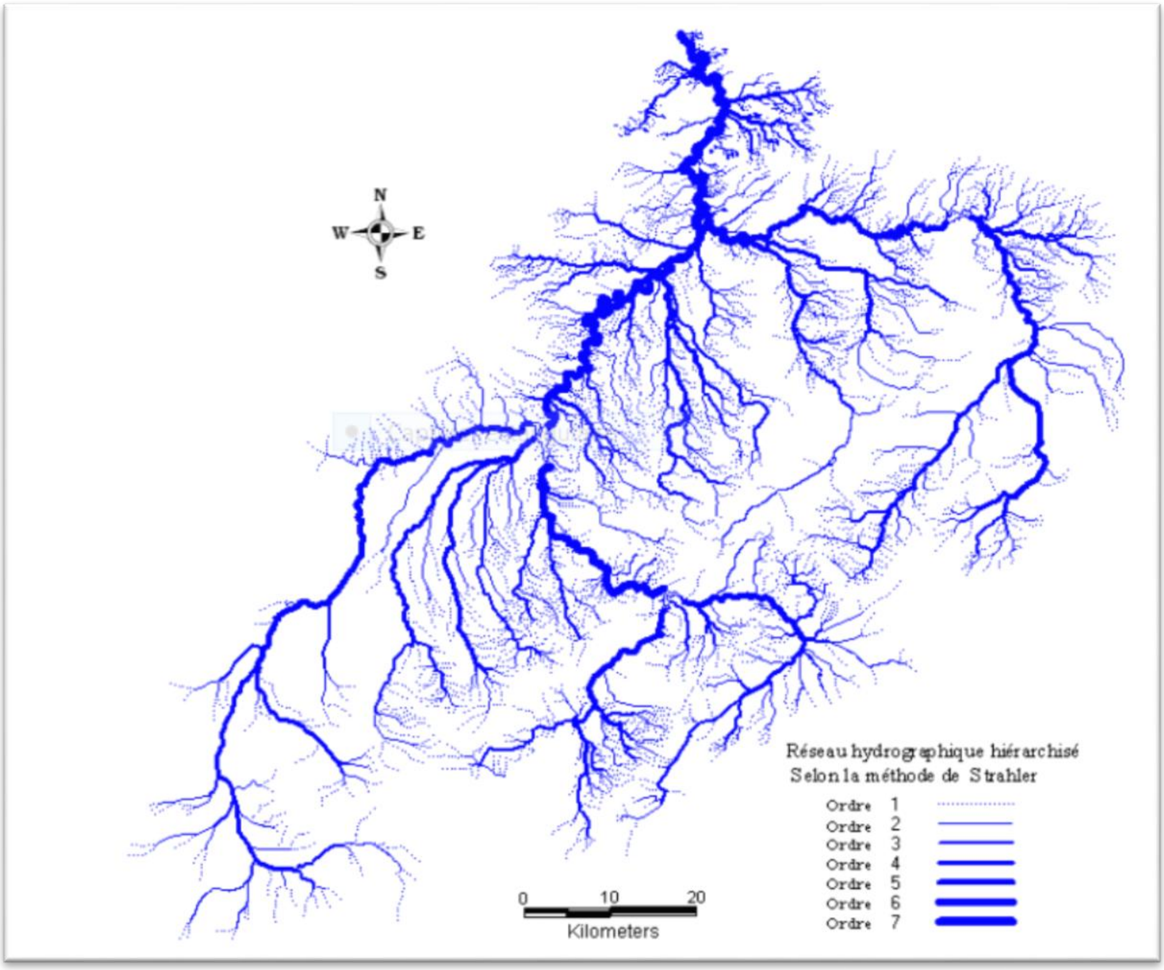

Figure III 3:Hydrographic network (19)

Important parameters that govern the hydrological regime of rivers are: Drainage density (Dd), the Confluence ratio (Cr) and the length ratio (Lr).

Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin. It is a measure of how well or how poorly a watershed is drained by stream channels. It is equal to the reciprocal of the constant of channel maintenance and equal to the reciprocal of two times the length of overland flow.

Drainage density (Dd), expressed by km / km^2, is defined by the following relation:

$$D_d = \frac{\sum_1^n L_x}{A} \text{ (eqI.11)}$$

With:

x: Length of the river of order x (km);n

Σ_1^n LX: Total length of the hydrographic network;

A: Watershed area.

Confluence ratio

This is the ratio of the number of thalwegs of order x and that of thalwegs of immediately higher order (x + 1). It is given by the following relation:

$$R_c = \frac{N_x}{N_{x+1}} \text{ (eqI.12)}$$

Length ratio

It is the ratio between the average length of the thalwegs of order (x + 1) by that of the thalwegs of order immediately lower (x). This report is given by the following relation:

$$L_R = \frac{L_{x+1}}{L_x} \text{ (eqI.13)}$$

Table III 3:Morphometric parameters of the main hydrological units Tafne

Sub-Basin	Dd	Cr	Lr
KhemisWadi	3.22	3.88	2.08
SebdouWadi	2.88	3.43	2.38
MouilahWadi	0.16	3.88	2.34
ZitounWadi	2.42	3.50	3.16
BoumessaoudWadi	2.39	3.55	2.83
ElnachefWadi	2.51	3.37	1.82
SikkakWadi	1.51	3.76	2.63
ChoulyWadi	0.61	3.76	2.81
IsserWadi(Bensekrane)	1.08	3.70	2.05
BoukiouWadi	2.97	4.25	2.53

Tafnawadi is the main river basin with 170 km in length, it takes its source in the mountains of Tlemcen. The course of this river can be divided into three parts: the high Tafna, middleTafna, andlow Tafna(53);(55)

High Tafna:

The wadi originates in the OuledOuriach and asserts itself after the junction of a large number of branching dug in Jurassic grounds and descend from peaks reaching 1500m. These branching meet around Sebdou at an altitude about 900m.

From this point until SIDI MEDJAHED, the river follows a course in a deep valley dug in the Jurassic. In this mountainous area, the river receives TafnaOuedKhemis (right bank) and WadiSebdou (left bank).

MiddleTafna :

From SidiMedjahed, the wadi enters the tertiary basin and flows into a shallow valley in more or less clay soils, this part of the Tertiary basin is furrowed by numerous tributaries among which some are important:

On the left bank: Tributaries are less important than the right bank, only wadiMouilah that originates in Morocco is remarkable for its course and flow. Boukiou is less important, originates in the mountains of Traras to join during the Tafna in the plain of Ghossel.

On the right bank: the Tafna receives the wadiBoumessaoud, wadiZitoun and finally wadiIsser, tributary most important for its long circuit than for its high flow. WadiIsser starts in the Jurassic, the mountains of Tlemcen and thus extends to the east of the high Tafna region. On entering the tertiary basin is grown north of OuledMimoun by Lakhdarwadi (egChouly) (left bank) and Wadi Ain Tellout (right bank). In the north of the plain of OuledMimoun, he crossed the small plain of ElFehoul. At the western end of the plain, he receives on the left a sizeable rivers: OuedSikkak, down from Terny tray.

The low Tafna:

The lower reaches of Tafna extend from the gorge to the village of Tahouaret Peter Cat Rachgoune to the beach in the Mediterranean Sea, a distance of 20 km in the case of Tafna, the significant size. Catchment (7245 km^2) and even that partial basins controlled by gauging stations as well as its geological complexity, make such a very delicate study. Also, the work scale adopted corresponding to 1/200000 does not allow high precision in the determination of morphometric parameters in question. Therefore, we will limit ourselves to a few physical characteristics that could describe the basin in general and its various units while those appearing before them, without claiming to draw comprehensive conclusions.

3.4 Hydrology

The hydrological regime of the wadis is Mediterranean;during the wet period the flow of the wadis is relatively high, due to the heavy rain which characterizes the season, contrary to the dry period the flow decreases until the total dryness.Like all Mediterranean wadi, Tafnawadi is characterized by violent floods (56).

In any season, severe storms can cause flooding morphogenscapable of destroying bridges and redoing or move wadi beds, erodethe banks and move huge amounts of sediment. The upper portions of wadissupplied by sources are often perennial, which is not the case of the downstream portions, whichhave strong drying accentuated by the introduction of deductions (BeniBahdel, HammamBoughrara)(56).

3.5 Geology

The large basin of Tafna is characterized by a very complex geology and qualifiedlarge tectonic. The evolution of terrain encountered is from Primary to Quaternary(57).

The primer is a coarse clastic formation, reddened. It outcrops in the basinMouillah the wadi, at the MontsGharRoubane west, and east Fillaoucen:

- Lagoon deposits rich in gypsum, halite and clay in the BéniBahdal region and in that of RharRouban, which are anticlinal zones; shale and quartzite to Traras and Blessed Boussaid includes metalliferous veinsRharRouban(56).
- The Triassic consists of purplish red clay racing levels of gypsumfibrous, they are often accompanied by basalts, tuffs, limestones and dolomites. Locatedsubstantially at Beni-Bahdel and in the river basin Mouillah.
- The Late Jurassic is characterized by a rock calcairo- Dolomitic and sandstonevery compact limestone slab beds more or less thick interspersed with marl bed;their thickness is notable, powerful dolomites BeniBoussaid. On the southern edge ofBasin Tafna Miocene outcrops along the massive Jurassic.

- The Miocene represented by mainly marine deposits of volcanism of the Oran tell; Basalt, seat of puddings flush locally and weathered marl where sandstone benches are inserted. This formation extends in the North-East direction, on a small thickness with the appearance of calcareous crust, some layers of clay and marl, argillites or by place a detrital rock having a relatively high porosity.

- The Quaternary consists of nested fields and recent alluvial deposits occupying largewadi valleys and money by sometimes clayey silt. This training occurs atalluvial depressions, including that of TafnaValley .

- For medium and low Tafna encountered deposits covered by alluvium recent sandy-gritty, sand and silt, and also discontinuous scree slopesandsilty and clayey colluviums (58).

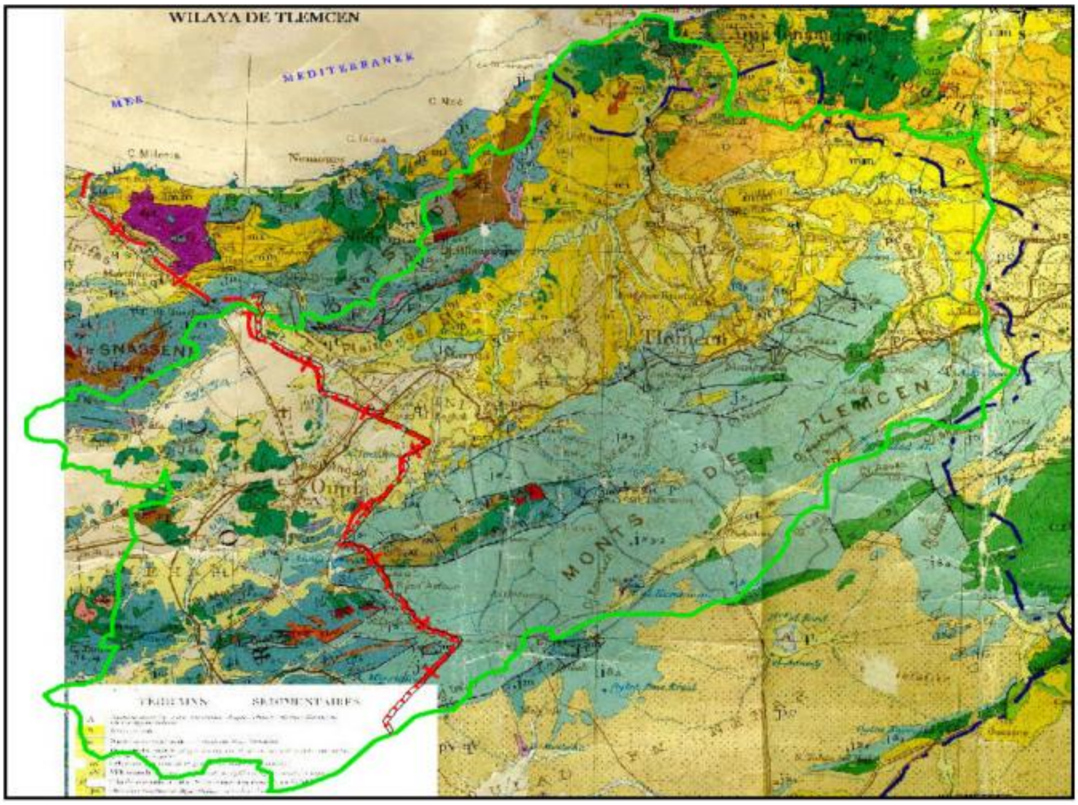

Figure III 4:Geological map of north of Algeria (59)

3.6 Relief

Watershed Tafna is characterized by a diverse areas(59):

3.6.1 Mountainous areas

The mountainous areas surround the Tafna basin on the northwest side, the south side and theNorth side to leave the Center an area of plains and depressions. These areas are:

Mountains Trara

It is a coastal mountain range of 1250 square kilometers, with an average altitude ranging from 500 to 1000 meters, which occupies the north-west of the province of Tlemcen.

Monts Sebaa Chioukh

It is a mountain range of 250 square kilometers, located in the north-east of the wilaya of Tlemcen. It forms the extension of the east side of the mountains of Traras with an average altitude between 600 and 800 m.

Monts de Tlemcen

They are located in the south of the wilaya of Tlemcen forming the southern border of the watershed. The mountains of Tlemcen are the highest reliefs of the region (1848 m at Jebel Tenouchfine).

They occupy an area of 3000 Km2 and extend in the West to the Kingdom of Morocco and the East to the wilaya of Sidi-Bel-Abbès.

3.6.2 Plains and high plains

The plains and plateaus occupy the central part of the basin enclosed between the mountainous areas, we distinguish:

Maghnia Plain

It is limited to the north and north-east by the southern foothills of the Traras, to the south by the northern foothills of the Tlemcenmountains and to the west by a natural extension formed by the plain of Angad (Morocco).

Hennaya Plain

It located in the north of the town of Hennaya at a distance of 9.25 km north of the town ofTlemcen. On an area of 28 km2 ,it is bounded by the Isser wadi to the north, by the Jurassic karst lands of the Tlemcen Mountains to the south, by the Sikkak wadi to the east and the Khalouf wadi in the West.

ZenataOuled-Riah high plain

It is located northwest of the plain of Hennaya, it is composed of Mediterranean red soils resting on crusts or sometimes on the calcareous carapace.

Sidi-Abdelli-Ain-Nahala high plain

It is formed of calcareous brown soils; their clay content is of the order of 45%. As a result of the change in the humidity of these soils, the structure expands in summer giving rise to large slits.

3.7 Vegetation and soil

The vegetation is a determining factor in the speed of the surface runoff, the evaporation rate and the pelvis retention capacity. So the presence of vegetation will play the role of regulator in the flow regime.

The vegetation in our study area, changes from upstream to downstream. In the southern mountainous area above 1200 meters, we meet a Green Oak association, Aleppo pine, Genet, of Mastic, Cistus and Herbs such as rosemary and the Asphodel. The Cork Oak is found mostly on rich land in silica. Below 1200 m altitude, we find a combination of oxycèdre, some vestiges of Holm oak, of Saw Palmetto and Thyuas(56). To the east of the Monts de Tlemcen and following degradation, the forest has been replaced by scrub and crops. In the north, the plains of Maghnia and Remchi are characterized by crops (cereals, arboriculture), for market gardening along the rivers (TafnaMouillah and Isser) and natural vegetation very degraded.

According to a study done in 1993, Four soil types characterize our study area , which are (56)(59):

The brown soils fersialitic

They are distinguished by their richness in organic matter with a high concentration of plant residues on the surface, are black rendzinas drill,. They are very thick, up to 30cm. They appear under the forest cover in the mountains of Tlemcen.

The slightly evolved erosion soils (lithosols)

These are two soil horizons, they were formed mainly of limestone and sandstone and are thin (10 to 15cm), they are limited deep by a hard rock, it is usually soil slopes affected by erosion because they are poorly protected. They are located on the means and upper river and some hills.

Alluvial soils

These soils are generally calcareous silty texture to clay. Their richness in organic matter gives them a dark color (brown soils alluvial). Alluvial are fertile and suitable for deep-rooting crops. They are observed in areas of Sidi MEDJAHED and HammamBoughrara.

The fersialitic soil

They exist on different substrates limestone, sandstone and marl. Their depth easily reaches 60 cm especially in tilled and irrigated soils. Their color varies from red to reddish brown. These are leached soils, the horizon is thin, and rich in clay. They dominate in SidiMedjahed area in the low foothills and in some foothills of mountains. In general, we can say that the slightly evolved erosion soils characterize the high slopes, while the accumulation soils are found in areas down slope.

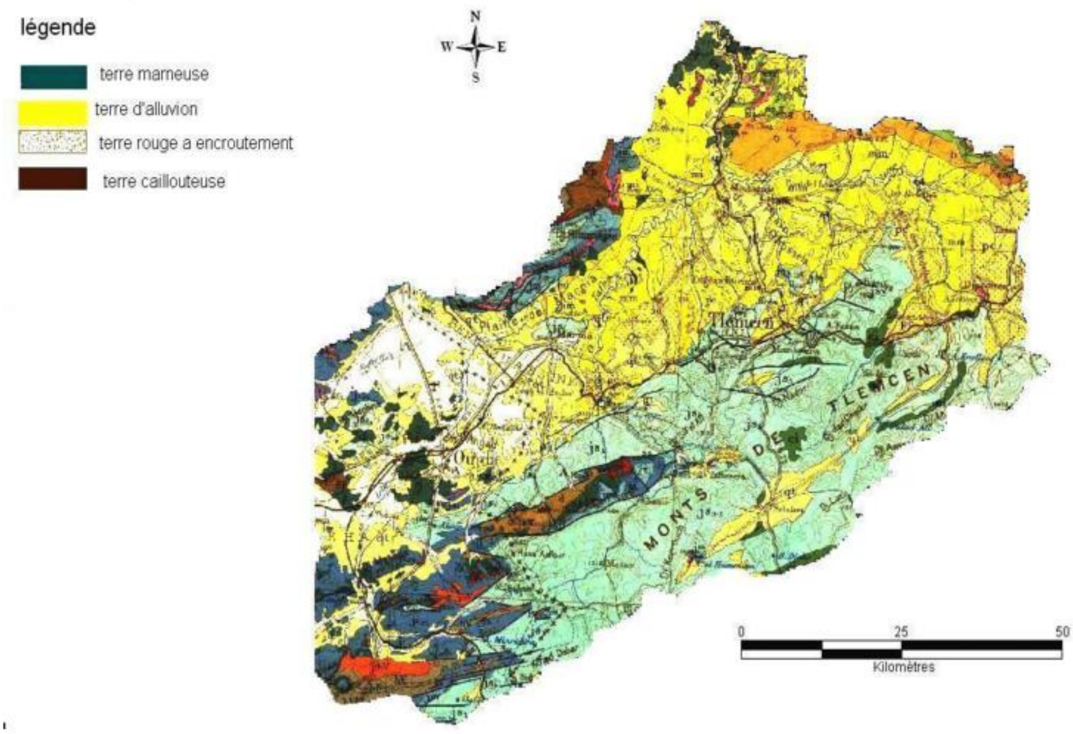

Figure III 5:Tafna soil types(59)

3.8 Slope

The slope is important in hydrology, it directly affects the infiltration and runoff water catchment and used in determining the power with which the running waters attack and transport rocky materials. The plains are characterized by low slopes of the order of 0 to 3% on the other hand mountainous areas have steep slopes (> 25%) (60). in the watershed of Tafna, the slope varies from upstream to downstream. It is low at the source since it is a tray (GharBoumaaza), then it becomes important from the city of Sebdou, high Tafna to the dam of BniBahdelwhere the slope is greater than 25% (61). Downstream Tafna average continues to present an average gradient which is becoming weaker. The slope decreases progressively to the mouth at Rachgounwhereit becomes very low or even zero.

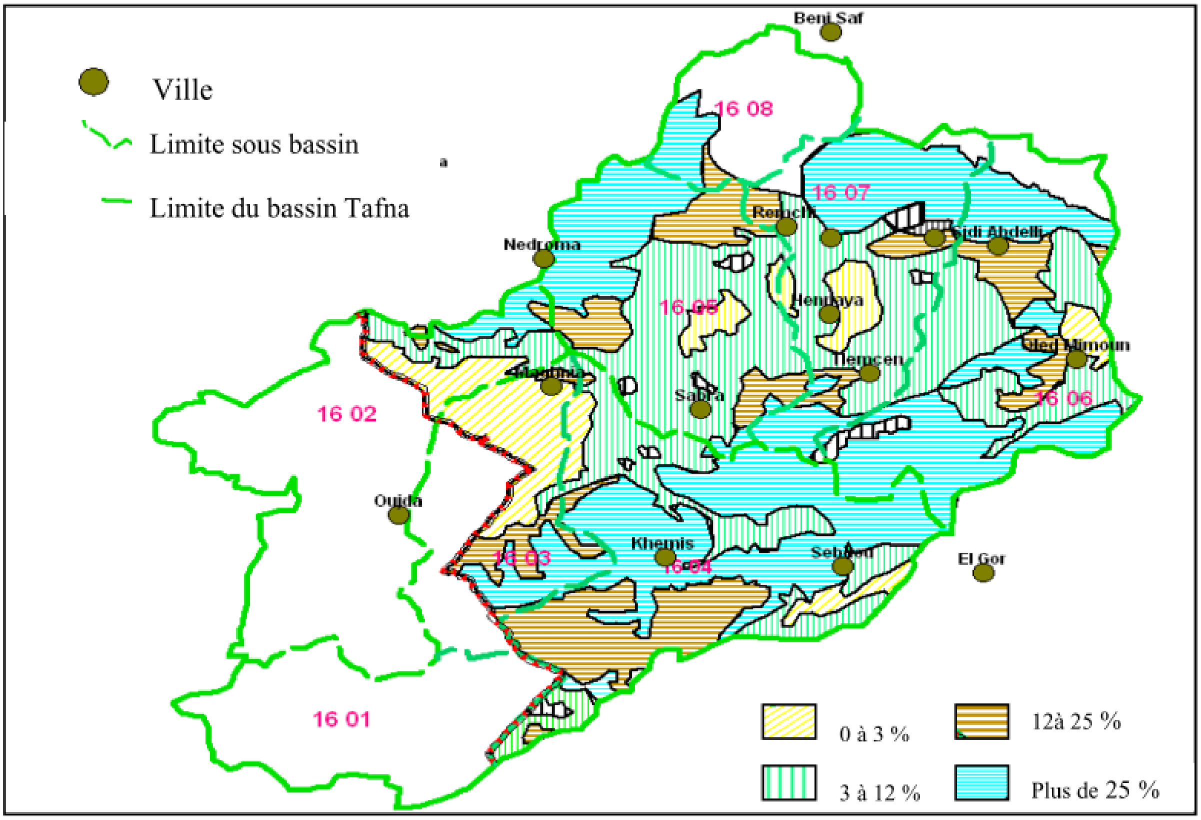

Figure III 6:Slopa map of Tafna catchment (61)

3.9 Climate

In the north of Algeria's deficit in rainfall Was Observed from the end 70 mostly western (rainfall deficit between 13 and 30%) decades 80 and 90-have-been dry with the Largest deficits, temperature-have risen more than 0.5 ° C from the 80's, the Was the warmest decade 1992-2002 about (0.7 ° C), the downward trend in rainfall and Higher temperature is Mainly due to the positive phase of the North Atlantic oscillation (10).

The climate of the Tafna watershed is semi-arid type, The geographical situation, the differences of altitudes makes the climate complex,Tafna region is characterized by two season:

One is cold and wet from the month of October to the month of May with enough irregular rains, the other warmer and dry extends from June to September with a low rainfall and a high temperature(52).

Currently Watershed Tafna comprises over 30 rainfall stations mostly managed by ANRH (national agency of water resources).

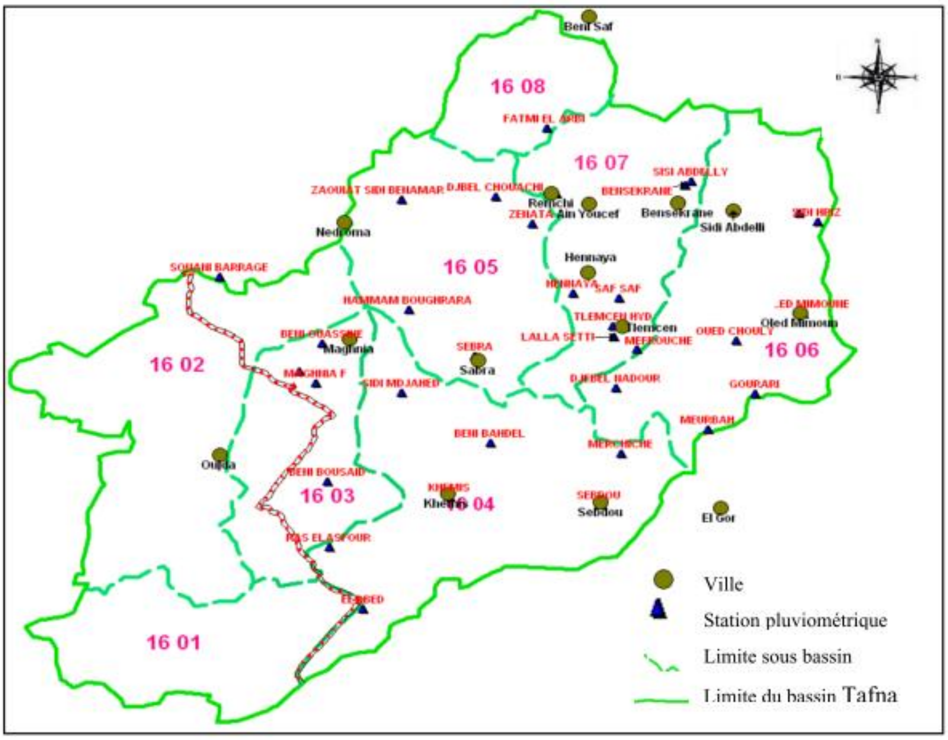

Figure III 7:location of Tafna rainfall station

3.9.1 Precipitation

The Rainfall is ranging from 285 to 660 mm / year we DISTINGUISHED that:

- Rainfall shows a significant increase when moving from West to East.
- Rainfall between 400 and 450 mm recorded at the level of the littoral zone (low Tafna), explained by the presence of the lowland areas.
- Rainfall area between 450 and 550 mm registered in the center, at the high reliefs altitude(62).

3.9.2 Temperature

During the dry season the maximum temperature can reach more than 40 ° C and the average temperature oscillates around 26 ° C. the temperature of the wet season typically ranges around 12 ° C on average. The minima are recorded in

January and the maximum in July and August, the annual temperature of Tafna basin is around 18 ° C, We can see that autumn is warmer than spring, summer is the hottest of seasons and winter is coldest.

3.9.3 Sirocco

Siroccois a strong wind from the south. Most often, it is responsible for extremely tenuous sand particles. It occurs in any season, but it is much more common during the spring, summer and autumn than during winter(63).

3.9.4 Snow

Notes that at Tafna region, solid precipitation present only a small proportion of total precipitation. The solid precipitation (snow), become more and more rare and remain variable according to the years(64).

In general,the snow frequency of Tafna basin varies from one year to another and depend on the altitude and the exposure of the mountains,

It is occur, between the months of December and February. Its appearance is noted from 800 m altitude where thethickness of snow cover varies between 15 and 30 cm, the maximum recorded at HAFIR being 1.50 m(65). Tafna region is also characterized in this winter period by the freezing which is an ordinary phenomenon but no less prejudicial; depending on when they occur (December until the end of March but they are more frequent during the month of January), they may have more or less consequences.

3.10 Assessment of Tafna water resources

The water resources of Tafna basin represent 22,63% of the updated potentialities of the North-West of Algeria these potentialities conferred very early the status of Western Water Reservoir (61).

Before the drought period only two dams exist to provide the needs of the population, BeniBahdel and Mefrouch. Local authorities have built three large dams and underground water have launched surveys across the mountains of Tlemcen.

With an area of 7245 square kilometers, the basin's potential in surface water normal values are estimated approximately about 308 Hm3 / year estimated solely on the basis of inputs from under mobilizable basins integrated into the Tafna basin. This potential has always represented big part of the reserve of the wilaya of Tlemcen and of the hydraulic system West(61).

To mobilize this resource, hydraulic structures have been installed within the basin.

These works consist of:

3.10.1 Surface water resourcesmobilization

Dams

Until 1980, the two major dams BeniBahdeland Meffrouche were the only dams that provided the needs of the local population as well as that of Oran city. The increase ofpopulation, the significant decrease in rainfall and the socioeconomic development of the region has prompted local authorities to seek to further mobilize water resources. Thus, other major works were carried out (66).

Currently Tafna basin contains 5 operating dam These damsare made on the Tafnawadi the Isser and Sikkak.

Tafnawadi: BeniBahdelDamand HammamBoughraraDam

Isserwadi: SidiAbdelliDam

Sikkakwadi: Meffrouche and Sikkak Dam.

The table III 4below summarizes the main characteristics of large dams in the province of Tafna

Table III 5: The Main characteristics of large dams in Tafna basin

Dam Name	Capacity (Mm^3)	Volume regularisable Mm^3	Area (km²)	Date of commissioning
Beni Bahdel	63	63	1016	1952
Mefrouch	15	15	90	1963
Sidi Abdelli	110	50	1137	1987
HaammamBoughrara	177	56	4000	1998
Sikkak	30	25	251	2006

Small Dams

These smaller dams are mainly intended for agricultural development. Eight small dams have been made with a total water volume of**7.38** Mm^3.

The table lists some characteristics of the eight small dams located in the Tafna basin.

Table III 6:small dams across the basin Tafna (28)

Name	**Area (km²)**	**Capacity Mm^3**	**Height of dam (m)**	**irrigated area (square kilometers)**	**locality**
ElGuettara	**21.4**	**0.5**	**15**	**80**	**Amieur**
ElAtchane	**45.59**	**0.916**	**18**	**100**	**OuledRyah**
SidiSenouci	**15.5**	**0.5**	**13**	**80**	**Sidi Abdelli**

Chabet El Alia	**20**	**0.5**	**14**	**80**	**Sidi Abdelli**
Magoura	**50**	**1.4**	**8**	**120**	**Bouihi**
Aich	**24.9**	**1.783**	**18**	**120**	**Beni Boussaid**
Tiloua	**22.4**	**0.781**	**18**	**100**	**Bensakerane**
Khelfoun	**78**	**1**	**17**	**200**	**OuledMimoun**

Hillside dams

It's small reservoirs, easy to achieve and implement that does not require large investment .They are intended for storing insignificant amounts of water ranging between 10 000 and 100 000 m^3They are primarily intended for Agricultural Development (67).

At the level of the Tafnabasin, all the hillside are in poor condition and have a capacity of 3,263,960$\boldsymbol{m^3}$ **.**Many reservoirs were washed away or totally silted during the first recorded flood. The reasons for this semi-failure are to put in the assets:

- The not always appropriate locations. Many deductions were washed away or totally silted in the first recorded flood;

- A persistent drought that has made that much has rarely been met;

- Lack of awareness of the fellahs for the maintenance of these structures.

Table III 7:The small dams throughout the province of Tlemcen

DAIRA	Period of implementation		State in June 2000
	1985/1989	1990/2000	
Maghnia	05		Silted 100%
Mansoura	04		1 in good condition
Ghazaouet	02		destroyed
Sebdou	09		06 in good condition
Remchi	13		02 in good condition
Nedroma	09		destroyed
O.Mimoun	14		destroyed
Bab El Assa	14		03 in good condition
Sabra	07		01 in good condition
Chetouane		04	Out of order
Honaine		02	Out of order
Fillaoucene		02	Out of order
A.Tellout		08	07 in good condition
Total	77	16	20

Springs

There are more thentwenty sources in Tafna bassin :Aïn Sidi Youcef, Aïn El Karma, AïnEldjer, Aïn El Ghorab, AïnSafsaf, AïnBouchkour, Aïn Sidi Abdallah, AïnTanfif, AïnGhata, AïnDefla, AïnTaghra, Aïn El Ainyoun, AïnTahoudine, Aïn

Ben Hellal, Aïn Sidi El Mekhfi, Aïn Dammam, AïnTalat, AïnBoulefane, AïnMissert, AïnMélala, AïnTazroud, AïnDjerrir ...

Thermal springs

Ben Raho, Berkani, Tahammamit, Chiguer, SidiBelkhir, Ain El Hammam,Tahammamit is the most known one.

3.10.2 Groundwater Resources

The supply of groundwater is through boreholes, wells and resources exploited at the level of all aquifers.

The Tlemcen Mountains have significant groundwater potential, it includes many sources that are generally exploited in traditional irrigation.The flow of these resources has decreased in recent years, and others have dried up with the decrease in the flow of sources that react as overflow.

The Maghnia nappe is a multilayer aquifer system with free water, it is fedmainly through the infiltration of precipitation and the underground discharge ofJurassic formations of RasAsfour .Its potential resource is estimated atabout 15 Hm^3 / year (52). It is largely overexploited in particular bythe Greater Irrigated Perimeter (GPI) of Maghnia. Water resources remain important despite the dramatic decrease in water flow . For the aquifer systems of the mounts of traras, it is about monolayer system with tablecloth generally free in formation greasy or sandy.The mobilization of groundwater resources at the Tafna basin is summarized as following:

84 wells at a rate of 957.8 exploited (l / s)

157 wells operated with a flow rate of 212.17 (l / s)

22 sources operated with a flow of 73 (l / s)

Table III 8: Table of groundwater resources of Tafna

Nape and Aquifers	Type	Area (km^2)	Resources exploitation Mm^3/years
Plain Maghnia	ground	188.82	15
plain Gossels	ground	36.6	0.8
Valley Tafna	ground	178.11	0.6
Mont Tlemcen	deep	3070.37	32.9
Mount Traras	deep	291.92	6.5

Evaluation of recycled water

The few sewage treatment plants carried out in the big cities (Tlemcen, Maghnia) are operational for the recycling of this type of resources.

Table III 9:evaluation of recycled water

towns	estimated 2002			estimated 2010			estimated 2020	
	population 2002	Volume recycled (Mm^3/an)	%	population 2010	Volume recycled (Mm^3/an)	%	population in 2020	Volume recycled (Mm^3/an)
Tlemcen	**168278**	**7.5**		**195162**	**8.5**		**234888**	**10.5**
Remchi	**28402**	**0.5**		**34,095**	**0.5**		**42842**	**1.5**
Ghazaouet	**28873**	**0.5**		**31191**	**0.5**		**34348**	**0.5**

Ouledmimoune	**28117**	**0.5**		**30920**	**0.5**		**39004**	**1.0**
Hennaya	**26860**	**0.5**		**32396**	**0.5**		**40947**	**1.0**
Maghnia	**83,080**	**2.7**		**105981**	**4.6**		**143679**	**12.5**
Sebdou	**33 748**	**0.5**		**46399**	**1.50**		**69080**	**2.5**
Nedroma	**22278**	**0.5**		**25555**	**0.5**		**30,336**	**0.5**
Total	**419636**	**13.2**	**15.9**	**501699**	**17.1**	**16.6**	**635 124**	**30.0**

Finally, the few wastewater treatment plants carried out in large cities are often not operational because of the low level of investment and control deployed in the recycling of this type of resource.

3.11 Data Availability

3.11.1 Climatic Data

The monthly metrological data for Tafna Basin were collected from National Meteorological Office (ONM), National Water Resources Agency (ANRH), (DRHWT)(ANBT)(DSA)(ABHOCC)

This Metrological data used for purpose ofand for downscaling the GCM data using Statistical Downscaling Model (SDSM)

Table III 10:List of monthly precipitation data available

Station	code	Latitude	longitude	Altitude (m)	Period (year)
Zenata	605310	35°01’00’’	-01°27’00’’	247	1923-2017
OuledMimoun	160607	34°54’11’’	-01°02’21’’	780	1923-2011
BeniBahdel	160403	34°42’33’’	-01°29’48’’	660	1941-2017
Bensakrane	160702	35°04’28’’	-01°13’26’’	247	1941-2017
Meffrouche	160701	34°51’19’’	-01°17’31’’	1110	1943-2017
Maghnia	160302	34°45’11’’	-01°48’04’’	395	1971-2010
HammamBoughrara	160501	34°53’28’’	-01°38’20’’	270	1971-2010
Piere de chat	160802	35°08’41’’	-01°26’46’’	60	1971-2010

The following table represents the monthly temperature data available:

Table III 11:list of monthly Temperature data available

Station	code	Latitude	longitude	Altitude(m)	Period
Zenata	605310	35°01’00’’	01°27’00’’	247	(1913-1938) (1980-2017)
BeniBahdel	160403	34°42’33’’	01°29’48’’	660	(1913-1938) (1980-2012)
HammamBoughrara	160501	34°53’28’’	01°38’20’’	270	(1913-1938) (1982-2017)

3.11.2 Data for modeling

Climate scenario data used for downscaling model (SDSM) were obtained from the Canadian Institute for Climate Studies Website (www.cics.uvic.cs.cgi) for model output of HadCM3 of two SRES scenarios A2 and B2 produced by greenhouse gas, sulphate aerosol, and solar forcing and NCEP reanalysis data. The predictor variables are supplied on a grid by grid basis so that the data will be downloaded from the nearest grid box asa zipped file to the study area.

Methodology

Continuous series of more than 30 years of observations was used to assess potential change of climate in this study.

4.1 Climate change assessment

4.1.1 Precipitation evolution

Available data series were segregated into three groups depending the length of records (long, medium, short):

Table IV 1:The three groups of the data series

The first group (Long series)	The second group (Medium series)	The third group (Short series)
OuledMimoun (1923-2017) Zenata (1923-2017)	BeniBahdel (1941-2017) Bensakrane (1941-2017) Mefrouche (1943-2017)	Maghnia (1971-2010) Hammam Boughrara (1971-2010) Piere de chat (1971-2010)

Three statistical parameters were used to understand in key climate observations:

A. Standard deviation (δ)

The standard deviation is a statistic that measures the dispersion of a dataset relative to its mean and is calculated as the square root of the variance. It is calculated as the square root of variance by determining the variation between each data point relative to the mean. If the data points are further from the mean, there is higher deviation within the data set; thus, the more spread out the data, the higher the standard deviation.

B. Coefficient of variation (CV)

A coefficient of variation (CV) is a statistical measure of the dispersion of data points in a data series around the mean. It is calculated as follows: (standard deviation) / (expected value). The coefficient of variation represents the ratio of the standard deviation to the mean, and it is a useful statistic for comparing the degree of variation from one data series to another, even if the means are drastically different from one another.

C. Skewness

Skewness is positive if the tail on the right side of the distribution is longer or fatter than the tail on the left side. The mean and median of positively skewed data will be greater than the mode. Skewness is negative if the tail of the left side of the distribution is longer or fatter than the tail on the right side. The mean and median of negatively skewed data will be less than the mode If the data graph symmetrically, the distribution has zero skewness, regardless of how long or fat the tails are.

First Group:

Table IV 2First groupstatistical parameters

Station	Mean precipitation(mm)	standard deviation	coefficient of variation	skewness
Zenata (1923-2017)	507.09	201.269	0.396	0.412
OuledMimoun (1923-2017)	432.51	138.628	0.320	0.680

The annual precipitation over the period 1923-2017 varies between 162-986 mm for the Zenata station (Figure IV 1) and 197.9-881.30 mm (Figure IV 2) for Ouled Mimmoun station, the annual average precipitation series is respectively 507.09 and 432.51 mm, the coefficient of variation is quite important, we noticed that the decade80s is the most deficient for the both stations.

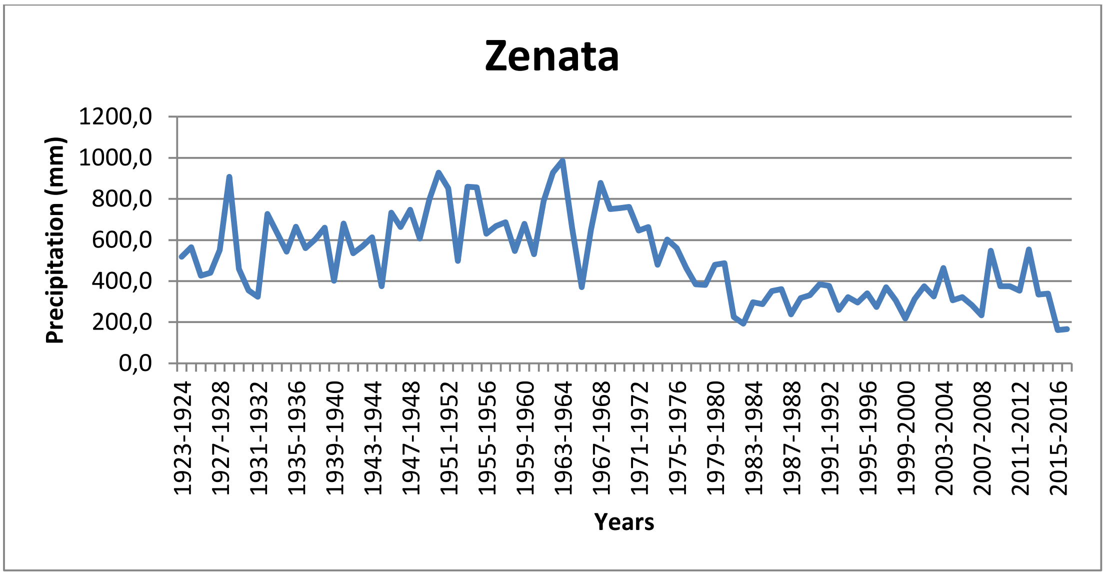

Figure IV 1:Precipitation evolution of Zenata station

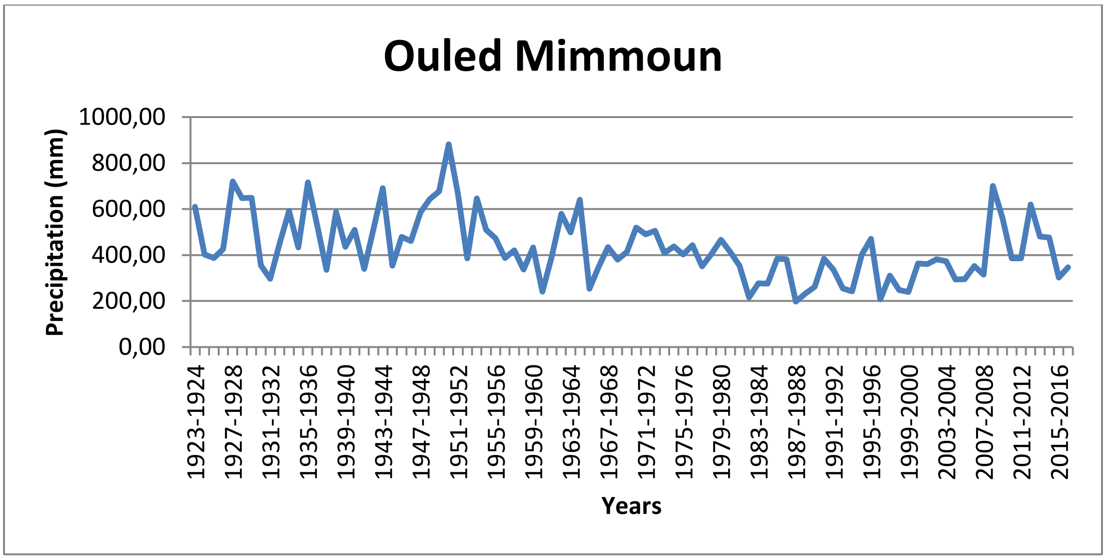

Figure IV 2:Precipitation evolution of Ouled Mimmoun station

Second group

Table IV 3:Second groupstatistical parameters

Station	Mean precipitation(mm)	standard deviation	coefficient of variation	Skewness
BeniBahdel (1941-2017)	461.87	139.807	0.302	0.162
Bensakerane (1941-2017)	426.21	123.469	0.289	0.336
Meffrouche (1943-2017)	623.89	169.081	0.271	0.321

The annual precipitation over the period 1941-2017 varies between 756.1-187.7 mm for the BeniBahde station (Figure IV 3), 725-197.90 mm for Bensakerane station (Figure IV 4) and 1144.90-346.50 mm for Meffrouche station (Figure IV 5), the annual average precipitation series is respectively 561.87, 426.21 and 623.86, the coefficient of variation is quite important, we noticed that the decade80s is the most deficient for the three stations.

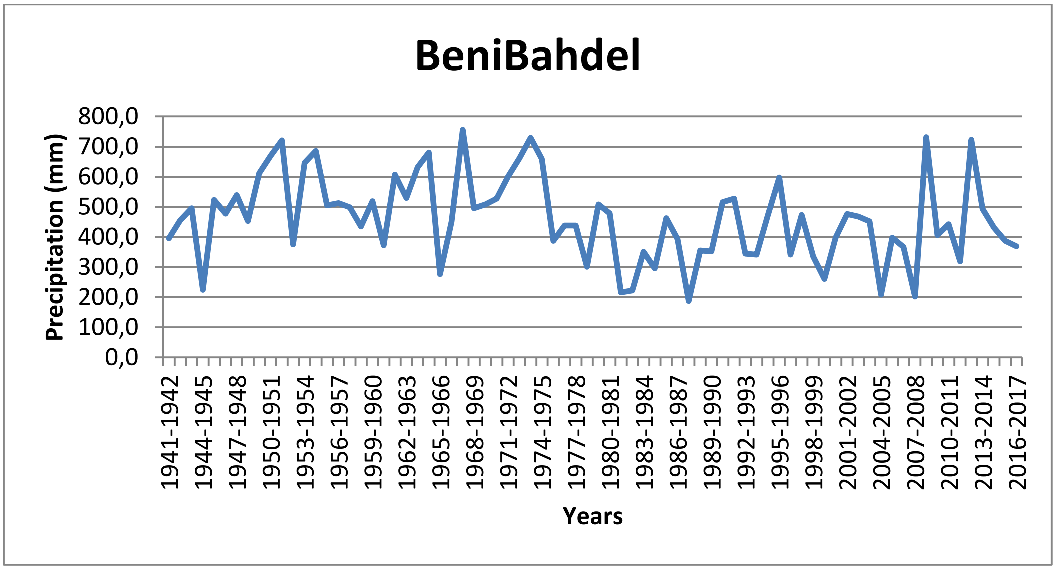

Figure IV 3:Precipitation evolution of BeniBahdel station

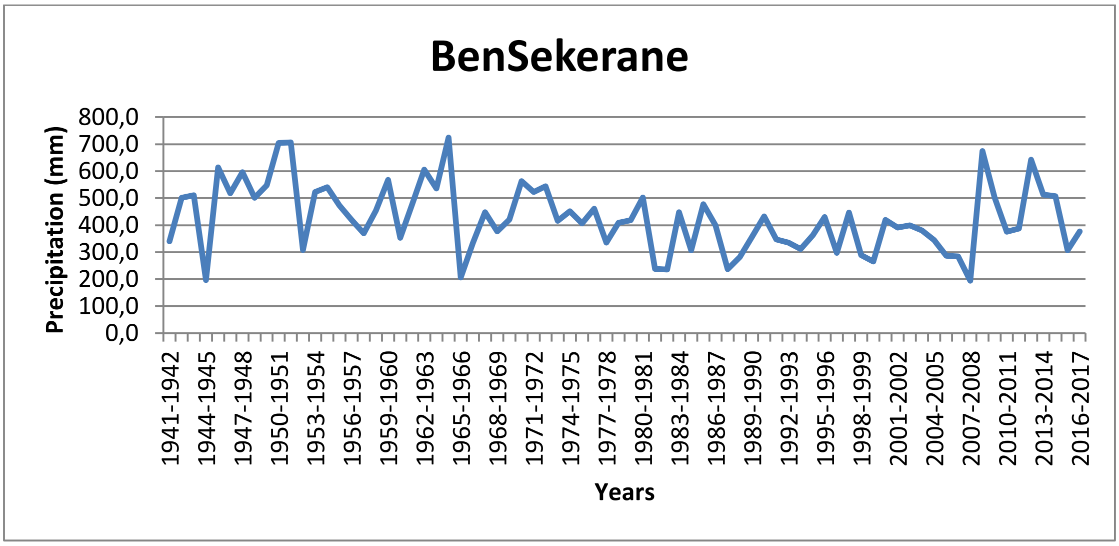

Figure IV 4:Precipitation evolution of BenSekerane station

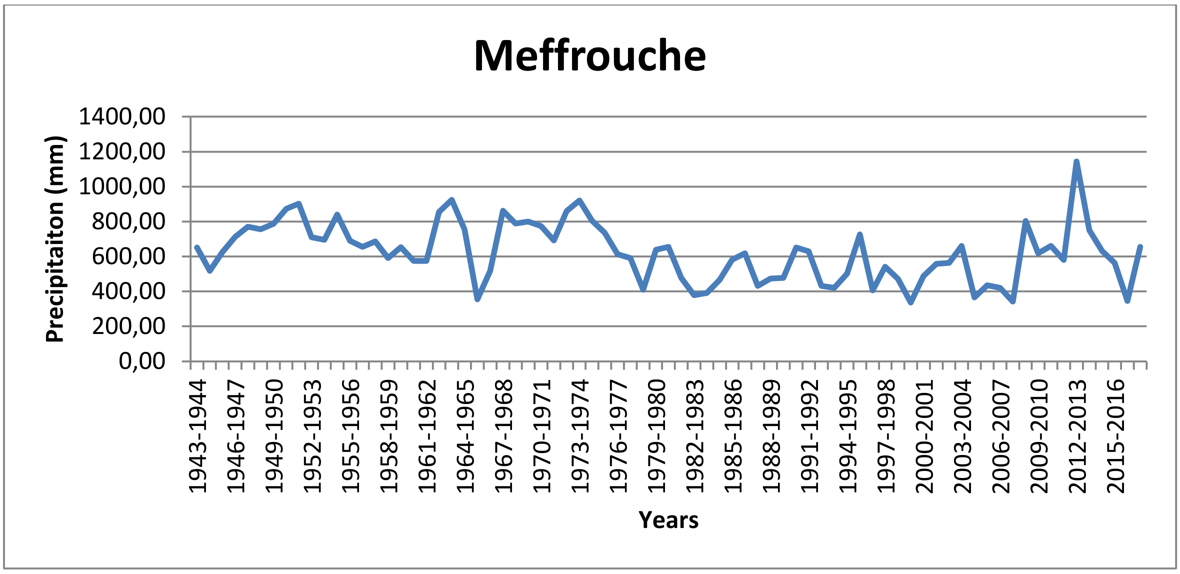

Figure IV 5:Precipitation evolution of Meffrouche station

Third group:

Table I 1 : Third group statistical parameters

Station	Mean precipitation(mm)	standard deviation	coefficient of variation	skewness
Maghnia (1971-2010)	338.80	112.000	0.330	0.492
HammamBoughrara (1971-2010)	249.44	114.406	0.458	0.536
Piere de chat (1971-2010)	325.54	93.585	0.287	0.539

The annual precipitation over the period 1971-2010 varies between 586.6-173.2 mm for Maghniae station (Figure IV 6), 496.9-74.1 mm for Hammam Boughrara station (Figure IV 7) and 594.6-135.4 mm for Piere de chat station (Figure IV 8), the annual average precipitation series is respectively 338.80, 249.44 and 325.54, the coefficient of variation is quite important, we noticed that the decade80s is the most deficient for the three stations.

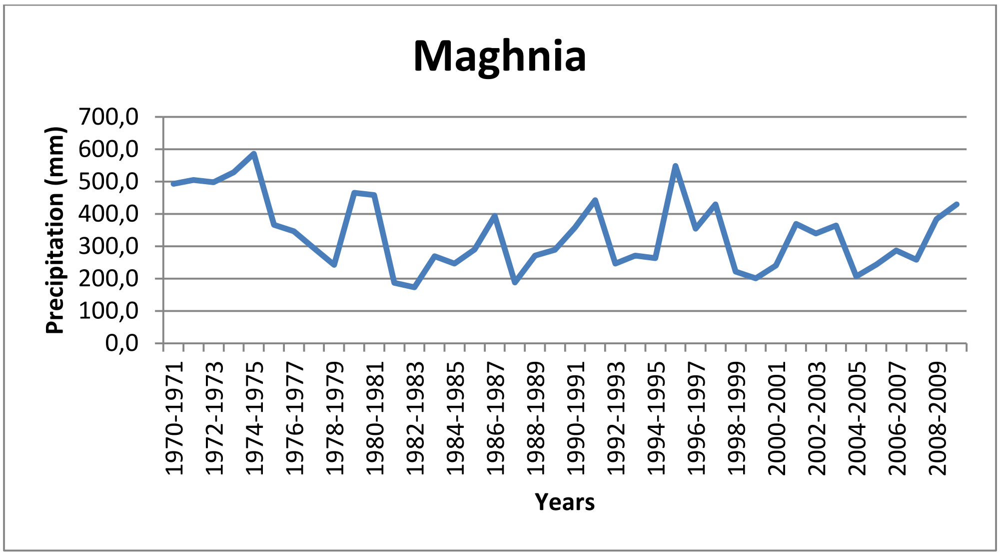

Figure IV 6:Precipitation evolution of Maghnia station

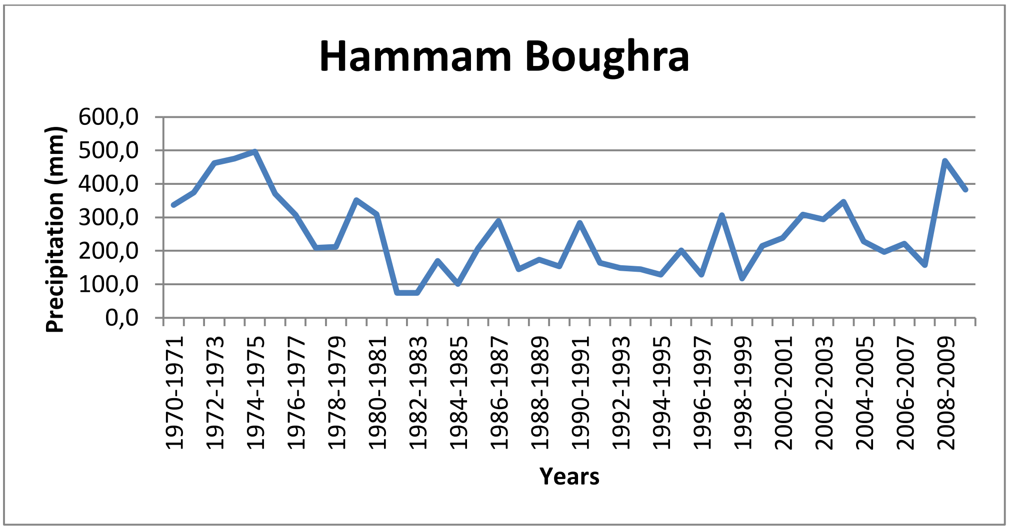

Figure IV 7:Precipitation evolutionof Hammam Boughrara station

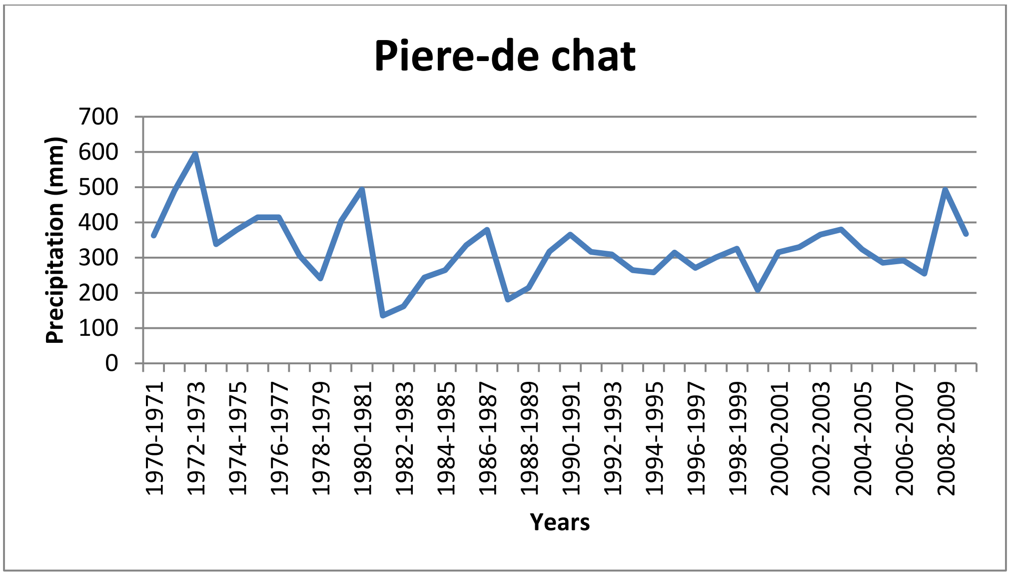

Figure IV 8:Precipitation evolution of Piere-de chat station

4.1.2 Standardized precipitation index

SPI was used to verify the meteorological drought at the eight stations

First group:

The chronological variation of the SPI index relative to the first group shows that the SPIgo through a global deficit trend with the existence of two distinct periods.

A relatively wet period occurred before the early 1980s and another dry after that date.There is a large difference between the mean positive SPI and the mean negative SPI for the both stations, the most important peak for Zenata station is negative, unlike OuledMimmoune it is positive. The table IV 4 shows the SPI main statistical parameters.

Table IV 4:SPI main statistical parameters for the first group

Station	Max positive	Max negative	Mean positive	Mean negative	Skewness
Zenata	1.986	-2.243	0.857	-0.840	-0.054
OuledMimoun	2.599	-2.033	0.809	-0.727	0.135

The histograms below for Zenta stations and OuledMimmoun station shows that a significant change occurred in the value of SPI during the period 1923-2017 (Figure IV 9) and (Figure IV 10), in fact it has been observed that there is a rainfall deficit after 80s.

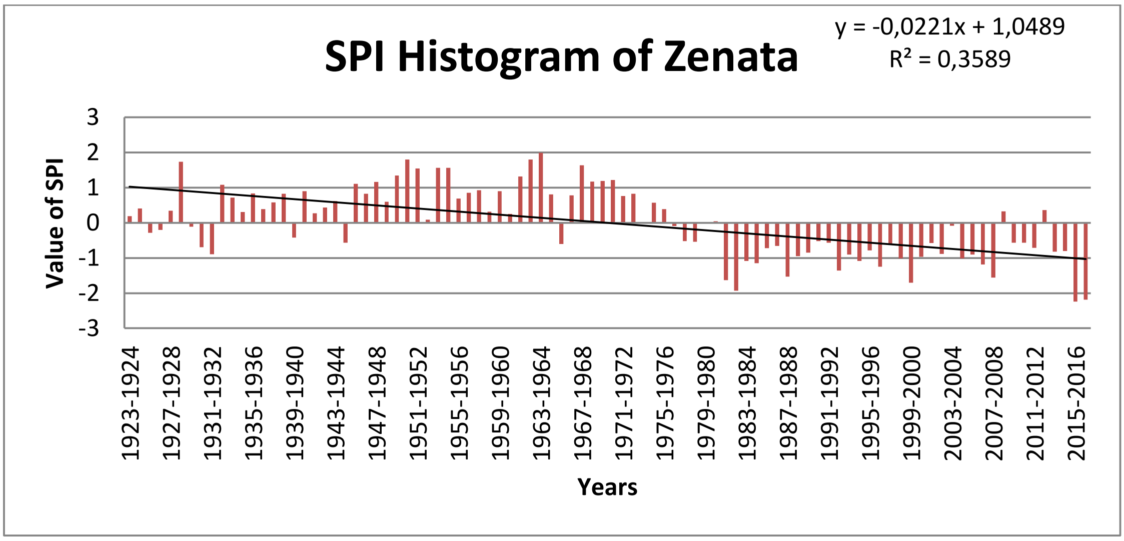

Figure IV 9:The annual SPI evolution of the Zenata station

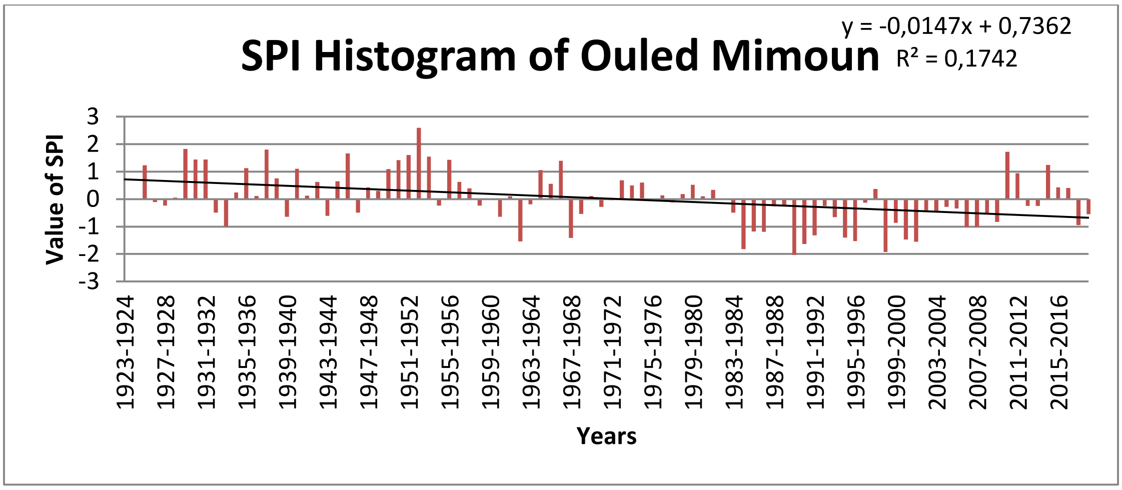

Figure IV 10:The annual SPI evolution of the Ouled Mimmoun station

Second group:

The trend of the SPI relative to the second group shows that there is an important decrease in the SPIvalue after 1980s.There is a large difference between the mean positive SPI and the mean negative SPI for the three stations, the most important peak for BeniBahdel station and Bensakerane is negative respectively -2.395 and -2.253, unlike Meffrouche it is positive 2.564. The table IV 5 shows the SPI main statistical parameters.

Table IV 5:SPI main statistical parameters for the second group

Station	Max positive	Max negative	Mean positive	Mean negative	Skewness
BeniBahdel	1.695	-2.395	0.715	-0.826	-0.398
Bensakerane	2.076	-2.253	0.718	-0.788	-0.137
Meffrouche	2.564	-1.967	0.739	-0.894	-0.099

The histograms below for BeniBahdel stations, Bensakerane station and Meffrouche station shows that a significant change occurred in the value of SPI after 1980s (Figure IV 11) (Figure IV 12) , and (Figure IV 13),an important decrease in rainfall which result a negative SPI value for all the stations.

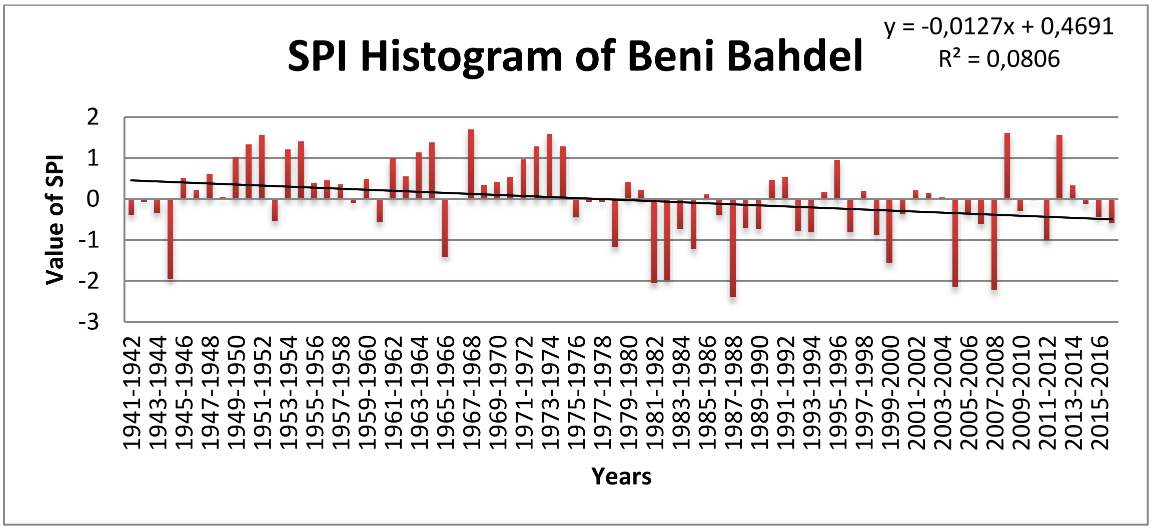

Figure IV 11:The annual SPI evolution of the BeniBahdel station

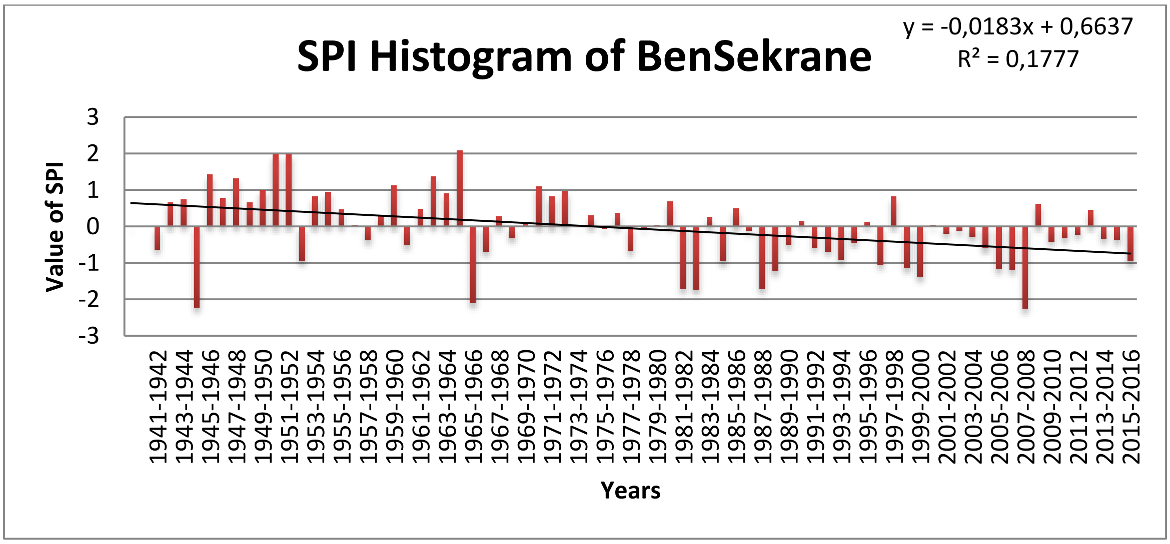

Figure IV 12:The annual SPI evolution of the Bensakerane station

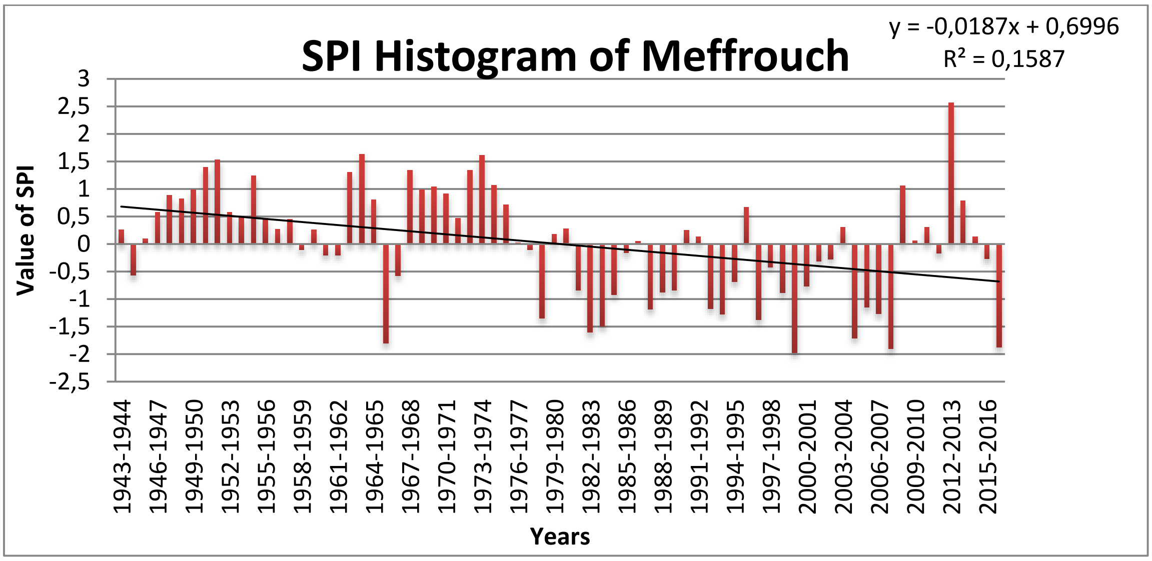

Figure IV 13:The annual SPI evolution of the Meffrouche station

Third group:

As the two other groups the trend of the SPI shows that there is an important decrease in the SPIvalue after 1980s, with a large difference between the mean positive SPI and the mean negative SPI for the three stations, the most important peak for Hamma Boughrara station and Piere de chat station is negative respectively -2.024 and -2.559, unlike Maghnia it is positive 1.970. The table IV 6 shows the SPI main statistical parameters.

Table IV 6:SPI main statistical parameters for the third group

Station	Max positive	Max negative	Mean positive	Mean negative	Skewness
Maghnia	1.970	-1.752	0.857	-0.851	0.193
HammamBoughrara	1.831	-2.024	0.856	-0.737	-0.037
Piere de chat	1.652	-2.559	0.547	-0.710	-0.118

For this group although we have a short series it is clear that after the 1980s the value of SPI has decreased (Figure IV 14), (Figure IV 15) and (Figure IV 16) ,The histograms below for Maghnia stations,Hammam Boughrara station and piere de chatstation, for the period 1971-2010 shows that rainfall has become low.

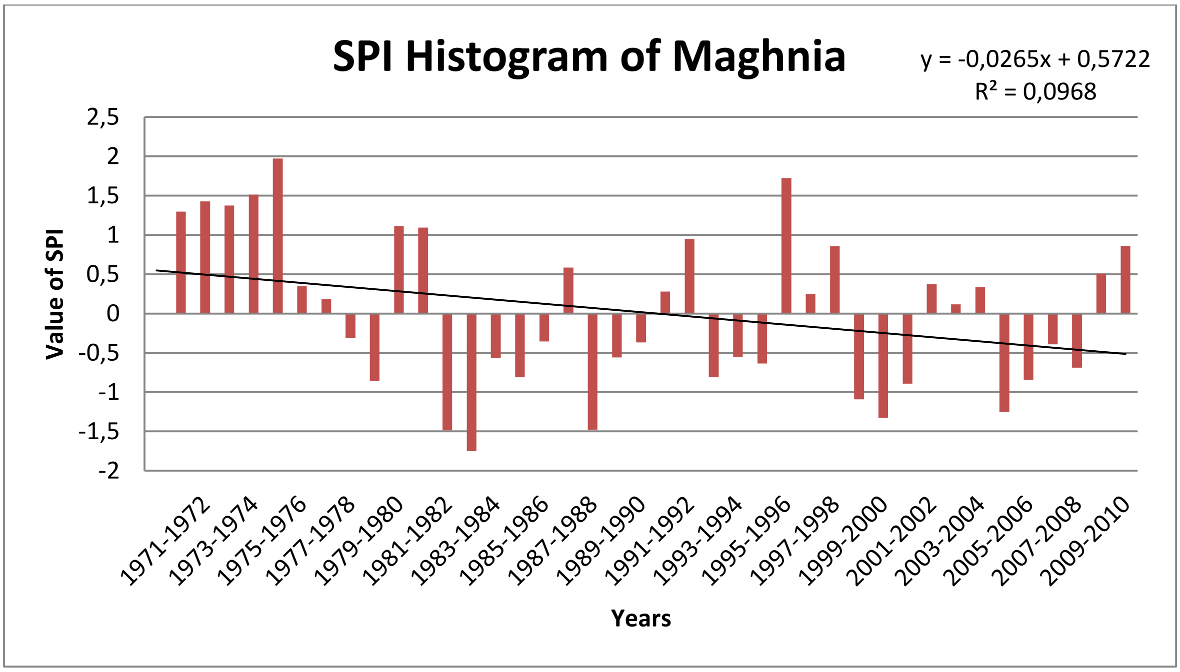

Figure IV 14:The annual SPI evolution of the Maghnia station

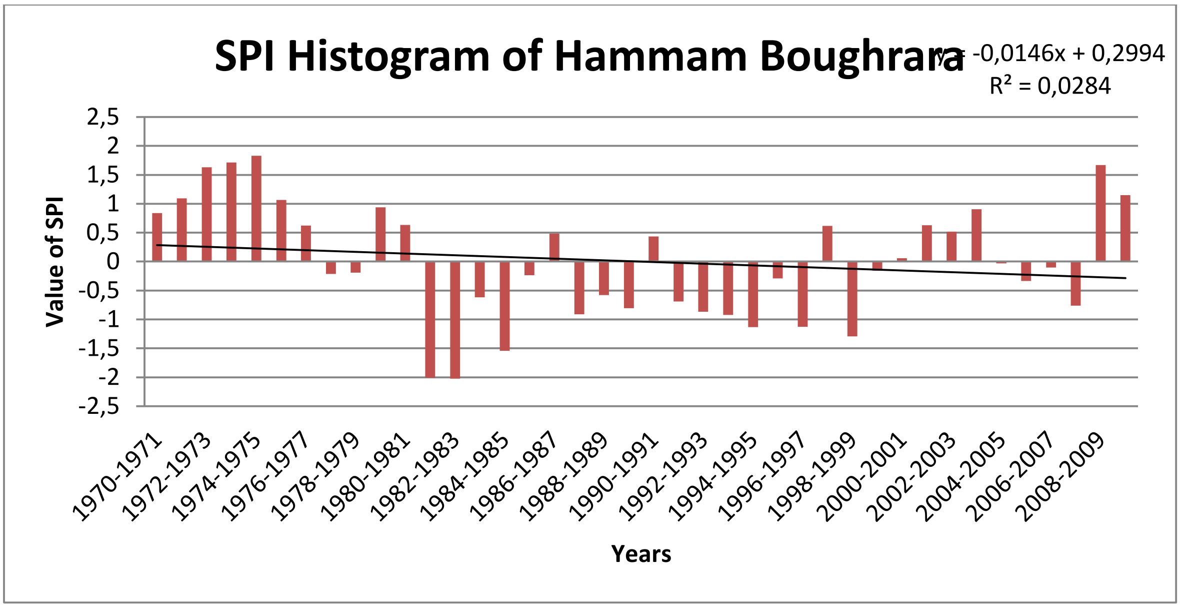

Figure IV 15:Tthe annual SPI evolution of the Hammam Boughrara station

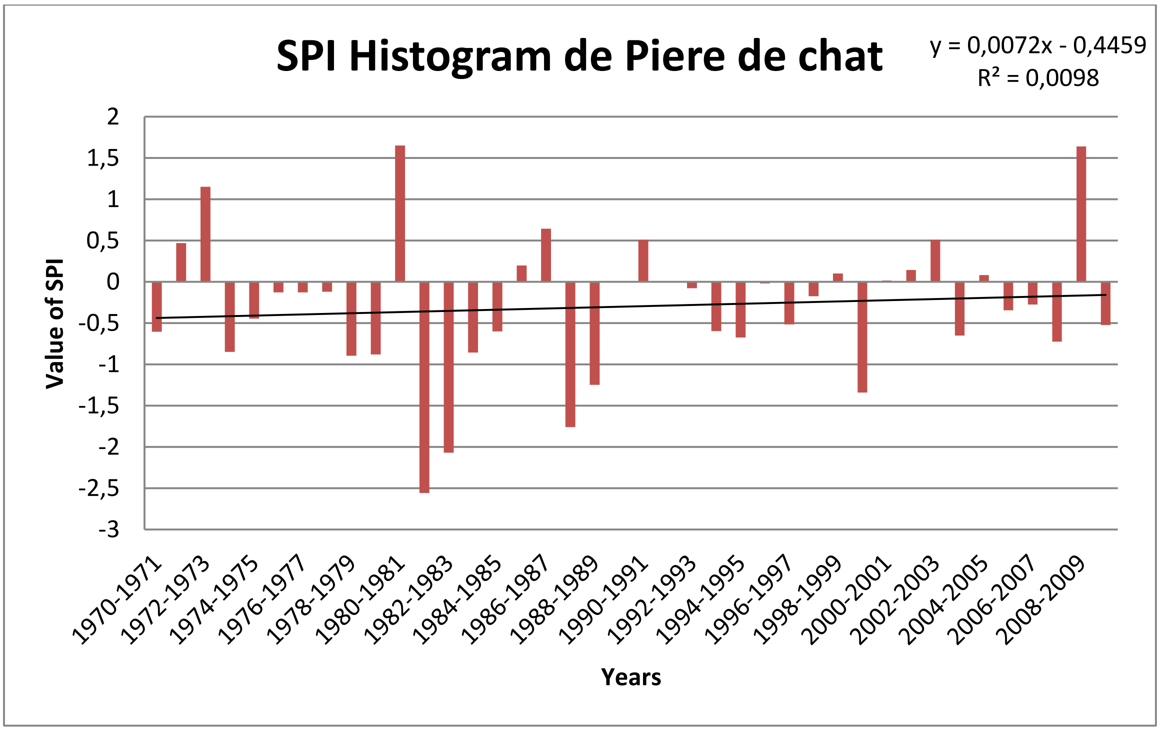

Figure IV 16:The annual SPI evolution of the Piere de chat station

4.1.3 Comparative study between two periods

According to several researchers the changes in temperature and precipitation in the Tafna region began in the early 80's, Building on exiting works for the region, in this study the data series were divided in two parts, in order to make a comparison between two period before 80s and after 80s, to find out how the climate is changing in the Tafna basin (1) (10).

First group:

For Zenata and OuledMimmoun stations the SPI value before 80s was positive, and after 80s is negative, the climate was mildly wet and becomes mild drought. The annual rainfall totals have been reduced by 47.30% for Zenata station and by 26.37% for OuledMimmoun station.Table IV 7 below shows the comparison.

Table IV 7:Comparison before and after 80s for the first group

Station	**Mean SPI**		**Mean Precipitation (mm)**		**Deficit**	
	Before 1980	**After 1980**	**Before 1980**	**After 1980**	**Difference (mm)**	**Deficit (%)**
Zenata (1923-2017)	0.618	-0.911	627.00	330.4	296.6	47.30%
OuledMimoun (1923-2017)	*0.407*	*-0.561*	484.12	356.46	127.66	26.37%

Second group

For BeniBahdel, Bensakerane and Meffrouche stations the SPI value before 80s was positive, and after 80s is negative, the climate was mildly wet and becomes mild drought. The annual rainfall totals have been reduced by 23.18% for BeniBahdel station, by 19.81% for Bensakerane station and by 23.52% for Meffrouche.Table IV 8 below shows the comparison.

Table IV 8: Comparison before and after 80s for the second group

Station	**Mean SPI**		**Mean Precipitation (mm)**		**Deficit**	
	Before 1980	**After 1980**	**Before 1980**	**After 1980**	**Difference (mm)**	**Deficit (%)**
BeniBahdel	0.405	-0.444	520.6	399.9	120.7	23.18%
Bensakerane	0.363	-0.518	471.5	378.1	93.4	19.81%
Meffrouche	0.508	-0.508	707.06	540.73	166.33	23.52%

Third group:

For Maghnia and HammaBoughrara stations the SPI value before 80s was positive, and after 80s is negative, the climate was mildly wet and becomes mild drought.For Piere de chat station, given the short period of data, SPI doesappear to be much different between the two periods.

The annual rainfall totals have been reduced by 28.93% for Maghnia station, by 40.87% for HammaBoughrara station and by 23.39% for Piere de chat station.TableIV 9 below shows the comparison.

Table IV 9: Comparison before and after 80s for the third group

Station	Mean SPI		Mean Precipitation		Deficit	
	Before 1980	After 1980	Before 1980	After 1980	Difference (mm)	Deficit (%)
Maghnia	0.804	-0.330	432.7	307.5	125.2	28.93%
HammamBoughrara	0.933	-0.311	359.7	212.7	147	40.87%
Piere de chat	-0.242	-0.317	394.81	302.45	92.36	23.39%

T test

The t test (also called Student's T Test) compares the averages (means) of two groups to know if they are statistically different from each other. It use correlation and regression to see how two variables vary together. The t test also shows how significant the differences are. In other words, whether or not those differences could have happened by chance.

As such, T test was performed for the 8 stations in order to investigateif the changes are significant. The Tteste showed that the series are statistically significant which means that there is really changes in the climate before and after 80s, except for Piere de chat station it is no statistically significant. This station also has very short record prior to 80s that may explain the result.

Table IV 10:The t test result for the eight stations

Station	extremely statistically significant	very statistically significant	not statistically significant
Zenata	**X**		
OuledMimoun	**X**		
BeniBahdel	**X**		
Bensakerane	**x**		
Meffrouche	**x**		
Maghnia		**X**	
HammamBoughrara		**X**	
Piere de chat			**x**

4.1.4 Temperature evolution

Three station were used to study the changes intemperature study: Zenata, BeniBahdel, Hammam Boughrara.

Mean temperatures fluctuated, a comparison between two periods was made to evaluate the change, for Zenata station the temperature has gone up from anaverage of 16.45 c° during 1913-1938 to 18.31 c° during 1980-2017 (difference of 1.87 c°) (Figure IV 17). For BeniBahdel station the temperature has gone up from the average of 16.75 c° during 1913-1938 to 17.65 c° during 1980-2017 (a difference of 0.90 c°) (Figure IV 18). Lastley, for Hamam Boughrara station the temperature has gone up from the average of 16.82 c° during 1913-1938 to 17.87 c° during 1980-2017 (a difference of 1.05 c°) (Figure IV 19).

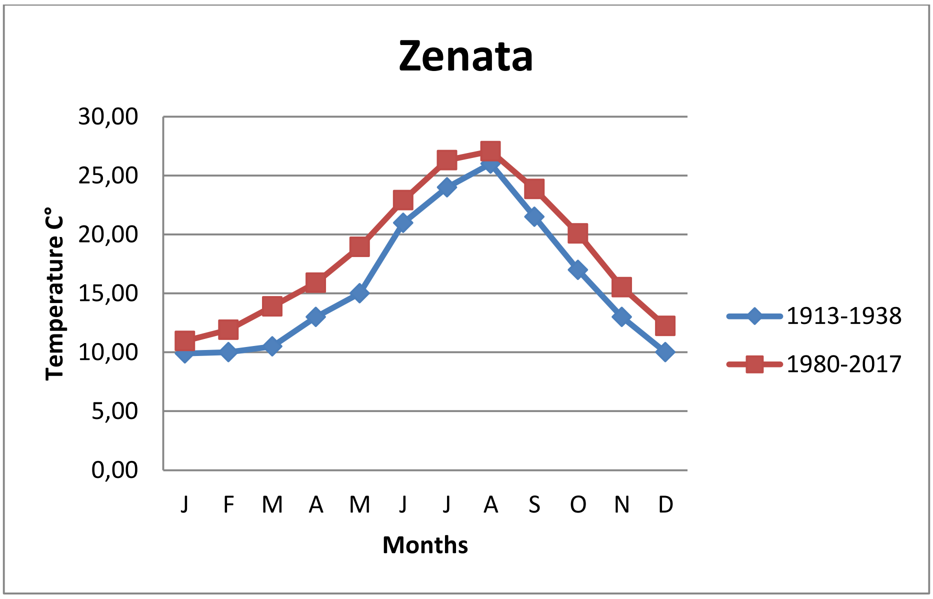

Figure IV 17: Monthly temperature evolution for Zenata station

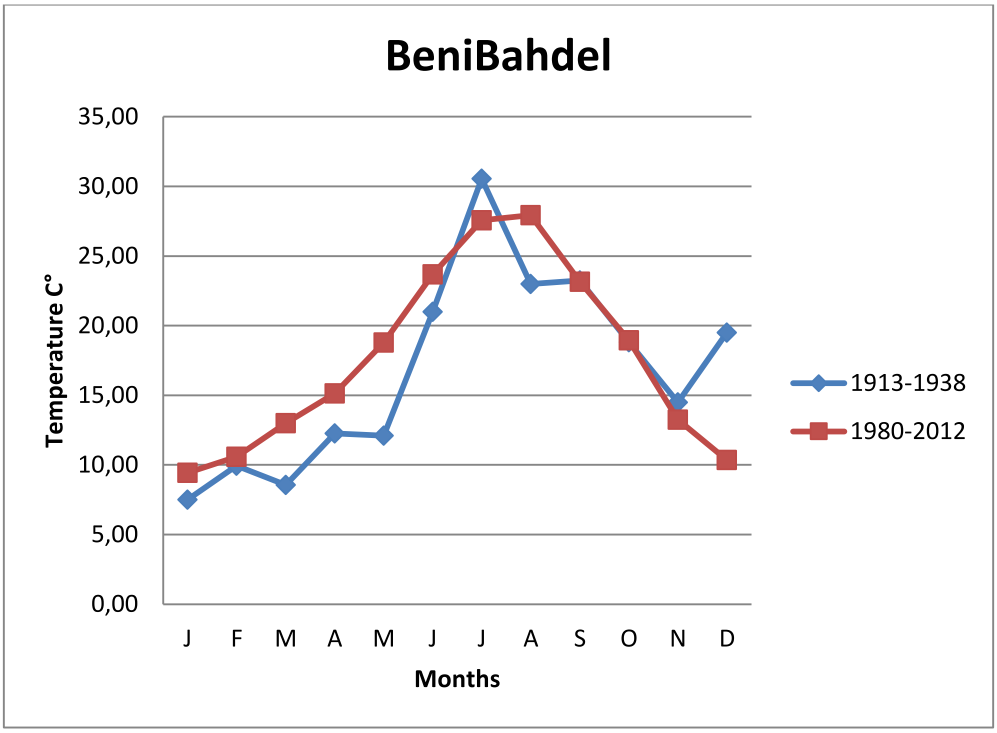

Figure IV 18: Monthly temperature evolution for BeniBahdel station

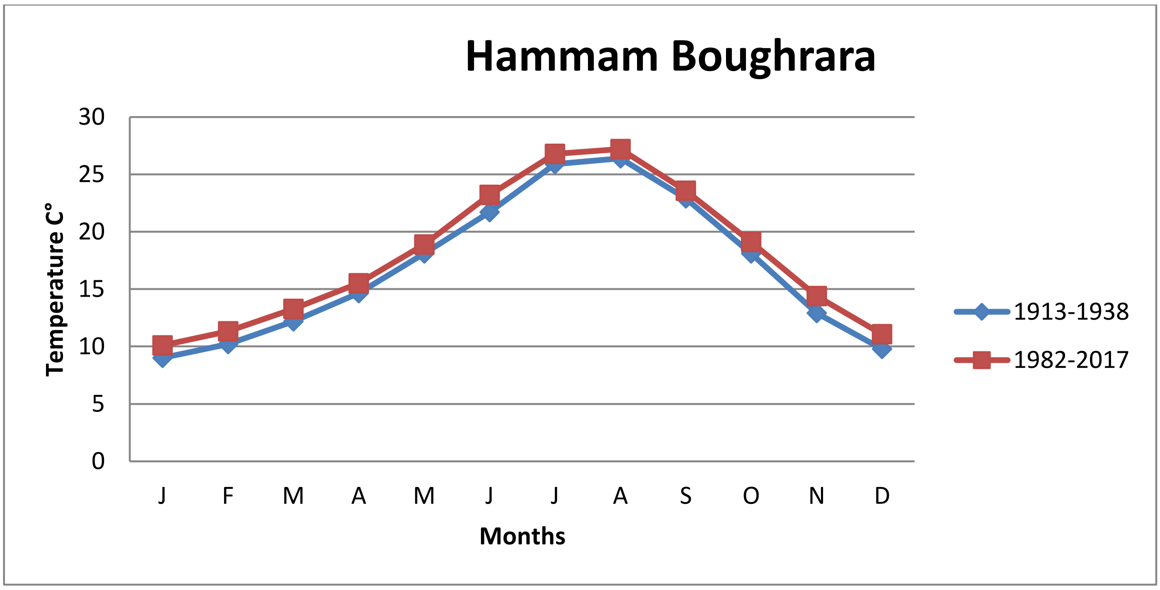

Figure IV 19: Monthly temperature evolution for Hammam Boughrara station

For the Zenata and Hamam Boughrara stations the temperature has increased during the fourth seasons (Figure IV 20) and (Figure IV 21), but for the

BeniBahdelstation (Figure IV 22)the temperature has increased for the spring and summerseason, and decreased for the winter, it remain the same for the autumn.

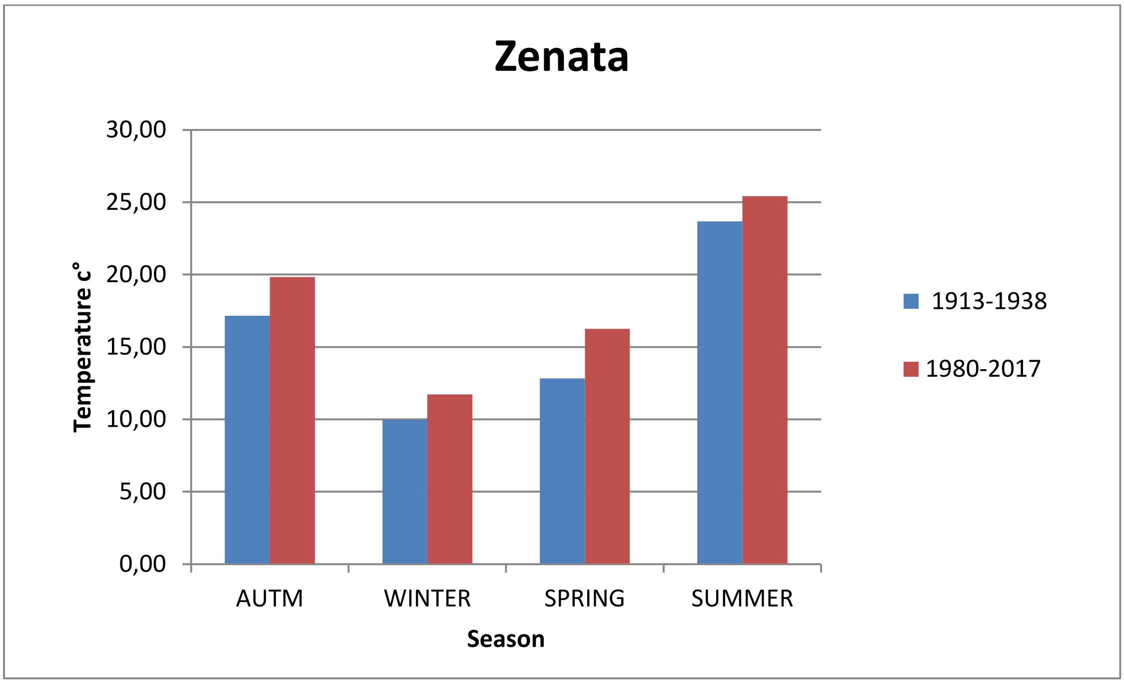

Figure IV 20:Seasonal temperature evolution for Zenata station

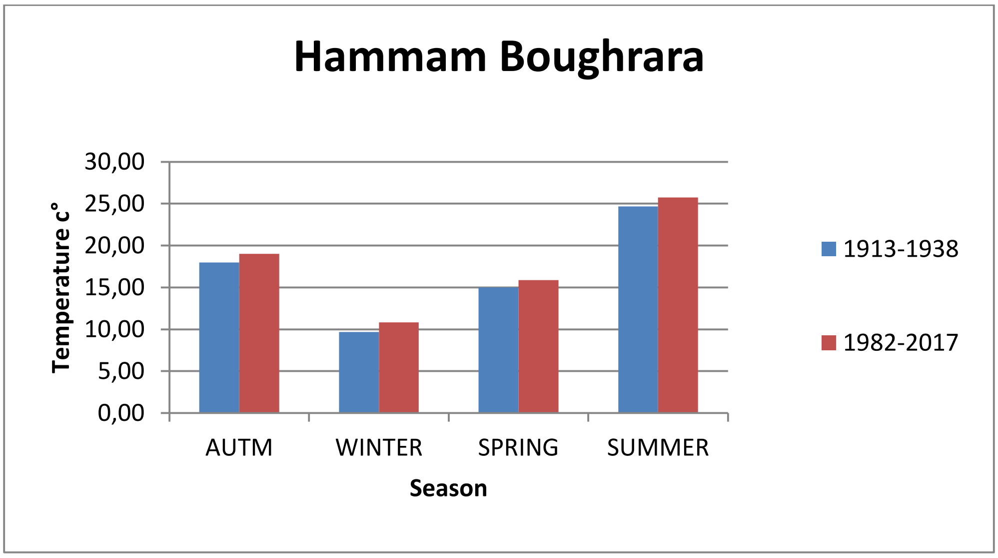

Figure IV 21:Seasonaltemperature evolution for Hammam Boughrara station

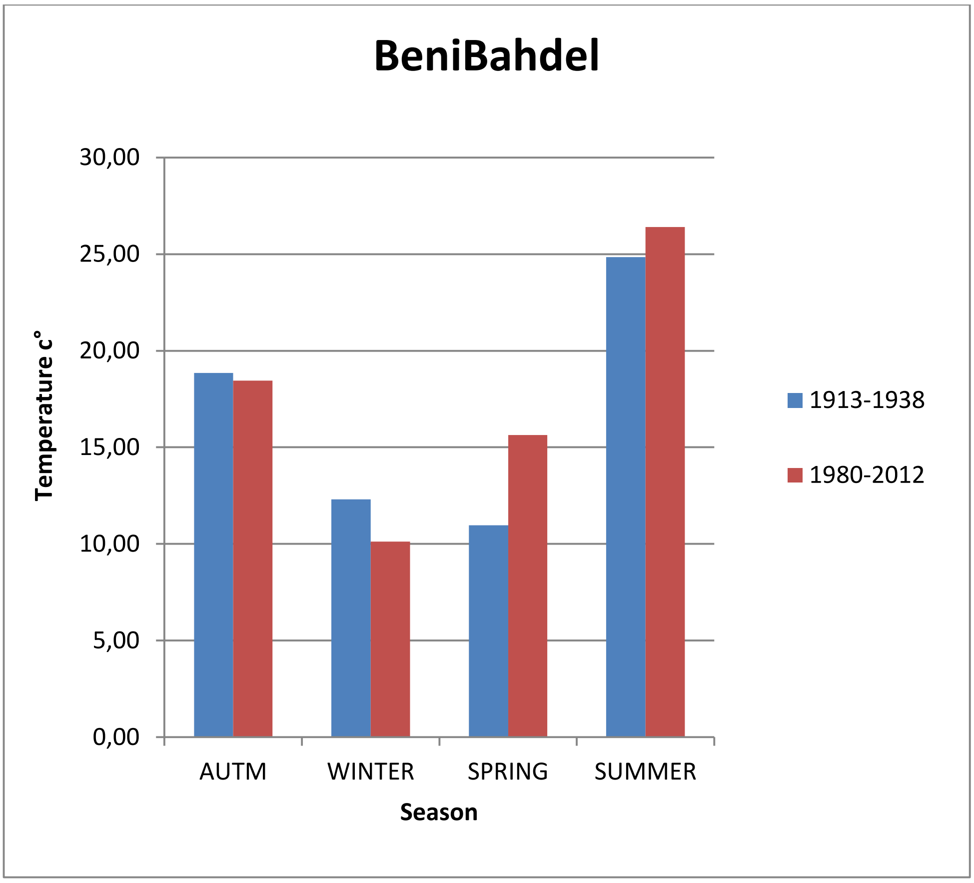

Figure IV 22:Seasonal temperature evolution for BeniBahdel station

4.1.5 Ombrothermic Diagram

The impact of a decrease in precipitation and an increase in temperature (a "double whammy") as shown above could become significant in terms of hydrologic responses of Tafna Basin. An Ombrothermic Diagram may be used to understand this relationship and potential impact on water resources. The Ombrothermic Diagram allows to determine the dry period from the wet period.For the Zenata station 6 monthswet (from mid-October to mid-April) the rest remains dry, for Beni bahdelstation 6.5 monthswet (from mid- October to the end of April) the rest remains dry, and for the Hammam Boughrara station 5.5 months wet (from the mid- October to the end of March) the rest remains dry.

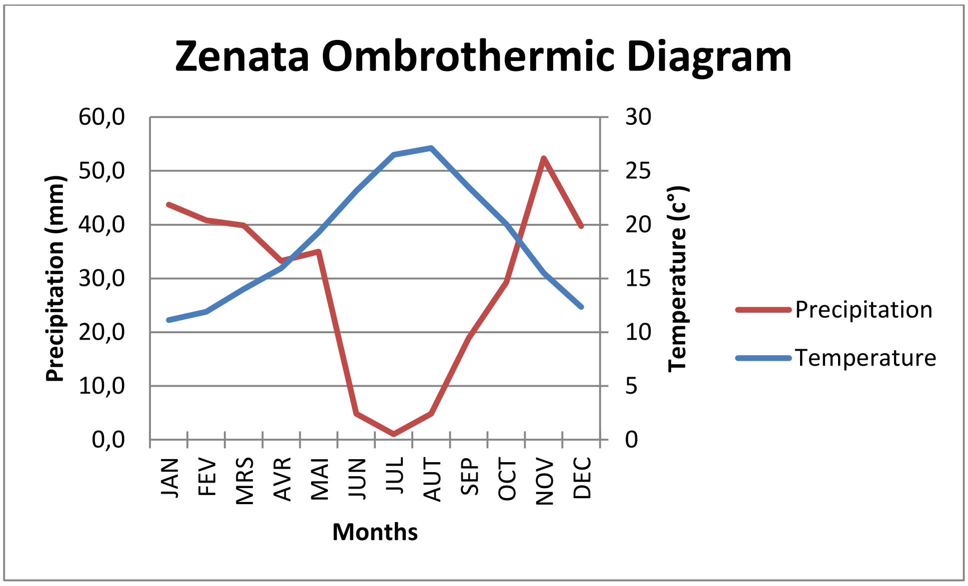

Figure IV 23:Zenata Ombrothermic Diagram for (1992-2012)

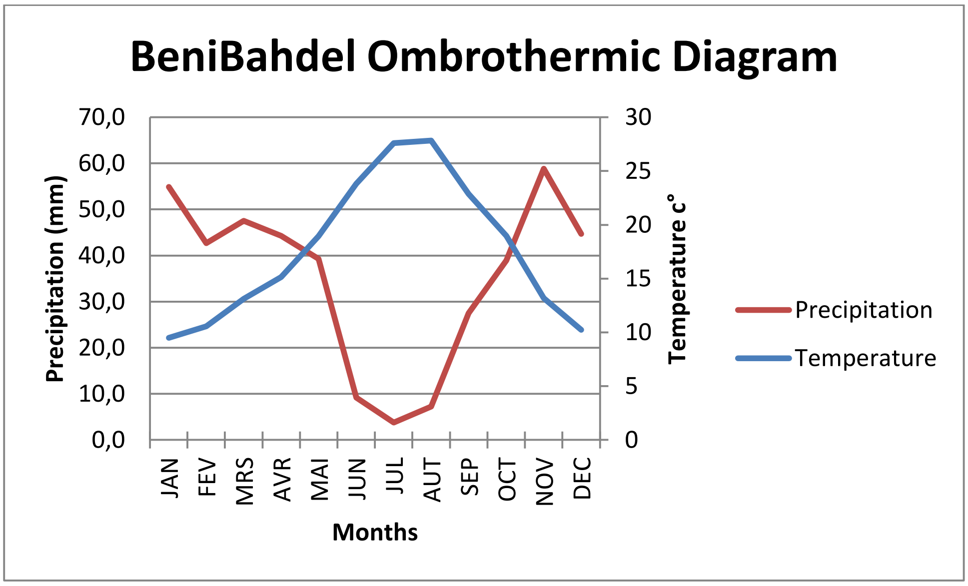

Figure IV 24:BeniBahdel Ombrothermic Diagram (1992-2012)

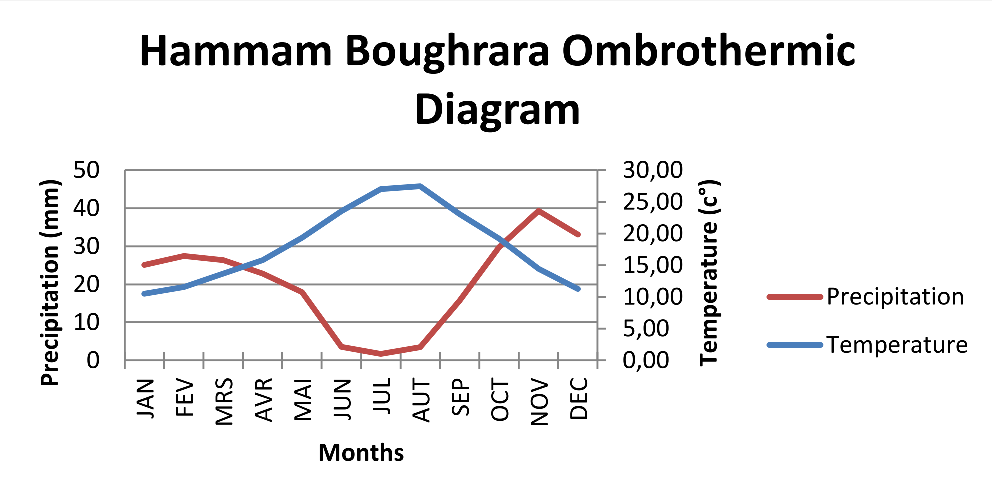

Figure IV 25:Hammam Boughrara Ombrothermic Diagram (1992-2012)

4.2 Climate Change Downscaling

In the present study, a series of downscaling models were examinedusing correlation and regression method. To do so, past predictor data obtained from the NCEP/NCAR reanalysis data archive (1961-2001) and observed data of precipitation and temperature for each station for each station were used.

Stepwise regression was used to select suitable predictor at the preprocessing stage. Consequently, results of aMultiple Linear Regression (MLR)output was compared with observed precipitation of 2 stations, then MLR was employed to relate the GCM predictors obtained from UK Hadley Centre for Climate Prediction and Research namely the HadCM3 (daily data converted to monthly data using a Matlab program) with the monthly Predictands such as the locally observed precipitation and temperature at Zenata and Hammam Boughrara meteorological station which is located in Tafna basin. Appropriate predictand-predictor relationships were found out for the region by carrying out sensitivity analysis.Regression equations were developed and subsequently future monthly and annual projections for precipitation and mean temperature for the 2020s 2050s and 2080s were made under excel programs under the assumption of relationship (regression) constructed using historical data would stay the same in the future (a necessary assumption in all statistical downscaling approaches).

4.2.1 Data Used in Downscaling

To achieve climate simulations of the future, there must be a climate model that integrates the components necessary for the representation of climate and reverse actions that may occur. Such a model at least consists of an atmospheric model and an ocean model but other components may be useful according to the simulation duration achieved.

In this study, a single climate model (HadCM3) type AOGCM was chosen from existing models. This choice is motivated by the wide use of this model for climate projections and data availability. Global models are mostly used to assess climate average trends. HadCM3 is accessible GCM. Seven scenarios feed this model has a rectangular grid 96 grid points in longitude and latitude of 73 points. It is also divided into 19 vertical layers. It therefore has grid points of 3.75 degrees in longitude and 2.5 degrees in latitude (68). The HadCM3 predictors can be easily obtainedfrom the Canadian climate-scenarios website. The predictor variables contain the historical NCEP data with the specific climate change scenarios H3A2a (medium-high) and H3AB2a (medium-low) inside the spatial grid cell of the large-scale climate change GCM-HadCM3 model.

The available values range from 1961 to 2099. The data are monthly minimum maximum temperature, and precipitation for both scenarios.

The second data used for downscaling is the observed data (precipitation, maximum and minimum temperature) as predictand variables at a local scale of Tafna basin.

The Zenata and Hammam Boughrara stations were used to downscale monthly precipitation and mean temperature by using MLR method.

Table IV 11:stations used for downscaling in Tafna Basin

Station	Latitude	longitude	Altitude (m)	Precipitation Period (year)	Temperature Period (year)
Zenata	35°01’00’’	-01°27’00’’	247	1982-2017	1982-2017
Hammam Boughrara	34°53’28’’	-01°38’20’’	270	1982-2017	1982-2017

4.2.2 Large -Scale Atmospheric Variable (Predictors)

Observed and modelled predictors come respectively from the National Center forEnvironmental Prediction (NCEP) reanalysis and the Hardley Center Couple Model (HadCM3).The Canadian Institute for climate studies website provides all the NCEP and HadCM3 data andit can be downloaded from (http://climate-scenarios.canada.ca/?page=pred-hadcm3) in the grid boxbased on the value of latitude and longitude of the study area. The grid box provides a zip filecontains three directories: NCEP-1961-2001, H3A2a-1961-2099 and H3B2a-1961-2099.Observed large scale NCEP reanalysis data are prepared by the Canadian Institute for climatestudies under Canadian Climate Impact Scenarios (CCIS) project. NCEP data contains 26predictor daily atmospheric variables which are extracted from the grid box covering thepredictands. The grid box (1X, 20Y) for Zenata and Hammam Boughrara consist of large scale predictor (NCEP, H3A2a and H3B2a) used for this study area,(Figure IV 26)shows the grid of this model in Tafna basin.

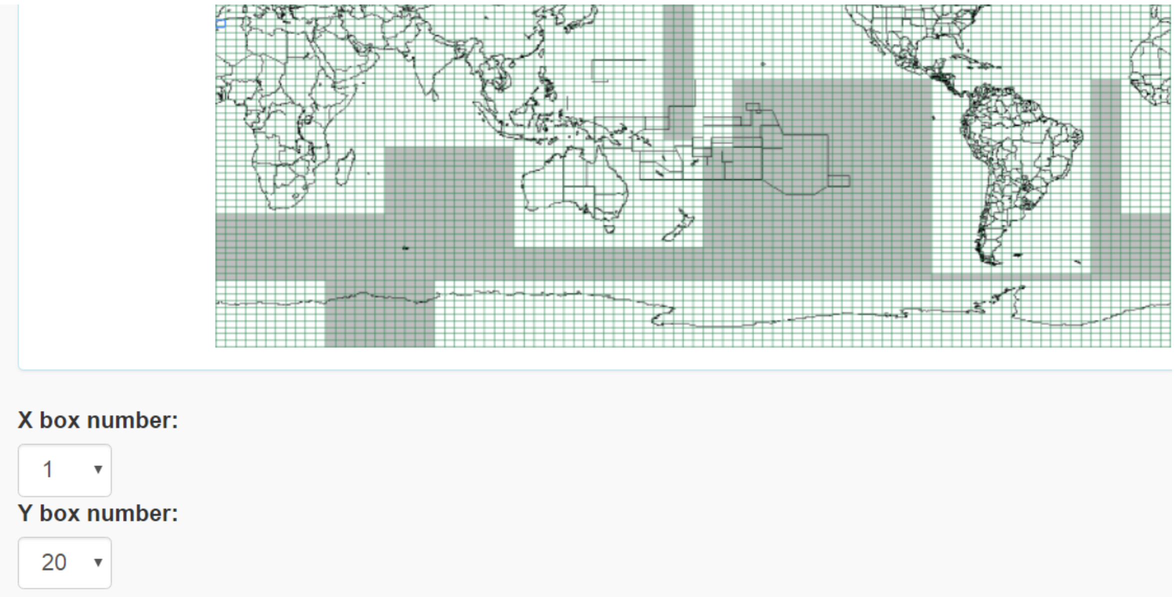

Figure IV 26:The Grid box large scale predictor (NCEP, H3A2a and H3B2a) data

4.2.3 MLR for Tafna basin

In the present study, the Statistical Downscaling Model (SDSM) that was built in climate data repository couldnot be used for the downscaling because the daily meteorological datawere not available.Instead, for Tafna basin rainfall and temperature are modelled by using Multiple Linear Regression (MLR) which is one of the most widely used forms of regression. The MLR model developed in this study was programmed in Excel and MATLAB and used method of maximum likelihoodto estimate model parameters. The main problem with MLR model is that it tries to model the conditional mean, whichis not best suited for predicting extremes. However, in this study prediction of extreme rainfall and temperature are not the focus rather the mean behavior of these important climatic variables. Hence, MLR is deemed adequate for the purpose of the research. If extreme rainfall and temperatures are needed one may have to look as forms of downscaling.

4.2.4 Screening predictor variable

Selection of appropriate predictors is the most important step in the development of statistical downscaling procedure. It would generallynot be useful to include all potential predictors in a final model. This is because the predictor variables are almostalways mutually correlated, so that the full set of potential predictorscontains redundant information. Identifying empiricalrelationships between gridded predictors and single site predictands is central to all statisticaldownscaling. The predictors relations in this research are formed based on correlation coefficients between them. Stepwiseregression is applied in the present study for selection of predictors from the NCEP climatic data as it has been shownas a powerful method by many previous studies (69).The application of these empirical predictor-predictand relationships of the observed climate is todownscale ensembles of the same local variables for the future climate. This is based on theassumption that the Predictor-Predictand-Relationship (PPR)under the current condition remain validunder future climate conditions. The monthly values of the 26 predictors variable were used in screening process.Predictors that have high correlation with the predictands were chosen forfuture prediction. The selected large-scale predictors for all the local predictands are listed intable IV 12.

Table IV 12:list of selected large-scale predictor variables for predicting monthly precipitation and mean temperature

Station	Predictands	Predictor NCEP Analyses data	Predictor variable	Correlation
Zenata	P	Surface specific humidity	ncepshumas	0.50
		Near surface humidity	nceprhumas	0.47
		Surface velocity	ncepp_zeu	0.46
		500 hpa geopotential height	ncepp500as	0.45
	T	Surface specific humidity	ncepshumas	0.91
		500 hpa geopotential height	ncepp500as	0.86
		Surface velocity	ncepp_zeu	0.86
		Mean temperature at 2 m	nceptempeu	0.82
Hammam Boughrara	P	500 hpa wind direction	ncepp5theu	0.42
		Surface velocity	ncepp_zeu	0.38
		Mean sea level pressure	ncepmslpeu	0.34
		500 hpa geopotential height	ncepp500as	0.33
	T	Mean temperature at 2 m	nceptempeu	0.85
		Surface specific humidity	ncepshumas	0.90
		Near surface humidity	nceprhumas	0.84
		Relative humidity at 850 hpa	ncepr850as	0.82

4.3 Weather and scenario generator

In order to validate the results of the weather generator operation a verification of the reliability of the outputs was carried out. The results of downscaling indicate that the model run is satisfactorily validated between simulation data and observed data.

Temperature at Zenata

The results of downscaling mean Temperature at the Zenata station indicate that there issatisfactory agreement between simulation data and observed data.Generally observed and downscaled values show similar pattern (Figure IV 27). The model in downscaling the annualmean temperature shows a slightly decrease of 0.21%. The monthly downscaledtemperature shows slightly lower value forsome months and it is slightly higher for the other.

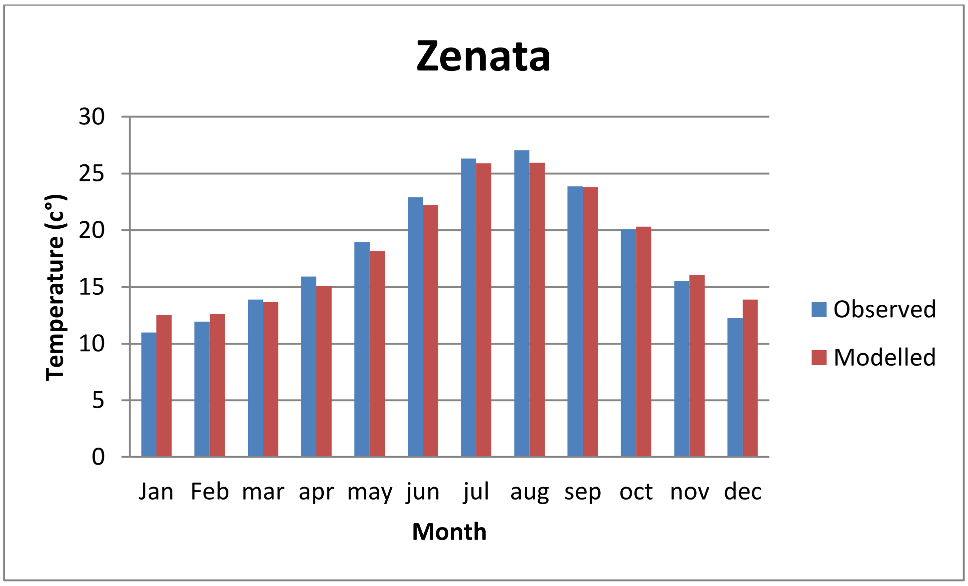

Figure IV 27:Monthly mean temperature between observed and modeled at Zenata station

Precipitation at Zenata

The downscaled precipitation value at Zenata station are slightly different from the observed value.Rainfall prediction has a larger degree of uncertainty than those for temperature.The total annual precipitation downscaled value at the Zenata stationsshows a 1.13 % difference compared to observed value. The model overestimate in somemonths and underestimate in other (Figure IV 28).Generally the result is considered satisfactory.

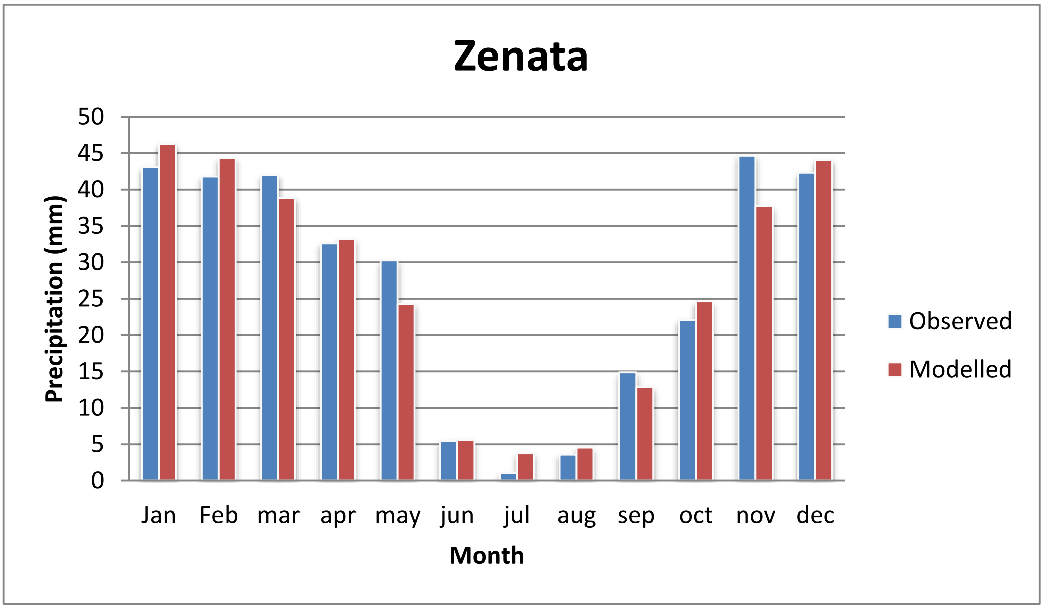

Figure IV 28:Monthlyprecipitation between observed and modeled at Zenata station

Temperature at Hammam Boughrara

The results of downscaling mean temperature at the Hammam Boughrara station indicate that there issatisfactory agreement between simulation data and observed data.Generally,observed and downscaled values show similar pattern (Figure IV 29). The model in downscaling the annual mean temperature shows a decreaseof 1.72%. The model overestimated in somemonths especially in the month of November, December, January and February and underestimates in some in the other months.

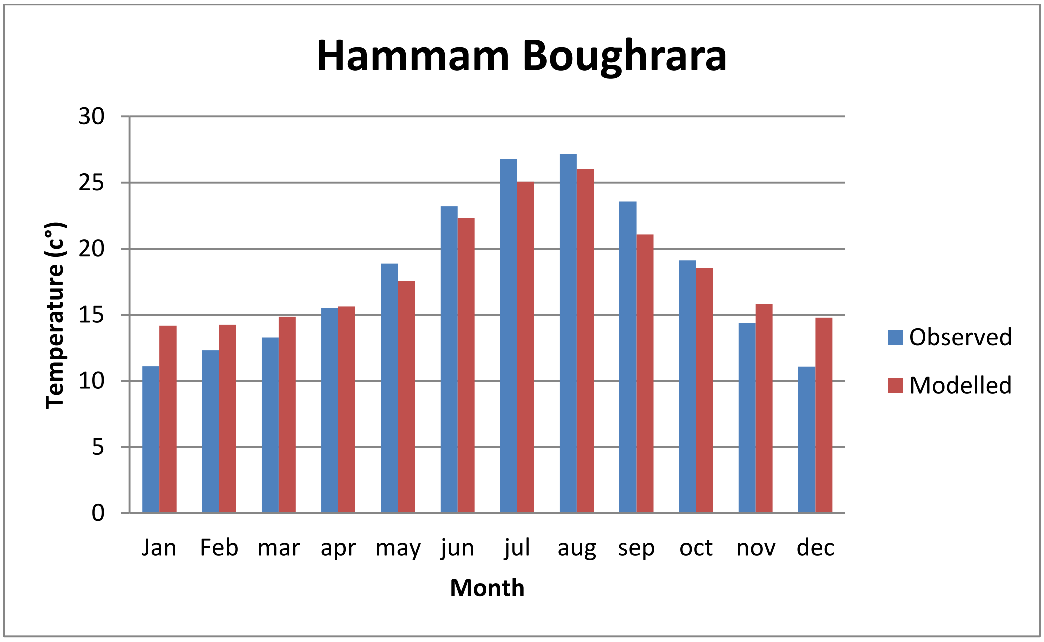

Figure IV 29:Monthly mean temperature between observed and modeled at Hammam Boughrara station

Precipitation at Hammam Boughrara

The downscaled precipitation values at Hammam Boughrara station indicate that there issatisfactory agreement between simulation data and observed data. As shown in (Figure IV 30). The total annual precipitation downscaled value at Hammam Boughrara stationsshows a 1.11% difference compared to observed value. The model is overestimated in somemonths specially July August and underestimates in other specially March November and October. Generally the result however, can be taken as satisfactory.

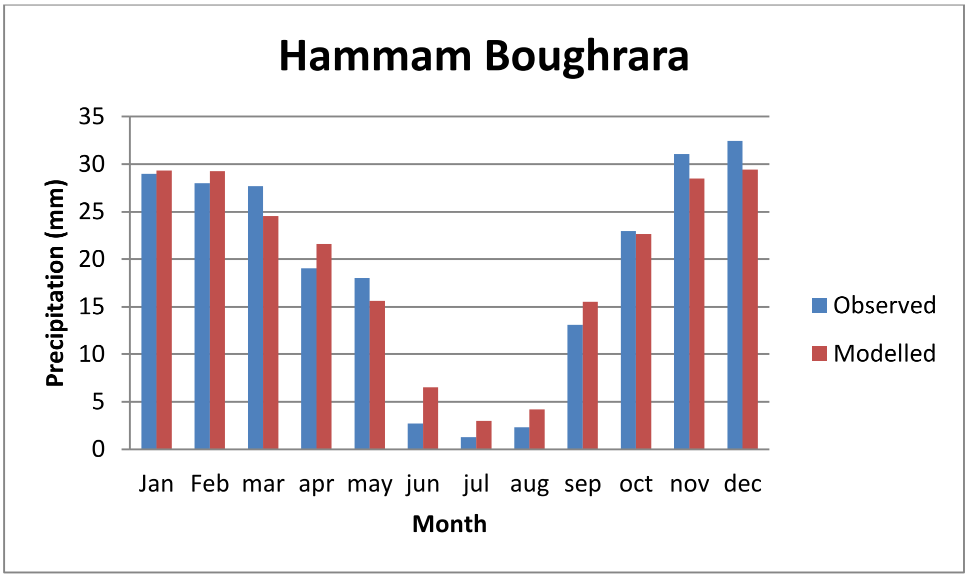

Figure IV 30:Monthlyprecipitation between observed and modeled at Hammam Boughrara station

Scenario Generator

The Hardley Center Couple Model (HadCM3) is used to downscale monthly future climatevariables for the next century at Tafna basin. The Scenario Generation operationproduces ensembles of synthetic monthly weather series given the regression weight produced during the calibration process and the monthly atmospheric predictor supplied by a GCM. Eight ensembles of synthetic monthly time series were produced (mean temperature,precipitation)for the two emission scenarios (HadCM3 A2s & B2a) for a period of 139 years (1961 to 2099) for Zenata station and Hammam Boughrara station. The future scenarios were developed by dividing the future time series into three period time slices 2020s (2010-2039), 2050s (2040-2069) and 2080s (2070-2099). HadCM3 modelsimulation use 360-day calendar, where each month is 30 days.

Temperature in Zenata

The downscaled mean temperature generated by the MLR approach based on the HadCM3 modelinput has projected mean temperature increases at Zenata. The projected meantemperature for future periods for A2 and B2 scenarios are shown in (Figure IV 31). The modelpredicts the annual mean temperature to increase by 4.11%, 10.78%, 23.17 %, for 2020s,2050s and 2080s respectively in A2 scenarios and 3.87%, 8.05%, 11.77%, for 2020s, 2050s and2080s respectively in B2 scenarios.

The highest mean temperature of the seasons occurred in August whose temperature is 26.89 c°, 28.47 c°, 31.33 c° for 2020s, 2050s and 2080s respectively in A2 scenarios and 27.84 c°, 28.92 c°, 29.96 c° for 2020s, 2050s and 2080s respectively in B2 scenarios.

The lowest mean temperature was occurred in January reaches about 13.41 c°, 13.96 c°, 15.71 c for 2020s, 2050s and 2080s respectively in A2 scenarios and about 11.78 c°, 12.80 c°, 12.096 c° for 2020s, 2050s and 2080s respectively in B2 scenarios.

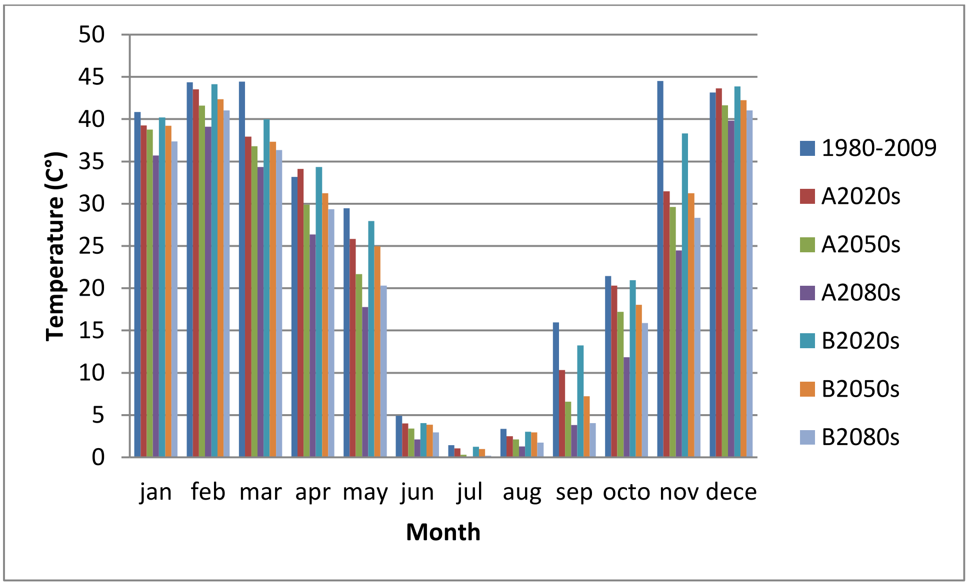

Figure IV 31:monthly mean temperature for future scenarios at Zenata station

Precipitation at Zenata

Projection of precipitation shows decreasing trend towards for all future time horizon for both A2and B2 scenarios at Zenata stations (Figure IV 32). The precipitation expected to experience a mean annualdecrease by 10.12%, 17.56% and 27.62% by 2020s, 2050s and 2080s respectively for A2scenarios and about 4.81%, 13.89%, 20.93% by 2020s, 2050s and 2080s respectively for B2scenario.

The wettest months are December and February reaches about 43.63 mm, 41.65 mm, 39.83 mm for 2020s, 2050s and 2080s respectively in A2 scenarios and 43.88 mm,42.36 mm, 41.03 mm for 2020s, 2050s and 2080s respectively in B2 scenarios.

The driest month is July The downscaled value 1.04 mm, 0.29 mm, 0.06 mm for 2020s, 2050s and 2080s respectively in A2 scenarios and 1.23 mm, 0.96 mm, 0.20 mm for 2020s, 2050s and 2080s respectively in B2 scenarios

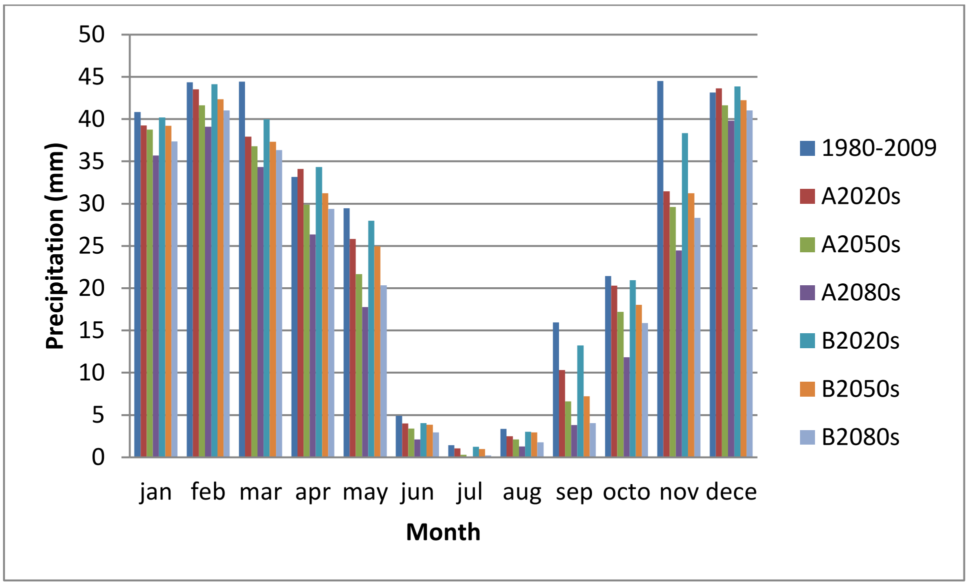

Figure IV 32:monthlyprecipitation for future scenarios at Zenata station

Temperature at Hammam Boughrara

The downscaled mean temperature generated by the MLR approach based on the HadCM3 modelinput has projected mean temperature increases at Hammam Boughrara. The projected meantemperature for future periods for A2 and B2 scenarios are shown in (Figure IV 33). The modelpredicts the annual mean temperature to increase by 7.11%, 11.66%, 17.46%, for 2020s,2050s and 2080s respectively in A2 scenarios and 3.95%, 8.44%, 12.56%, for 2020s, 2050s and2080s respectively in B2 scenarios.

The highest mean temperature of the seasons occurred on July and August whose temperature is 27.96 c°, 28.88 c°, 29.36 c° for 2020s, 2050s and 2080s respectively in A2 scenarios and 27.87 c°, 28.63 c°, 29.12 c° for 2020s, 2050s and 2080s respectively in B2 scenarios.

The lowest mean temperature was occurred in December and January reaches about 14.60 c°, 14.46 c°, 14.88 c for 2020s, 2050s and 2080s respectively in A2 scenarios and about 11.42 c°, 12.38 c°, 13.07 c° for 2020s, 2050s and 2080s respectively in B2 scenarios.

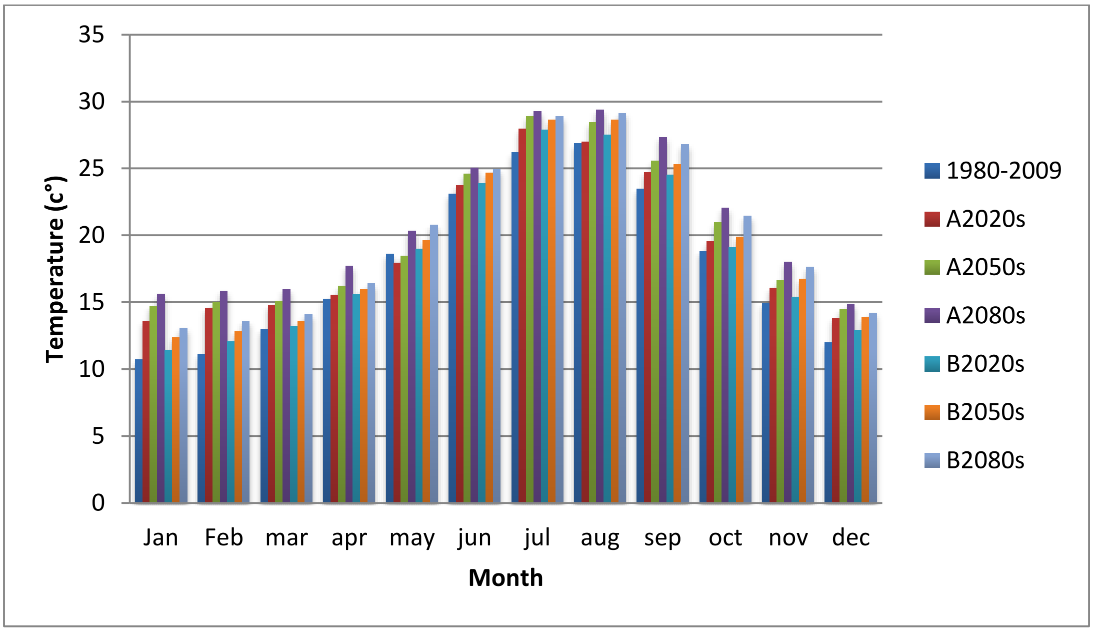

Figure IV 33:monthly mean temperature for future scenarios at Hammam Boughrara station

Precipitation at Hammam Boughrara

Projection of precipitation shows decreasing trend towards for two future time horizon (2050s and 2080s)for both A2and B2 scenarios at Boughrara stations, and increase for 2020s. The precipitation expected to experience a mean annualdecrease by 1.61%, 10.71% by 2050s and 2080s respectively for A2scenarios and about 2.90%, 11.77%, by 2050s and 2080s respectively for B2scenario. For 2020s the precipitation will increase by 1.47 %, 0.77% respectively for A2 and B2

Generly for this station the precipitation increases for certain months and decreases for others (Figure IV 34).

The wettest month is December reaches about 27.42 mm, 26.07 mm, 27.84 mm for 2020s, 2050s and 2080s respectively in A2 scenarios and 28.30 mm, 26.66 mm, 27.17 mm for 2020s, 2050s and 2080s respectively in B2 scenarios.

The driest months are July and august the downscaled value 2.56 mm, 3.38 mm, 3.37 mm for 2020s, 2050s and 2080s respectively in A2 scenarios and 2.47 mm, 3.10 mm, 3.13 mm for 2020s, 2050s and 2080s respectively in B2 scenarios

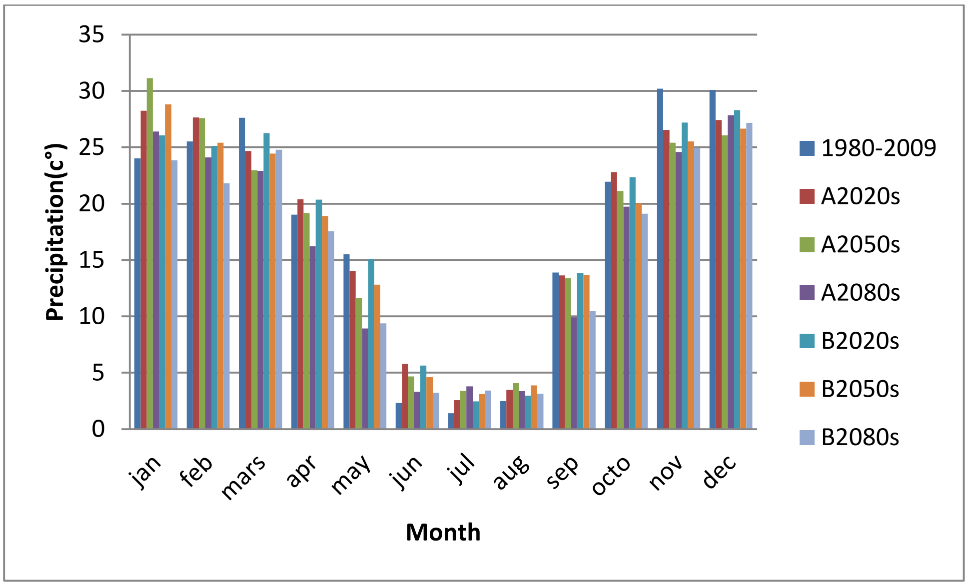

Figure IV 34:monthlyprecipitation for future scenarios at Hammam Boughrara station

Conclusion

This thesis research assessed the potential change in climate of Tafna basin during the period of 1923-2017 using different statistical methods. Monthly data series of eight stations were used to evaluate precipitation and temperature potential changes.

Assessments of rainfall variability in Tafna basin showed the existence of dry period post 80s. This resulted in an important rainfall deficit for all the eight stations studied. The minimum decrease is about 20% and the maximum is about 47%. The value of Standardized Precipitation Index (SPI)for stations has largely decreased after the rupture, and the majority of the peaks are negative. In parallel with this decrease in precipitation, the temperature has beedn found to have a significant increase, which generates changes inTafna basin climate after rupture.

The second part of this study assessed potential future climatic condition using climate projections and downscaling to local scale.A Multiple Linear Regression approach was used to downscale HadCM3 data. A2 and B2 emissions scenarios for future climate predictions was selected to understand the potential climate change.

The results of downscaled GCM data for baseline period showed a satisfactory agreement between simulation data and observed data for precipitation and mean temperature at all station.During calibration of the method historical performance was about 1% of actual observation, which was deemed satisfactory. The results of downscaled GCM data for future period showed increasing trend towards the endof century for mean temperature value under A2 and B2 scenarios in allstations. Correspondingly, the projection of precipitation showed decreasing trend towards end ofcentury at zenata stations.For Hamam Boughrara stations some months the value of rainfall has found to be increasing and for other to decrease but in general rainfall declinewas found under both A2 and B2 scenarios.

This increase in temperature and decrease in rainfall will decrease in the surface runoff, and increase in evaporation and evapotranspiration over Tafna basin, affecting negatively the water resources quantity and potentially generating a water shortage as demand for water grows.

This modest work cannot be described as perfect in the field of assessment of the impact of climate change studies. We hope to supplement it with other more detailed studies, based on daily data and with a larger number of stations for a better representation of the region, and for important observational periods.

At the end of this study, the results found remain to be completed. However, the problem of meteorological data availability for the other sub-basins meant that they were not integrated into the study. This lack also did not lead to a good spatial representation of our results. We wanted to estimate the water budget to verify the influence of climate variability on the latter but the lack of data and constraint in time remains an obstacle to assess how this impact in precipitation and temperature could potentially translate into impact to the hydrology of the watershed.

REFERENCES

1. *Caractérisation de la sécheresse par les indices SPI et SSFI (nord ouest de l'Algérie).* **A.Ghenim et A.Megnounif.** 2011, Revue scientifique et technique LIFE N°18.

2. *hydrological drought in tafna Basin-northwest of algeria.* **M.Meddi, S.Toumi et M.Mehaiguene.** 2013, Revue scientifique et technique, research gate.

3. **N.A.S.A.** climate.nasa.gov. [En ligne] 2017. [Citation : 14 Juin 2018.] https://climate.nasa.gov/evidece/.

4. **N.Brooks.***Climate change, drought and pastoralism in the Sahel, discussio note for the world initiative on sustainabl pastoralism.* Washignton D.C : s.n., 2006.

5. **U.N.** Afria water atlas. New York : United nations Environment programme, 2010. ISBN:978-92-807-3110-1.

6. **E.Kostopoulou et P.D.Jones.** Assessment of climate extremes in the eastern mediterranean . s.l. : MeteorolAtmos, 2005. 00703-005-0122-2.

7. **D.Ventrella, et al.** Agronomic adaptation strategies under climate change for winter durum wheat and tomato in souhtern italy. Verona : Reg. Environ Change, 2011. P 407-417.

8. **M.Bahir, et al.** impact de la sécheresse sur les potentialités hydriques de la nappe alimentatnt en eau ptable de la ville d'essaouira. Mogador : Séch, 2002. Vol. 13, P 13-19.

9. **Y.Tramblay, et al.** Climate change impacts on extreme prediction in Morocco. Féz : Global planet, 2012. P 82-83. 104-1140.

10. **S.Taibi.** Analyse du régime climatique au nord de l'Algérie. *Mémoire de master.* Alger : U.H.B Alger, 2011.

11. **N.Huddleston.** Climate change!: Evidence,impacts and choices: answers to mmon questions about the science of climate change. California : Science direct, 2012.

12. **D.Boucherf.***Variabilité et changement climatique en Algérie.* Alger : s.n., 2007.

13. —. étude spatio-temporelle et prévision saisonnère des températrues sur le nord d'algérie. *mémoire de magister.* ALger : université d'alger, 2010.

14. *trente années de prospection et de mobilisation des ressources en eau souterraines, par forages dans la wilaya de Tlemcen.* **F.Bensaoula, I.Derni et M.Adjim.** 10, Tlemcen : Larhyss, 2012. 1112-3680.

15. **F.Sylvestre, S.Servant-Vildary et M.Servant.***the last glacial maximmum (21000-17000 14C yrBP) in the southern tropical andes (Bolivia)based on diatom studies.* Andes : Sciences Series IIA Earth and planetary sciencce, 1998. 327(9),611-618.

16. **R.Henson.***The rough guide to climate change.* s.l. : Rough guides, 2008. 384p.

17. **P.Jones, et al.***High resolution paleoclimatic records for hte last millenium: interpretation, integration and comparaison with general circulation model controlrun temperature.* s.l. : The Holocene, 1988. 8(4),P455-471.

18. **F.Parrenin.** Datation glaciologique des forages profonds en antarctique et modélisation conceptuelle des paléoclimats. *Thèse de doctorat.* Grenoble : Université Joseph Fourier, Grenoble, 2002.

19. **K.E.Trenberth, et al.**The physical science basis contribution of working group I to the fourth assessment Report of the Intergovernemmental panel on climate hange . *Surface and atmospheroc climate change.* Cambridge : Cambridge university Press, 2007.

20. **T.B.Mckee, N.J.Doesken et J.Kleist.** The relationship of drought frequency and duration of tie scales. *Eighth conference on applied climatology.* California : American Meteorological society , 1993. P179-186.

21. **N.Kumara.** On the use of standardized precipitation index (SPI) for drought intensity assessment . *Development and database systems* . India : Group remote sensing & GIS application Area National Remote Sensing Center, 2009. Vol. P.500-625.

22. **T.R.Carter.** General guidelines on the use of scenario data for clmate impact and adaptation assessment Vol.2. *Group on data and scenario support for impact and climate assessment* . s.l. : Intergovermmental Panel Climate change, 2007.

23. **Y.Elmadahi.** Les changements climatiques et leurs impacts sur les ressources en eaux, cas du bassin du Cheliff. *Thèse de Doctorat.* Chlef : Université de Chlef, 2016.

24. **IPCC.** Contribution to the fifth assessment report of the intergovemmental Panel on climate change. *Summary for policymakers.* 2013.

25. **j, m et collins.** Temperature variability over Africa. s.l. : Journal of climate 24, 2011. Vol. P3649-3666.

26. **K.Bom, A.Fink et H.Paeth.***Dry and wet periods in the northwestern Maghreb for present day and future cclimate conditions.* s.l. : MeterologischeZeitschrift, 2008. 17,533-551.

27. **World Bank Group.** 2014.

28. *l'eau dans le bassin de la Tafna.* **S.Tadlaoui, M.Bouabdalla.** Tlemcen : Université Abou Bker Belkaid, 2016, noublez.

29. **Mate.** Seconde communication nationale de l'Algérie sur les changement climatiques à la CCNUCC. Alger : GEF, 2010.

30. **F.Giorgi et P.Lionello.***Climate change projections for the mediterranean region* . s.l. : Global Planet change, 2008. 63,P90-104.

31. **Mate.** elaboration de la stratégie et du plan d'action national des changements climatiques. *Projet ALG/98/G31.* Alger : s.n., 2001.

32. *evolution récente des conditions climatiques et des écoulements sur le bassin versant de la mecta.* **M.Meddi, A.Talia et C.Martin.** Alger : Physio-Géo Géographie physique et environnement , 2009, Vol. III.

33. *facing climatic and anthropogenic changes in the mediterranean basin.* **M.Milano, et al.** s.l. : Geoscience, 2012.

34. **J.G.Charney, R.Fjortoft et J.VonNeuman.***numerical integration of the barotropic vorticity equation.* mantoue : Tellus, 1950.

35. **C.Anterives.** impact du changement climatique sur les ressources en eau en région Languedoc-Roussillon. *Mémoire de DEA.* Paris : Université pierre et marie curie, 2002.

36. **Barro, J.Robert et J.W.Lee.** International data on education attainment: updates and implications. Londre : Oxford university, 2000.

37. *international journal of climatology.* **J.Turner, et al.** The performance of the hadley center climate model (HADCM3) : s.n., 2001.

38. **R.E.Benestad, I.Hanssen-Bauer et D.Chen.** Empirical statistical downscaling. Singapore : World scientific publishing, 2007.

39. **T.Hoar et D.Nychka.** Statistical downscaling of the community climate system model monthly temperature and precipitation projections. s.l. : institute for mathematics applied to geosciences, 2008.

40. **T.Skaugen, et al.** Scenarios of extreme precipitation of duration 1 and 5 days for norway caused by climate change. Oslo : Norgesvass ogenergidirektorat, 2002.

41. **A.R.C.C.** A review of downscaling methods for climate change projections. Burligton : Tetra TechARD, 2014.

42. **K.Matthews.** Assessment of climate change impacts on stream flow trending Using . *A water alance model.* Florida : University of Florida, 2012.

43. **Wilby et Dawson.** Statistical downscaling model SDSM. UK : Virsio, 2007.

44. **L.Robert, et al.** Climate change unit,. *User manual.* Nottingham : Environment Agency of England and Wales,Nottingham, 2004.

45. **A.Goly et S.V.Ramesh.** development and evaluation of statistical downscaling models for monthy precipitation. Florence : Earth interactions V 18, 1995.

46. **D.S.Wilks.***Statistical methods in the atmospheric sciences.* San Diego : Academic press, 1995.

47. **K.Leahy.** modeling data for marketing, risk and costumer relationship management. new york : O.P.J.W, 2001.

48. *projection of the ganges-Brahamputra precipitation downscalled from GCM predictors.* **M.Shariar-Pertez et M.H.Geoffrey.** 2004, journal of Hydrology.

49. **K.Reza.** Assessment of climate change impacton runoff and peak flow-a case study on Klang watershed in west Malaysia. Nottingham : University of Nottingham, 2014.

50. **D.Yahiaoui.** Impact of climatic variations on agriculture in Orani. *mémoire de master*. Oran : University of Oran, 2015.

51. **A.Megnounif et A.N.Ghenim.** Détection de la sécheresse luviométrique dans le bassin de la tafna au cours des six dernières décennies. Tlemcen : Science & technology COST, 2013.

52. **A.B.H.** Bassin de la Tafna. *Document de synthèse.* Oran : cadastre hydraulique, 2006.

53. **H.Kamni.** Modélisation et régionalisation de la relation "pluie-débit" face au changement climatique: impact sur les ressources en eau. *Th-se de doctorat.* Tlemcen : Univesité abou bakr Belkaid Tlemcen, 2017.

54. **A.Benmoussat.** Mobilisation et protection des ressources en eau. *mémoire de magister.* Tlemcen : Université Abou bekr Belkaid, Tlemcen, 2012.

55. **A.Bouanani.** Hydrologie,transport solide et modelisation, étude de quelques sous bassins de la Tafna. *thèse de doctorat.* Tlemcen : Université Abou bekr Belkaid, Tlemcen, 2004.

56. **A.Rezougui.** Contribution à l'analyse des tendences d'évolution de peuplement des macro invertébrés benthique dans un contexte de rechauffement climatique cas de la tafna. *Mémoire de magister* . Tlemcen : Université Abou Bekr Belkaid, tlemcen, 2012.

57. **Benest.** Evolution de la plate forme de l'ouest algérien et du nord-est marocain au cours du jurasique supérieur et au début du crétacé: Stratigraphie, milieux de dépôts et ddynamiqe sédimentaire. *Thése de doctorat.* Lyon : Université de Lyon, 1985.

58. **P.Gardia.** Géodynamique de la marge alpie du continent africain d'après l'étude de l'oranie nord occidentale. *Thèse de doctorat.* Nice : université de nice, 1975.

59. **I.Derni.** Reflexion sur les cirtères de choix d'une méthodologie pour la cartographie de vulnérabilité à la pollution des eaux souterraines cas du bassin de la Tafna. *mémoire de magister.* Tlemcen : université Abou bekr belkaid, Tlemcen, 2011.

60. **A.Rahmi.** Contribution à l'étude des trichptères au niveau d'oued chouly (Nord-ouest Algérie). *Mémoire de master.* Tlemcen : Université abou bekr belkaid, Tlemcen, 2014.

61. **A.N.A.T.** actualisation du plan d'aménagement de la wilaya de Tlemcen. *bilan de la situation actuelle et problèmatique d'aménagement* . Tlemcen, Tlemcen, Algérie : ANAT, 2009.

62. **A.Ghenim.** Evaluation des changemnts dans la luviométrie du bassin versant de la Tafn. Tlemcen : Algérie research gate, 2014.

63. **B.Collignon.** Applied hydrogeology of karstic aquifers of the Tlemcenmountains. *thèse de doctorat.* Avignon : university of avignon, 1986. Vol. 1.

64. **C.Kazi-Tani.** possibilities of enrichment by introduction of broadleaved speciesin the mounts of Tlemcen. *thèse de doctorat.* Tlemcen : université de Tlemcen, 1995.

65. **Seltzer.***The climate of Algeria "Alger".* Alger : s.n., 1946.

66. *La mobilisation des ressources en eau: contexte climatique et contraintes socio-économique.* **F.Bensaoula et M.Adjim.** 2008, Larhyss.

67. *évaluation des coûts de production de l'eau selon divers types d'ouvrages hydraulique: les données récentes dans la wilaay de Tlemcen.* **F.Bensaoula et B.Collignon.** Oran : s.n., 1986. Colloque "Les ressources en eau et l'aménagement du territoire ".

68. **M.Collins.***Understanding uncertainties in the response of ENSO to Greenhouse warming.* Londre : Geophysoca research letters, 2000.

69. **C.Harpham et R.I.Wilby.***multi-site downscalling of heavy daily precipitation occurence and amounts.* Pretoria : s.n., 2005.

70. **R.Masmoudi.** Etude de la fiabilité des systèmes de distribution d'eau potabel en zones arides cas de la région de Biskra. *Thèse de Doctorat.* Biskra : Université de Biskra, 2009.

71. **R.L.Wilby et I.Harris.** A framework for assessing uncertainties in climate change impacts. Londre : Water resiyrcecs researcg, 2006. Vol. 42.

72. **A.Beneddine.** Modélisation du fonctionnement hydrologique et des processus d'érosion et de transport des sédiments dans le bassin de la Tafna . *Thèse de doctorat.* Tlemcen : Université abou bekr belkaid, Tlemcen, 2012.