People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research
University of Abbes Laghrour Khenchela
Faculty of Life and Natural Sciences
Department of Ecology and Environment

Dissertation submitted in Partial Fulfillment of the Requirements for

Master Degree in Life and Natural Sciences

Specialization: Fundamental and Applied Ecology

Title of Master's Thesis:

The Impact of Climate Change on Water Resources in North-Eastern of Algeria
Hydrochemical Characteristics and Water Quality Assessment
Case of : Khenchela Province

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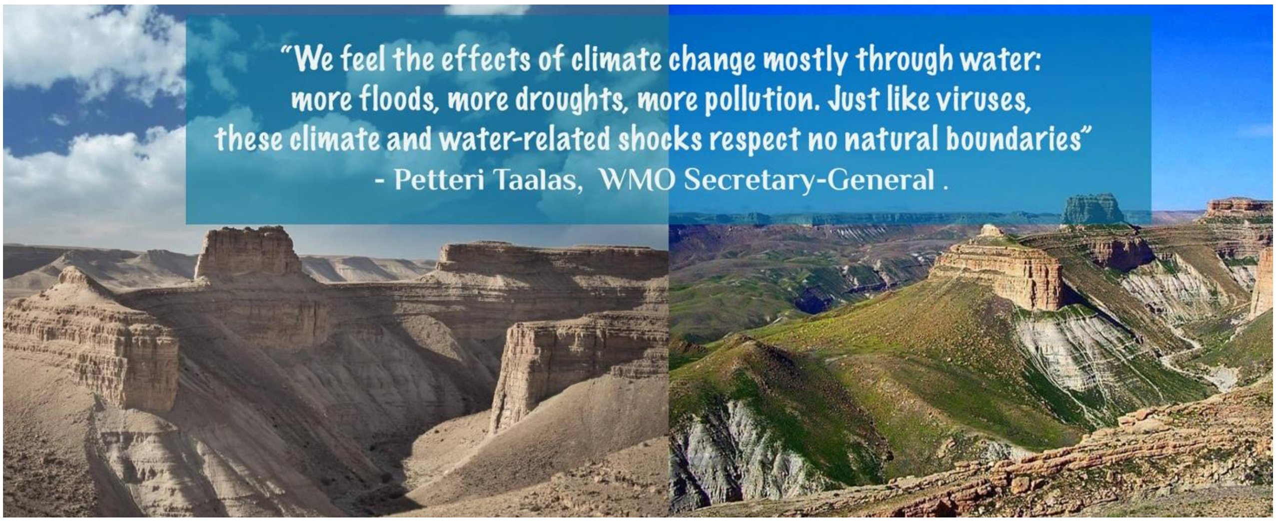
University year: 2021/2022



Mountains of Boudakhan (Highest peak Zekiw)

ACKNOWLEDGEMENTS

First and foremost, I would like to praise Allah the Almighty, the Most Gracious, and the Most Merciful for His blessing given to me during my study and in completing this thesis. May Allah's blessing goes to His final Prophet Muhammad (peace be up on him), his family and his companions.
The following document summarizes a year's worth of effort, frustration and achievement. I take this opportunity to express my gratitude to the people who have been instrumental in a way or in another in the successful completion of the research, study and dissertation of this thesis.

With honor, I would like to show my greatest appreciation to Dr. Sedrati ABDENNOUR, vice-dean of the Faculty of Life and Natural Sciences; as my thesis supervisor. For generously spent precious time in guiding and encouraging me, for his continuous optimism concerning this work, enthusiasm, and support.

We pray for your faster healing and recovery.

Further, I extend my gratitude to my committee members, Prof. Houha Belgacem, Dr. Boulabeiz Mahrez and Dr. Bouzekri Abd El Hafid, who have given me the honor of evaluating my work, may they find here the expression of our deep and sincere gratitude.

I also express my deep thanks to all the Professors and lecturers at the Life and Natural Sciences Faculty in Abbes Laghrour University Khenchela, and all the stuff workers. It would be impossible to list all names.

I am immensely grateful for the one who made me realize, I have wings, I can fly and reach my destination who continuously enhanced my capacities even at the moments of despair, who inspired me to move forward, opened before me unexpected avenues and enlightened my thoughts, at every stage of my academic career, MY ROLE MODEL, my brother, Dr. Chenaker HICHEM

I address my last acknowledgment to my parents: Abdel Hamid and Yamina Souad Zakia for their unconditional love and support. To my brothers: Lazher, Chaouki and Abedlaali. To my sisters: Nadhira, Hanan, Nadjet Widad and Amina. To my nephews and nieces.

It remains for me to thank so many people that I couldn't mention their names for fear of forgetting, they are still present in my minds and heart.
Finally, I have a great expectation that my study will be beneficial and useful for anyone who is interested in reading this final project.

Chenaker MAROUA.

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Introduction

I. Background Information:

Since the turn of the 20th century, climate change and water quality degradation have become a major global issue as they affect national economies, human and animal lives and the environment. **(IPCC, 2022).**

Water scarcity and degraded water quality have, of late, posed a great threat to a vast majority of mankind. Consequently, the study of the adverse impacts of global climate change (GCC) on water quality has become an emerging area of worldwide interest. It is also well accepted that human induced climate change is, to an extent, inevitable.

Current perspectives on global climate change based on recent reports of the Intergovernmental Panel on Climate Change (IPCC) are presented. Impacts of a greenhouse warming that are likely to affect water planning and evaluation include changes in precipitation and runoff patterns, sea level rise, land use and population shifts following from these effects, and changes in water demands. Irrigation water demands are particularly sensitive to changes in precipitation, temperature, and carbon dioxide levels. Despite recent advances in climate change science, great uncertainty remains as to how and when climate will change and how these changes will affect the supply and demand for water at the river basin and watershed levels, which are of most interest to planners.

Climate, change globally over the past century, the average annual temperature has increased by about 1 °C; in the Arctic, it has climbed 2 to 3 °C. By 2100 the average global surface temperature is projected to increase by 1.5 to 5.8 °C. **(Paris Agreement, 2015).** This variability is widely recognized as posing significant, increasing risks, with exponentially rising costs to the environment, to society, and to the global economy. Increasing global temperatures are expected to cause a broad range of changes. Sea levels are expected to rise by about 0.5m by 2100, due to thermal expansion of the ocean, in addition to melting of land ice. Changes in temperature and precipitation patterns are likely to increase the frequency, duration, and intensity of other extreme weather events, such as floods, droughts and heat waves, which will have a great effect on water quality. For these reasons, it is often said that climate change is felt most directly through water.

Touted as "the next oil", Water is life, as long as water is available and of good quality, sustains life on earth including human livelihood. However, the deterioration of water quality by any mean or the disturbance of water biogeochemical cycle, causing changes in water availability and/or quantity, can directly harm human health or severely damage the environment with negative socioeconomic repercussions that affect agriculture, ecosystem integrity and human well-being. **(Zaddem, S., & Ben Romdhane, A,2022).**

Typically, policy discussions and scientific studies today omit the important linkages between water quality and climate change, whereas the impacts of climate change on the quality of freshwater systems are likely to be significant. It is evident in our planet weather and climate patterns are changing and will continue to shift, which may increase in return the occurrence of extreme weather conditions and modify the normal balance of water bodies and ecosystems, leading to the degradation of water quality. These changes in water quality not only affect the economic and social welfare but also the sustainability of vital environmental flows, ecosystems and biodiversity**. (Water, U. N,2019).** Against this background and with the aim to tackle climate change and improve water quality, countries adopted the Transforming our World: the 2030 Agenda for Sustainable Development in 2015. Its 17 Sustainable Development Goals (SDGs) are interlinked and intended to support one another. For instance, "Ensure availability and sustainable management of water and sanitation for all" (SDG 6) supports the attainment of the other 16 SDGs. A good example demonstrating this connectivity is SDG 13: "Take urgent action to combat climate change and its impacts" (SDG 13). Given that the impacts of climate change are deeply linked to water (for example, floods, storms and droughts), many mitigation and adaptation measures include numerous water-based interventions. **(Water, U. N,2019).**

According to the IPCC (2014), the Eastern Mediterranean and North African regions are the most vulnerable to anthropogenic greenhouse gas (GHG) emissions, resulting in broad climate change impacts. Algeria, a Mediterranean hotspot (especially the northeastern parts), is located in one of the areas most susceptible to the effects of climate change in the twenty-first century; due to its geographical position and climatic characteristics, it is located between arid (Sahara) and wet (northern Europe). **(F. Sahnounea et al, 2013).** Algeria and especially the Northeastern part have experienced a persistent decline in annual rainfall associated with the significant increase in temperature during the twentieth century. **(Berhail, Sabri,2019).** This variability has been accentuated since the 1980 and has had in addition to different natural processes (water-rock interactions, and geological factors) and human activities (agriculture practices and urban waste), a significant impact on water resources and aggravated the degradation of water quality through the years.

II. Research Aim and objectives:

The main objective of this research is to determine the impacts of climate change on water quality in Northeastern of Algeria, specifically for the selected case study area of Khenchela province. In this purpose, we have adopted a Hydrochemical characterization of water quality parameters to accomplish this study, we have chosen 10 water resources from different sites, with different latitudes and different physical characteristics and climate from all over the province.

The specific objectives of the study are as follows:

- To understand the current status of water and climate in Algeria
- To define study area and data gathering.

- To learn different sampling methods and laboratory analysing technics
- To analyse the hydrochemical water quality used for human consumption agriculture and other domestic purposes
- To interpret the results of the water quality
- To elaborate a database that can be considered as a reference for future researches in the field of climate change impacts on water resources in this area.

III. Research Question:

To achieve this objective the following questions have been formulated

What is global climate change? and what are it's causes, consequences and scenarios ?

How can climate change influences on water quality?

How does the climate change in Algeria and what are the impacts of this change on water resources in the country?

What are the impacts of climate change on the quality of water resources in Khenchela (Northeastern of Algeria)?

IV. Structure of the thesis

The structure of the thesis consists of four broad parts. The introductory part is elucidated as general description of the problem, objectives and its components. Chapter I is about the review of relevant literature used in this thesis ; water, climate change, water resources and climate in Algeria, chapter II focuses on the description of the geographical, geological, climatological and hydrological context of our study area. Chapter III encompasses the general methodology of sample collection and analytical procedure adopted for the analysis of groundwater samples of khenchela in field and laboratory work using analytical methods and materials to investigate the different physicochemical water quality parameters. Chapter IV is elucidated to results obtained and part II summarises the discussion of the previously obtained results using maps elaborated by the GIS geostatistics module and Hydrochemical diagrams. The conclusion is described in the final part of the thesis Finally, some key recommendations made for policy-makers.

Chapter one: Literature Review

I. The Global Climate Change:

Since Earth's commencement, climate has constantly changed. While occurring normally, this is a slow process that has taken place more than hundreds and thousands of years. Earth's atmosphere has been changing with times that can be marked from previous records. Cycles of glacial and interglacial periods occurred after an interval of a long time. In the past Earth's climate, various glacial and interglacial cycles had occurred. During these cycles cooling and warming of the atmosphere, change in the ice-cover area, and sea level has been seen **(Folland et al., 1990).**

Currently, we are living in an interglacial period and the next glacial period seems far away, since climate data from the last century indicate warming of the climate system, at least on a global scale. An IPCC special report on "State of the Global Climate Change" (2021), displayed an increasing pattern for temperature and greenhouse gas (GHG) emissions. The global mean temperature in 2021 was 1.11 ± 0.13 °C above the 1850–1900 average **(IPCC,2021).** The six data sets used in the analysis place 2021 between the fifth and seventh warmest year on record globally, and all six show that the most recent seven years, 2015 to 2021, were the seven warmest years on record. **(IPCC,2021).** In 2020, greenhouse gas mole fractions reached new highs, with globally averaged surface mole fractions of carbon dioxide (CO2) at 413.2 ± 0.2 parts per million (ppm), methane (CH4) at 1889 ± 2 parts per billion (ppb) and nitrous oxide (N2O) at 333.2 ± 0.1 ppb, respectively 149%, 262% and 123% of pre-industrial (1750) levels.

The increase in atmospheric concentration in CO2 from 2019 to 2020 was slightly lower than that observed from 2018 to 2019, but higher than the average annual growth rate over the last decade. This is despite a decrease in fossil fuel CO2 emissions of approximately 5.6% in 2020 due to restrictions related to the COVID-19 pandemic. For CH4 and N2O, the increase from 2019 to 2020 was higher than that observed from 2018 to 2019 and also higher than the average annual growth rate over the last decade**. (IPCC,2021).**

Long-term climate change has been observed at continental, regional, and local scales, due to the variability of the temperature and GHG emissions. Including changes in precipitation amounts and timings, arctic temperatures, wind patterns, and aspects of extreme weather like heavy precipitation, drought, and heat waves. Global mean sea level reached a new record high in 2021, rising an average of 4.5 mm per year over the period 2013–2021 and The Antarctic Ozone Hole reached a maximum area of 24.8 million km2 in 2021**. (IPCC,2021).**

II. Definition of Climate Change:

Climate change is defined by the **Intergovernmental Panel on Climate Change** (IPCC) as *"a change in the state of the climate that can be identified (for example, by using statistical tests) by* *changes in the mean and/or variability of its properties, and that persists for an extended period, typically decades or longer"*. **(IPCC, 2007).**

NASA had also defined climate change as *"a broad range of global phenomena created predominantly by burning fossil fuels, which add heat-trapping gases to Earth's atmosphere. These phenomena include the increased temperature trends described by global warming, but also encompass changes such as sea-level rise; ice mass loss in Greenland, Antarctica, the Arctic and mountain glaciers worldwide; shifts in flower/plant blooming; and extreme weather events."* **(NASA, 2019).**

The United Nations Framework Convention on Climate Change **(UNFCCC)** defines climate change as: "*A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods"*. **(UNFCCC,1992).**

III. Causes of climate change:

Throughout Earth's history, the climate has changed globally, locally, and in nearly all periods. There are natural and anthropogenic causes of climate change. Natural factors, including ocean currents, volcanic eruptions, changes in the Earth's orbit, and solar fluctuations, significantly impact and alter the planet's climate. But the majority of scientists agree that the primary cause of the current global warming is a phenomenon called the "greenhouse effect." **(Desonie, Dana, 2008). (**Figure. 01)

Greenhouse effect : By volume, the Earth's atmosphere is made up of three significant gases: nitrogen (78.09%), oxygen (20.95%), and argon (0,93%). Nevertheless, the rare trace gases that have the most impact on our climate are carbon monoxide (CO), nitrogen oxides (NOx), chlorofluorocarbons (CFCs), and ozone (O3). Water vapor also affects climate significantly and has a very variable abundance (0.5-4%). The term "greenhouse gases" refers to these residues of gases. ". **(Desonie, Dana, 2008).**

Visible light waves and lower UV radiation from the Sun are unaffected by the atmosphere. Soil, rock, concrete, water, and other ground surfaces absorb the energy when this radiation strikes the surface of the Earth. The heat, or infrared waves, from the energy, are subsequently released into the atmosphere. The lower atmosphere warms due to greenhouse gases trapping part of this heat in the atmosphere. High greenhouse gases warm the atmosphere, whereas low concentrations cool it. There is a clear correlation between greenhouse gas concentrations and atmospheric temperature.

The average air temperature on Earth would be extremely low, at 0°F (-18°C), without the greenhouse effect. There wouldn't be much life on the cold planet. Similar to the Moon, the weather would be wildly unpredictable, blistering during the day and freezing at night. But, thanks to the greenhouse effect, Earth's average temperature is a moderate 59°F (15°C), and life is varied and bountiful. The main greenhouse gases are present in the atmosphere naturally, and natural processes can modify their concentrations. For instance, during volcanic eruptions, CO_2 is released into the atmosphere. Some greenhouse gases, like chlorofluorocarbons (CFCs), were created by humans but had only lately found their way into the atmosphere.

Different greenhouse gases can trap different amounts of heat. One CFC-12 molecule, for instance, may trap as much heat as 10,600 CO_2 molecules. Compared to CO_2, methane holds 23 times more heat. CO_2, however, is so much more abundant than these other gases that it has a significantly bigger influence on the world temperature while having a lesser capacity to trap heat: It accounts for 80% of greenhouse gas emissions by humans. The atmosphere contains different amounts of particles, often known as aerosols, volcanic ash, soot, and wind-blown dust. **(Desonie, Dana, 2008).**

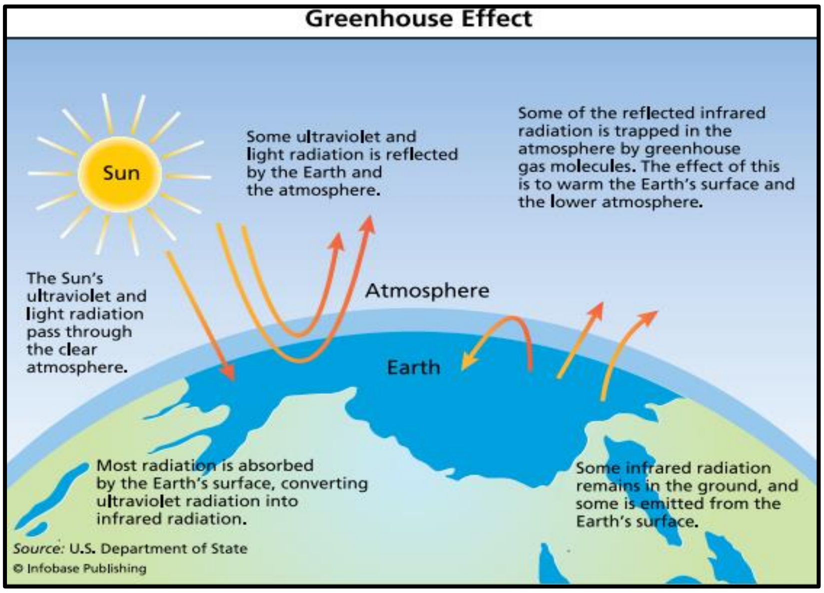


Figure 01 : Greenhouse gases trap some of the heat that radiates off of the planet's surface, creating the greenhouse effect. **(Desonie, Dana, 2008).**

IV. Impacts of climate change:

Climate change causes a cascade of side effects for the physical environment of the planet Earth and the living organisms on the globe. All the changes in the physical planet Earth's environment affect the life of plants, animals, and humans. Coral reefs, forests, and coastal human communities are particularly vulnerable to climate change. Some of the effects of climate change may be through the enhancement of the susceptibility to chemical pollution **(McMichael, A. J., & Lindgren, E, 2011)**.

IV.1. Impacts on the environment:

- **Wildfires:**

Climate change will significantly increase the frequency, intensity and duration of wildfires. Climate directly affects the production and condition of biomass, and weather that supports fire ignition and propagation. In the months preceding fire season, prolonged warm and dry weather reduces vegetation moisture, increasing risks of fire ignitions that may develop into wildfires and spread. In contrast, unusually high rainfall increases plant growth that then may serve as fuel in the next dry season. Large fires in woody ecosystems occur during prolonged drought events. Wildfires also worsen climate change; it contributes to global warming by releasing massive amounts of carbon into the atmosphere and reducing the amount of forest available for carbon sequestration. **(Xu, R., Yu, P., Abramson, M. J., Johnston, F. H., Samet, J. M., Bell, M. L., ... & Guo, Y, 2020).**


Figure 02: Wildfires of Ain Mimoun Forests Khenchela Algeria**. (Makaveli Photographie Facebook Page).**

- **Sea Levels Rising:**

Climate change triggers rise in sea levels. The sea levels rise following either an increase in the volume of the water already in the ocean as water warms and expands or an increase in the mass of the water in the ocean mainly due to melting glaciers. **(Hsiang, S., & Kopp, R. E,2018). O**ver the last 25 years, the global mean see level rose on average by 0.003 meter per year. **(Vineis, P., Chan, Q., & Khan, A,2011).** By 2100, based on different emissions scenarios, sea levels are predicted to rise between 0.40 and 1.50 meters. **(Hsiang, S., & Kopp, R. E,2018).** The sea-level rise will lead to disappearance of some islands and flooding with invasion of cities by water, leading to homelessness and population movement. The salty ocean water will challenge native plants and animals to adapt to the changing conditions. For humans, it causes salination of freshwater supplies and loss of productive farmlands. **(Vineis, P., Chan, Q., & Khan, A,2011).**

- **Floods:**

Climate change is expected to lead an increase of precipitation in many areas. Increased rainfall over extended periods will mainly lead to fluvial (river) flooding, while short, intense cloudbursts can cause pluvial floods, where extreme rainfall causes flooding without any body of water overflowing. In some regions, certain risks such as early spring floods could decrease in the short term with less winter snowfall, but the increased risk of flash flooding in mountain areas overloading the river system may offset those effects in the medium term.

Figure 03: Flood of Oued El Aamra Chechar Khenchela Algeria. **(Makaveli Photographie Facebook Page)**

- **Droughts:**

Drought is a complex and multivariate phenomenon influenced by diverse physical and biological processes. Drought is among the most expensive natural disasters. Climate change is responsible for more frequent and severe droughts (especially in subtropical regions), promoting the expansion of deserts **(Cook, B. I., Mankin, J. S., & Anchukaitis, K. J, 2018).** This will lead to misery, hunger, starvation, and population movement.

Figure 04: Drought in south region of Khenchela.(By the Author)

IV.2. Impacts on Food Security:

Climate change has the potential to increase food insecurity. Existing threats to food security and livelihoods will be exacerbated by climate change due to a combination of factors that include; the increasing frequency and intensity of climate hazards, diminishing agricultural yields and reduced production, rising sanitation and health risks, increasing water scarcity, and intensifying conflicts over scarce resources. These impacts of climate change on food insecurity will lead to new humanitarian crises as well as increasing displacement. Regions already vulnerable to food insecurity and societies that depend on natural resources or practice climate sensitive activities – such as rain fed agriculture – will be particularly vulnerable to the impacts of climate change and at an increased risk of food insecurity as a result. **(FAO, 2016).**

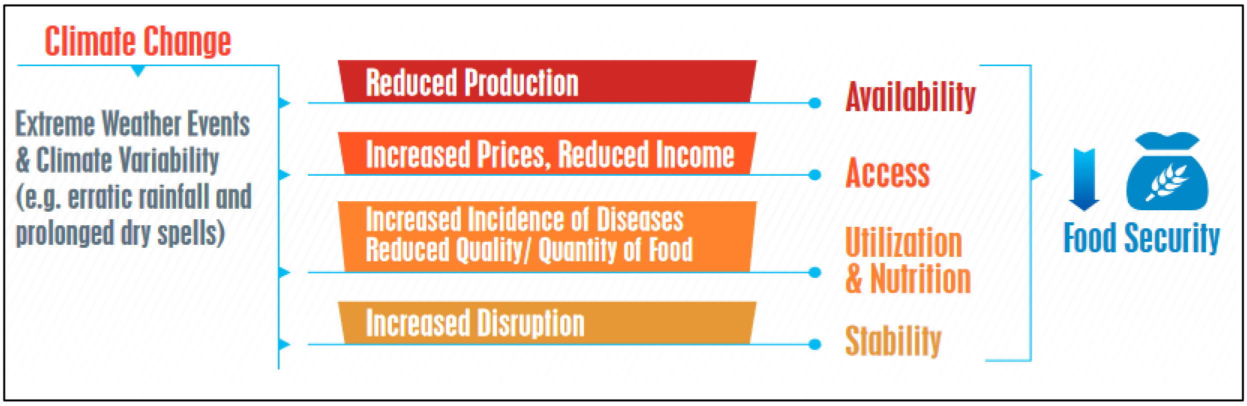


Figure 05: Impact of climate Change on the Four Dimensions of Food Security. **(FAO, 2016).**

IV.3. Impacts on Human Health:

Climate change is already impacting health in a myriad of ways, including by leading to death and illness from increasingly frequent extreme weather events, such as heatwaves, storms and floods, the disruption of food systems, increases in zoonoses and food-, water- and vector-borne diseases, and mental health issues. Furthermore, climate change is undermining many of the social determinants for good health, such as livelihoods, equality and access to health care and social support structures. These climate-sensitive health risks are disproportionately felt by the most vulnerable and disadvantaged, including women, children, ethnic minorities, poor communities, migrants or displaced persons, older populations, and those with underlying health conditions. **(WHO,2021).**

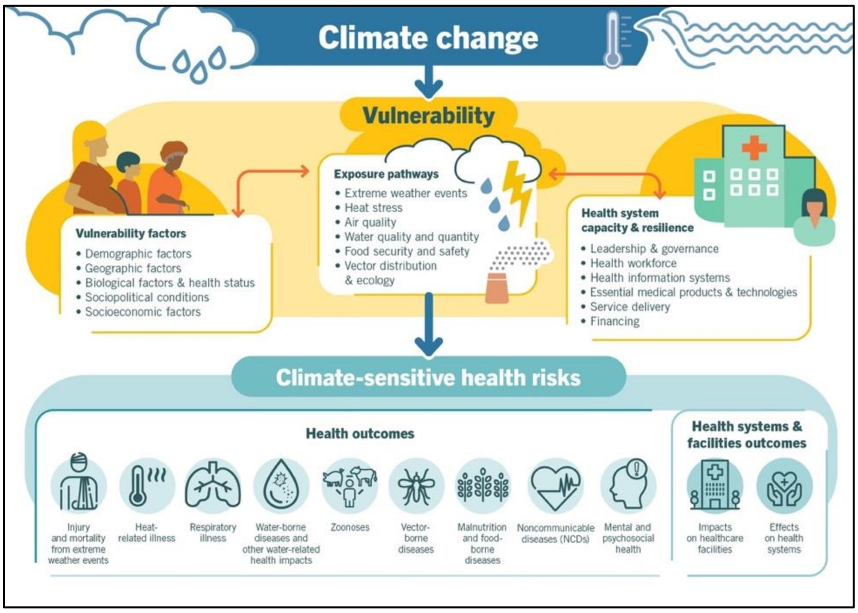


Figure 06: An overview of Climate Change Health Risk **(WHO,2021).**

IV.4. Impacts on Economy:

Changes in climate, no matter what the cause, have the potential to affect the goods and services provided by the natural environment within many market sectors. For example, changes in temperature and precipitation and a host of other meteorological variables influence the growth and development of commercial crops, the amount of runoff that is available for use from surface and groundwater sources by humans, animals, and industry. Changes in climate can also directly and indirectly affect the flows of environmental services that attract tourists to specific locations to engage in certain forms of recreation for their own enjoyment. You can't ski if there is no snow and going to the beach is not much fun when the air temperature is 400 C plus and the water temperature is not far behind. You cannot enjoy hearing the birds sing if they are gone. If climate change causes sea levels to rise, beaches can be lost and valuable beachfront property inundated. These are just some of the examples of how climate change can disrupt the flow of environmental services. **(UNPD,2011).**

V. Mitigation and Adaptation

There are two main strategies to reduce the expected negative effects from climate change: mitigation and adaptation. Mitigation is the process of reducing emissions or increasing sequestration of greenhouse gases in order to reduce or reverse further global warming **(IPCC, 2014a).** Adaptation is the process of making changes to human or natural systems in order to reduce the observed or expected negative effects of climate change and take advantage of the positive effects **(IPCC, 2014a).** These two strategies are complimentary and equally necessary **(IPCC, 2014a).** Mitigation is necessary because even the most effective adaptation efforts will not be able to counteract all the negative effects, of climate change if greenhouse gas concentrations increase beyond a certain level **(IPCC,2014a).** Adaptation is necessary because the planet will continue to warm for centuries unless current net CO2 emissions are quickly replaced with net sequestration over a sustained period **(IPCC, 2014a).**

When describing adaptations in crop production, some authors have distinguished between long-term, major changes, which they define as adaptations, and short-term, minor ones, which they define as adjustments **(Easterling, 1996).** In this nomenclature system, adaptations are changes that transform crop production systems and require new research, technologies, market mechanisms, or government policies, including the introduction of new crops, the translocation of crops, and resource substitution **(Easterling, 1996).**

Adjustments, on the other hand, are changes that maintain the basic structure of crop production systems while making them more resilient to future disturbances and are immediately available to producers, such as changes in the timing of operations and cultivars planted **(Easterling, 1996).** In this study, however, we will not distinguish between the two types of changes and refer to all of them as adaptations, as is standard practice.

VI. Future Climate Change Scenarios:

Based on state of the Special Report on Emissions Scenarios (SRES) **(IPCC, 2000),** climate change scenarios are not the prediction or forecast of the future but rather they are potential future scenarios and each of scenario represents a way in which the future might unfold. The 17 four scenarios describe future demographic conditions, environmental conditions, social conditions, economic conditions, technologies, and policies. The four scenarios are described by the **IPCC (2007)** as follows:

- **A1 Scenario**: "This scenario describes a future of 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 three A1 groups are distinguished by their technological emphasis: fossil-intensive (A1FI), non-fossil energy sources (A1T) or a balance across all sources (A1B)."
- **A2 Scenario:** "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 population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines."
- **B1 Scenario:** "This scenario describes a convergent world with the same low population growth as in the A1 scenario, but with rapid change 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."
- **B2 Scenario:** "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 towards environmental protection and social equity, it focuses on local and regional levels."

There are also some climate change mitigation scenarios that show possible futures where global warming can be reduced by planned actions such as using green energies. For example, one of the climate change mitigation scenarios can be defining a long-term goal of desired carbon dioxide concentration and selecting the actions to reach the goal such as limiting international and national emissions of greenhouse gases. Climate change mitigation scenarios can also be compared by the other climate change scenarios like A2 and B2 to have insight about their impacts on reducing the global warming. The concentration of carbon dioxide has reached about 375 ppm **(Pacalal. S., and R. Socolow, 2004).** Limitation of emission of carbon dioxide has a lot of issues such as cost which can make it hard to reach an agreement between governments and agencies. So, the 550-ppm policy is one of the feasible policies that can be considered by policy makers and scientists to project temperature.

VII. Water Resources and Water Quality:

Water resources include all sources of water that are valuable to humans **(Habets *et al.*,2013).** This includes groundwater, rivers, streams, lakes, reservoirs, basins and runoffs. It is imperative since it is required for life existence. Agricultural, industrial, domestic, recreational and environmental activities are the various uses of water. Nearly all of these human uses require fresh water. (**Felix *et al.*, 2017).**

Water resources are sources of water that are useful or potentially useful to humans. Uses of water include agricultural, industrial, household and environmental activities. Virtually all of these human uses require fresh water. 97% of water on the Earth is salt water, leaving only 3% as fresh water of which slightly over two thirds are frozen in glaciers and polar ice caps. The remaining unfrozen freshwater is mainly found as groundwater, with only a small fraction present above ground or in the air.

Fresh water is a renewable resource, yet the world's supply of clean, fresh water is steadily decreasing. Water demand already exceeds supply in many parts of the world and as the world population continues to rise, so too does the water demand. Awareness of the global importance of preserving water for ecosystem services has only recently emerged as, during the 20th century, more than half the world’s wetlands have been lost along with their valuable environmental services. Biodiversity-rich freshwater ecosystems are currently declining faster than marine or land ecosystems. The framework for allocating water resources to water users (where such a framework exists) is known as water rights. **(Radwan, Hanafi,2010).**

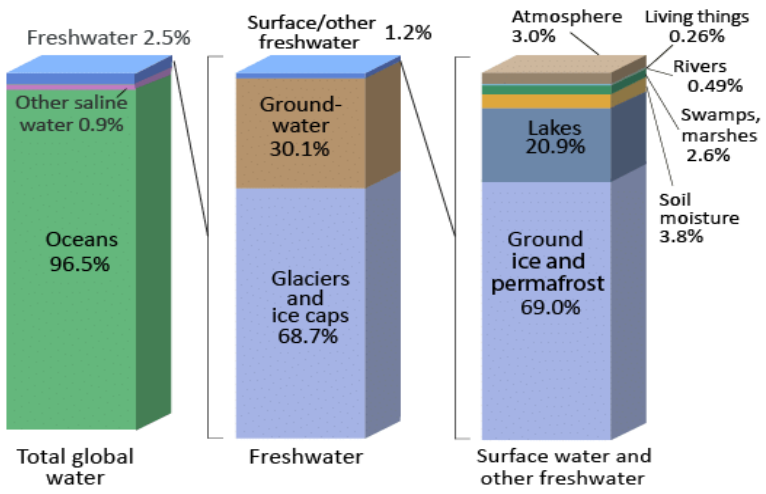


Figure 07: The Distribution of Global Water Resources **(Peter.H. Gleick ,1993).**

Water quality is one of the main challenges that societies will face during the 21st century, threatening human health, limiting food production, reducing ecosystem functions, and hindering economic growth. Water quality degradation translates directly into environmental, social and economic problems. The availability of the world's scarce water resources is increasingly limited due to the worsening pollution of freshwater resources caused by the disposal of large quantities of insufficiently treated, or untreated, wastewater into

rivers, lakes, aquifers and coastal waters. Furthermore, newly emerging pollutants like personal care products and pharmaceuticals, pesticides, and industrial and household chemicals, and changing climate patterns represent a new water quality challenge, with still unknown long-term impacts on human health and ecosystems. **(Heege, T., Schenk, K., & Wilhelm, M. L,2019).**

VIII. Impacts of Climate Change on Water Quality

Climate change aggravates existing surface water quality problems in the world. It can result in significant changes in the variables that affect the quality of water. Water quality is a direct reflection of the chemical inputs received from the air and surrounding landscape, and the biogeochemical processes that transform those inputs within the water body itself. Inputs from natural processes and human activities such as atmospheric deposition to the water surface or point source pollutant discharge represent direct chemical injections into the aquatic system. Water that falls on the adjacent watershed must take a more indirect route through variable portions of the vegetation, soil, and deep soil ecosystems, each of which may contribute to, extract from, and transform the chemistry of that water before it reaches a stream. The hydrologic flow path that waters takes through the watershed, and the resulting transformations that take place along that route, will determine its chemical characteristics when it enters the surface-water system. **(Mujere, Never & Moyce, William,2017).**
Levels of water quality are assessed in terms of:

- *The physical characteristics*, for example: Color, Temperature, Taste, Turbidity, Hardness and Smell or odor, which are determined by senses of touch, sight, smell and taste.
- *The chemical characteristics* used to assess water quality, include: Conductivity, Dissolved salts and Oxygen demand.
- While *biological characteristics* comprise, for example, the number of micro-organisms present such as bacteria, protozoa and algae parameters (Moore, 2007).

Climate change will affect water quality both through increased temperature, and through hydrological changes in rainfall affecting run-off and mobilization of nutrients and other pollutants. Physical changes may occur in water temperature, ice-cover, stratification of water masses in lakes and water discharge including water level and retention. Chemical changes relate in particular to oxygen content, nutrient loading and water color while the biological changes influence the structure and functioning of freshwater ecosystems. Changes in these variables lead to impacts on all the socio-economic and environmental goods and services that depend on these systems directly or indirectly. Increased water temperature will affect ice cover and circulation patterns in lakes and rivers, as well as the rate of biogeochemical and ecological processes that determine water quality. In areas where river flow and groundwater recharge will decrease, water quality may also decrease due to less dilution of pollutants. Higher intensity and frequency of floods and more frequent extreme precipitation events are expected to increase the load of pollutants (organic matter, nutrients, and hazardous substances) washed from soils and overflows of sewage systems to water bodies. **(Mujere, Never & Moyce, William,2017).**

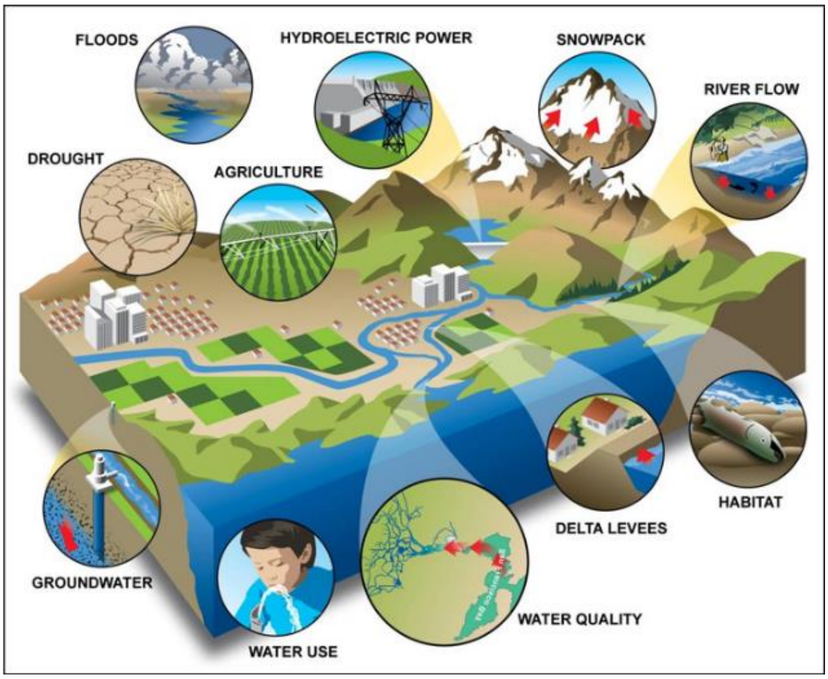


Figure 08: The Impacts of Climate change on the Quality and Quantity of Water Resources **(Department of Water Resources. Climate Change in California Fact Sheet).**

Climate change alters physico-chemical water quality. Climate change directly affects the temperature of water. Indirectly, physical and chemical processes related to temperature in the water column will change. Changes that are expected to occur include; increased rates of (bio) chemical processes, a decrease in oxygen concentration and changing stratification patterns. **(Mujere, Never & Moyce, William,2017).**

A changing hydrology will indirectly affect the physico-chemical water quality. Heavy precipitation events will increase soil erosion, which will lead to increased nutrient and pollutant run-off to surface waters. Water systems will become more eutrophic and as a result, water transparency will decrease.

Droughts, as well as a rising sea level, can lead to the salinization of surface waters. In general, it is expected that climate change will reduce the physico-chemical water quality. **(Mujere, Never & Moyce, William,2017).**

Climate change however, poses a threat to the physico-chemical quality of surface waters. Different parameters of physico-chemical water quality are changing due to climate change which affects biochemical processes such as:

- Acidification,
- Salinization,
- Nutrient/contaminant concentrations,
- Stratification,
- Light conditions.
- Oxygen concentrations.

The rates of biochemical reactions depend on a number of factors, including the chemical nature of the reacting chemicals and the external conditions to which they are exposed. In general, higher temperatures lead to increased rates of chemical reaction (Verweij et al., 2010). Therefore, global warming which leads to a warmer land surface, soil and groundwater is directly associated with increased rates of biochemical processes. **(Mujere, Never & Moyce, William,2017).**

IX. Climate Change and Water Resources in Algeria:

IX.1. Water resources in Algeria:

Algeria is in one of the most unfavorable regions of the world in terms of water availability, below the theoretical threshold of scarcity set by the World Bank at 1000 m3 per capita per year (Analysis of Climatic Drought using Drought Indices in Algiers Region). The potential of renewable water resources is located in the North of Algeria, which includes the tributary basins of the Mediterranean and the closed basins of the High Plateaus. The country's renewable water potential amounts to about 17 billion m3, of which 80% are located in the northern fringe of the country. **(British Geological Survey, 2018). (Figure. 09)**

Table 01: The distribution of water resources in Algeria **(Hamiche A, Stambouli A and Flazi S, 2016)**.

	Resources (Billion m3)			
	Surface	**Underground**	**Total**	**%**
North	12	2	14	80
South	1,5	1,5	3	20
Total	13,5	3,5	17	100
%	80	20	100	

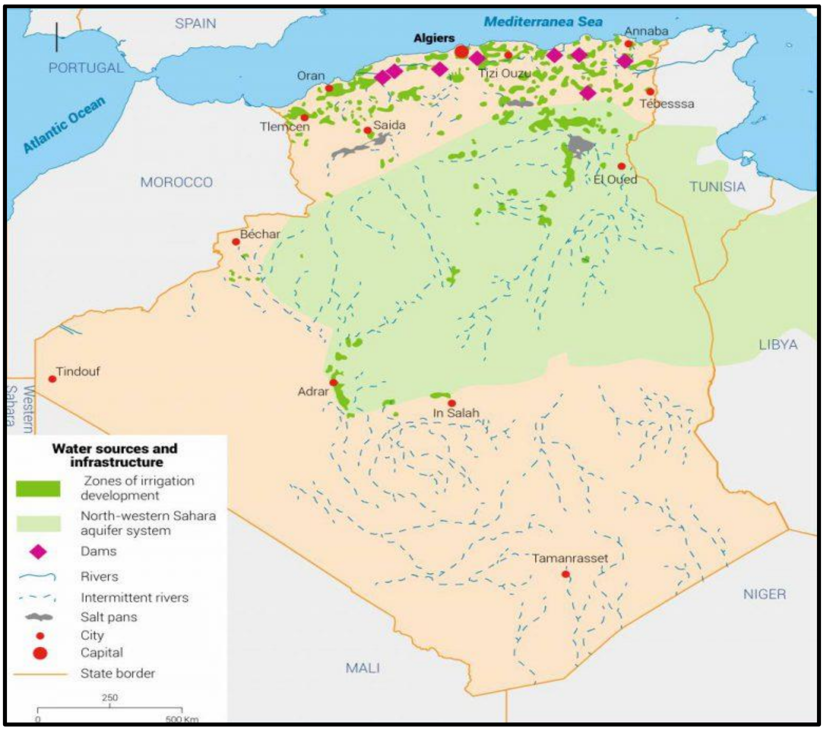


Figure 09: Water sources and infrastructure, highlighting North Sahara Aquifer System. **(Fanack Water, 2019).**

The non-renewable resources concern the aquifers of the northern Sahara (Continental Intercalary and Terminal Complex), which would be exploited as a deposit and which results in a continuous decrease in the level of these aquifers. The aquifer system of the Northern Sahara is the largest aquifer in the world, and it is shared between Algeria, Tunisia, and Libya. Despite having a 5 BCM/yr. operational capability, only 1.7 BCM/yr. are actually exploited. Its surface area is about 1 million km2 (650,000 km2 in Algeria (65%), 250.000 km2 in Tunisia (25%), 100.000 km2 in Libya (10%)). The total volume of this aquifer system is estimated at 60,000 billion m3. It corresponds to a fictitious flow of 100 m3 /s for 2000 years. **(Zella L, 2007)**.

- **Surface water resources in Algeria**

The Algerian territory covers an area of nearly 2.4 million km2, but 90% of this area corresponds to a desert where rainfall is almost nil. In this territory, surface water resources are meager and limited, mainly from the Atlas mountainside; Algeria is divided into five main river basins, totaling 17 catchments, with the majority located in the north. The renewable surface water resources are estimated to total 11 BCM **(GIZ/BGR/OSS, 2016*).*** The Saharan basin receives just 0.5 BCM in a total of water inflows inputs annually. The north depends mainly on surface water since a handful of medium and big dams catch almost 7 BCM. **(Hamiche A, Stambouli A and Flazi S, 2016*)***

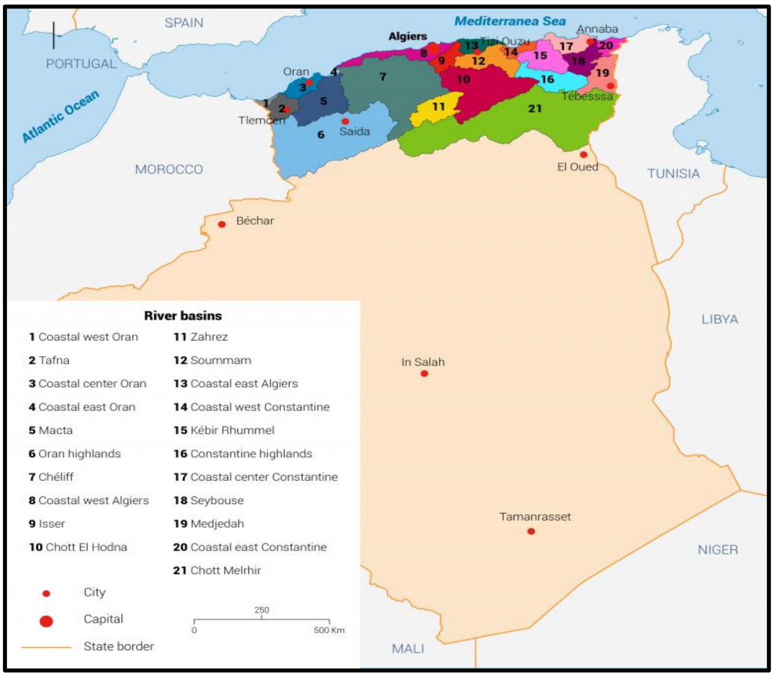


Figure 10: Algeria's major river basins**. (Fanack Water,2019)**

- **Underground water resources in Algeria**

The underground resources are abundant but are very weakly renewable (aquifers of the northern Sahara). Groundwater resources are estimated to total 7.6 BCM, but demand is much higher in the country's north. Important aquifers in the Sahara meet 96% of water demand in the south. **(Bouchekima B, Bechki D, Bouguettaia H, Boughali S, and Tayeb Meftah M, 2008).** Groundwater in the south is mainly fossil with very low renewability. The water resources are contained within two major overlapping aquifers, the Complex Terminal and the Continental Interlayer, which form the transboundary North-Western Sahara Aquifer System (NWSAS). The Complex Terminal (100-400 meters deep) and the Continental Interlayer (1,000-1,500 meters deep) contain significant reserves of 30,000-40,000 BCM. **(Hamlat, A., & Guidoum, A, 2018).**

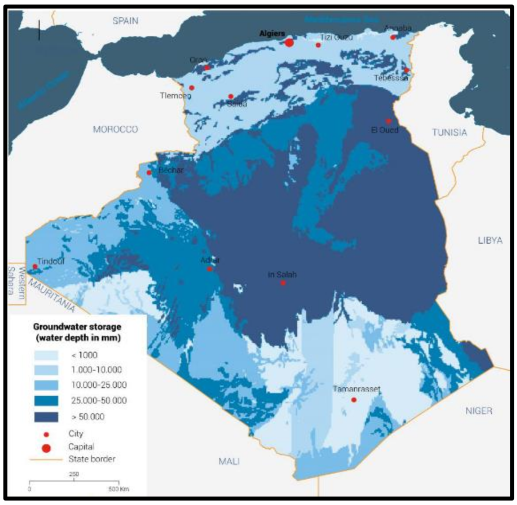


Figure 11: Groundwater storage (water depth in mm), **(Fanack Water, 2019).**

- **Water Quality in Algeria**

Socio-economic development and rapid urbanization in Algeria have had a detrimental impact on the quality of water resources, and industrial and urban pollution has been observed in dams, groundwater and rivers. **(Bouchekima B, Bechki D, Bouguettaia H, Boughali S and Tayeb Meftah M, 2008).**

According to the National Agency of Water Resources, significant sections of rivers in the Tafna, Macta, Cheliff, Soummam and Seybous basins are polluted. Most of these surface waters are polluted by uncontrolled and untreated municipal and industrial wastewater due to either a bad connection or non-functioning wastewater treatment plants. Untreated sewage or low-quality treated effluents amounting to about 200 MCM are discharged annually directly into natural waterbodies **(Atlas, A. G,2018).**

According to the Agence de Bassin Hydrographique's national plan to monitor water quality in Algeria's aquifers, groundwater quality is generally good. However, some changes have occurred due to both natural causes and anthropogenic activities. **(Food and Agriculture Organization of the United Nations, 2009).**

In the north, most groundwater is non-saline, with salinity values less than 1 gram per litre (g/l). However, some coastal aquifers in Mitidja and Bas Sebaou suffer from seawater intrusion due to their high permeability and overexploitation. In the southern Sahara, salinity levels are variable and can reach up to 9 g/l in the Complex Terminal. Salinity also increases in aquifers surrounding saline lakes. **(Safar-Zitoun M, 2018)**.

Links between shale gas exploitation and deterioration of water resources have been established globally. As a result, shale gas exploitation in Algeria in 2015 saw strong public opposition. A few days after the inauguration of the first exploratory drilling near the city of In Salah, the local population marched with the support of its scientists and activists to prevent the local aquifer from being irreversibly polluted. **(British Geological Survey, 2018)**.

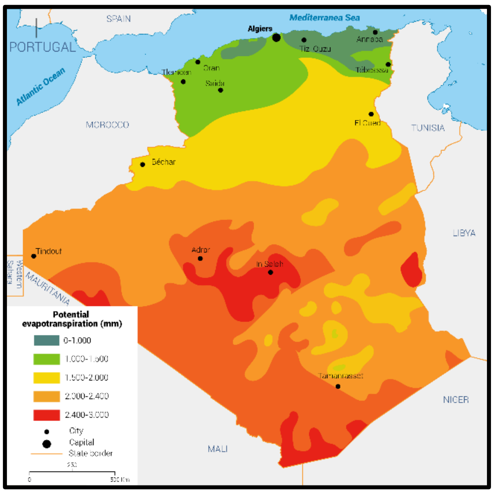
IX.2. Climate change in Algeria:

Due to its geographical position and climatic characteristics, Algeria is highly vulnerable to climate change. Even a moderate temperature increase would result in various socioeconomic issues that would inhibit the country's progress. **(Sahnoune, F. et al, 2013).**

Regional models based on the IPCC scenarios applied to Algeria for 1990–2020 predict an average temperature of 0.8–1.1°C, 10% less precipitation, and a rise of 5–10 cm in sea level. The decline in the amount of water mobilized in dams and groundwater will be accentuated by increased evaporation and decreasing precipitation. Temperature increases of 1.5 to 2.5 °C and a 10 to 50% reduction in precipitation are expected by 2050. Precipitation can be reduced by 10% with a 1-2 °C increase. This will significantly impact how much water from the dam may be released, up to 0.64 billion m3.

According to climate change models, rainfall may reduce by more than 20% by 2050, which would cause water shortages in Algeria's several basins to exacerbate even more.

According to the simulations, rainfall events would be less frequent but more severe, whereas droughts will be more frequent and last longer.



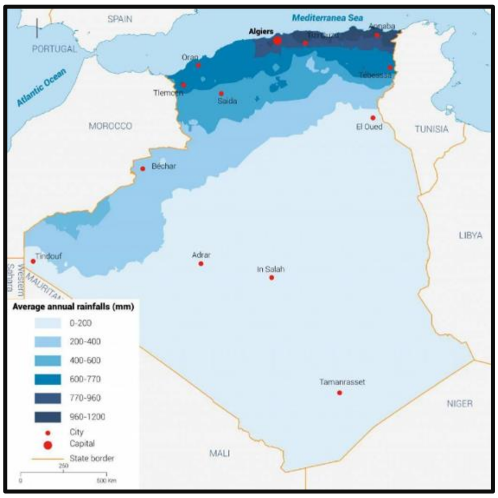


Figure 12 : Potential Evapotraspiration (mm) **Figure 13:** Averege Annuel Precepitation (mm)

- **The evolution of greenhouse gases GHG emission in Algeria**

Algeria used 23.2 million Toe of energy in 2008 across all sectors. GHG emissions reached 153 MT CO2 equivalent in 2012 and were increasing at a pace of more than 3%. By 2030, greenhouse gas emissions might be reduced by 7% to 22% compared to the "business as usual" (BAU) scenario, but only with external help in the form of funding, technological development and transfer, and capacity building. National efforts will be used to accomplish the 7% GHG reduction. Algeria will demand 50.02 million Toe of energy by 2030 (with an average yearly growth rate of 4%), resulting in annual emissions from the energy industry of almost 180 MT CO2 (power plants to natural gas).

(PNC,2020). By 2030, there will be a 300 MT CO2 eq increase in the total amount of CO2 that can be reduced. 2030 will see a concentration of 460 ppm, up around 25% from the year 2000. (370 ppm). **(PNC,2020)**. Algeria will consume 50.02 million Toe of energy by 2030 (an average yearly growth rate of 4%), which translates to 180 MT of CO2 emissions annually from the energy **(PNC,2020)**

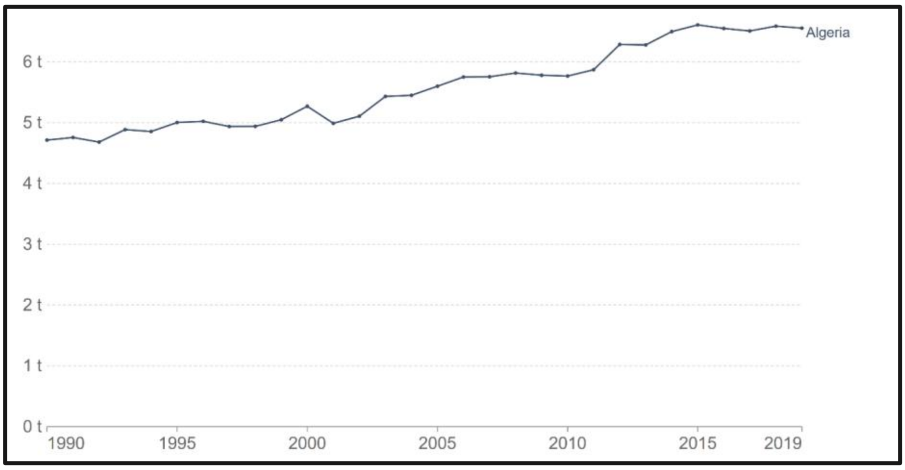


Figure 14: Per Capita Greenhouse emissions in Algeria **(Climate Analysis Indicators Tools (CAIT): Climate Data explorer Via Climate Watch, 2020)**

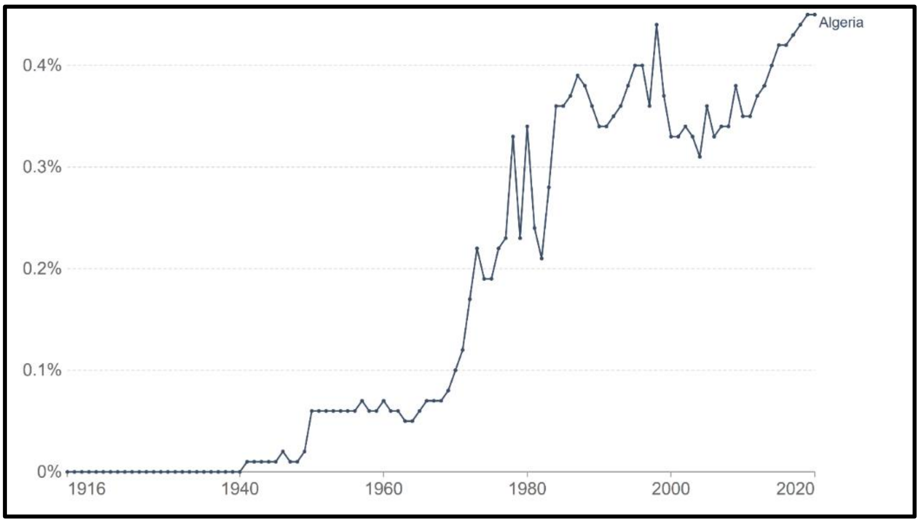


Figure 15: Annual Share of Global CO2 Emissions in Algeria **(Our World in Data based on the Global Carbon Project, 2020)**

The energy sector is the largest emitter with 75% of total emissions. Emissions from this sector result from energy consumption (46%), hydrocarbon production, processing and transportation (20%) and natural gas liquefaction (8%). Agriculture, land use change and forestry generate the remaining 11% of total GHG emissions. The waste and industrial processes sectors account for 10% (95% is emitted as methane from landfills) and 5% (60% is from the cement industry in the form of CO2) of total emissions respectively. **(PNC, 2019).**

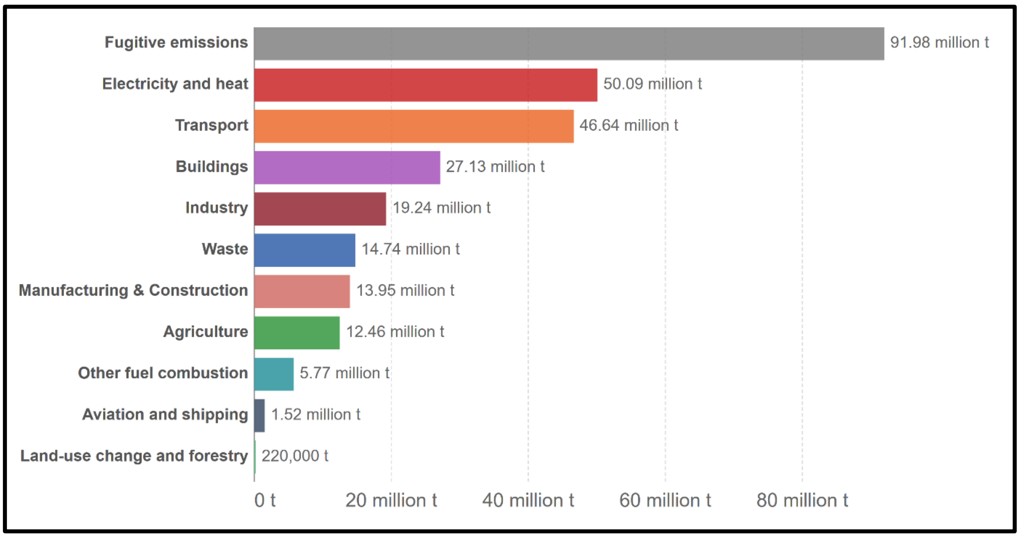


Figure 16: Greenhouse Gas Emissions by Sector in Algeria, 2019 **(Our World in Data based on Climate Analysis Indicators Tools (CAIT), 2020)**

IX.3. The impact of climate change on water resources in Algeria:

Climate data collected in the Maghreb region during the twentieth century indicate a warming of more than one °C during this century, with a pronounced trend in the last thirty years; general circulation models converge to estimate probable warming of the region by 2 to 4°C during the twenty-first century. Algeria is exposed to physical circumstances and unfavorable hydro weather because of its geographical location in the dry and semi-arid zone, which is exacerbated by periods of chronic drought. Algeria is very vulnerable to climate change, particularly in the highlands and steppes that represent around 60% of usable land in the north. **(Bolin, 1980).**

- **The impacts on surface runoff:**

the intense and persistent drought that has been observed in Algeria over the last 30 years has been characterized by a rainfall deficit estimated at 30% (50% during the year 2001-2002), which has had a negative impact on flow regimes, watercourses, causing serious consequences for all socioeconomic activities in the country. **(Mohammed, T., & Al-Amin, A. Q,2018).**

- **Changes affecting the dam waters**

Changes affecting the retention of surface water are due to due to siltation and reduced runoff **(Kadi, 1997).** Siltation is linked to the structure and topology of the steep terrain, fragile plant cover, lack of afforestation, and urbanization of upstream dams, which cause severe erosion that affects dam storage capacity by 2 to 3% per year owing to siltation transport and sediment deposition by precipitation. Currently, 14 dams are impacted by siltation. Similarly, since runoff input to surface water has constantly declined, it adds to the degradation of the situation. The current dams cannot be filled because the flow is too low. **(Mohammed, T., & Al-Amin, A. Q,2018).**

- **Changes affecting groundwater**

Reduced rainfall owing to drought since the early 1970s has resulted in a gradual depletion in groundwater supplies of key aquifers in the north. Groundwater levels have decreased at an alarming rate (> 20 m.) in several plains across the country. Droughts are becoming more severe, and the overexploitation of groundwater has resulted in the mineralization of unsaturated zones of deep aquifers in semi-arid regions such as the Oran plateau and the high western plains. In the Northern region, the average rate of groundwater consumption is 79%, although it can sometimes approach and surpass 90% in some locations. In coastal places, the drop in hydrostatic pressure levels has already resulted in the intrusion of seawater into fresh water sources of coastal aquifers regions of Mitidja, Oran, and Annaba. **(Mohammed, T., & Al-Amin, A. Q,2018).**

- **Flood Risk**

Experts predict that heavy rain and storms like those that have ravaged sections of Bab El Oued, Ghardaia, and Bechar will become more common, based on scientific studies. Algerian government must prepare for an intensification of these meteorological occurrences, which will become more intense and dangerous. **(Mohammed, T., & Al-Amin, A. Q,2018).**

Chapter Two:

Materials and Methods

V. **Description of the Study Area**

I.1. Geographical location

Located in the East of Algeria and the South East of the Constantinian coastal, covering the geographically limited area by the latitudes 35° 7', 35° 38' N and 6° 32' , 7° 34' E longitude, the city of Khenchela covers an area of 9715 km2 formed by 21 municipalities grouped in eight Daira. It is limited by Oum El Bouaghi city in the North, Biskra and El Oued city in the South, and Tebessa city in the East. In West Batna city (Fig. 17). Topography varies between the highest point in the Aurès Mountains, which straddle the border between Algeria and Tunisia, and the second highest peak in Algeria, which reaches 2,328 meters, and El Mitta in the Saharan Atlas, the second lowest point in Algeria, which reaches – 20 meters in altitude.

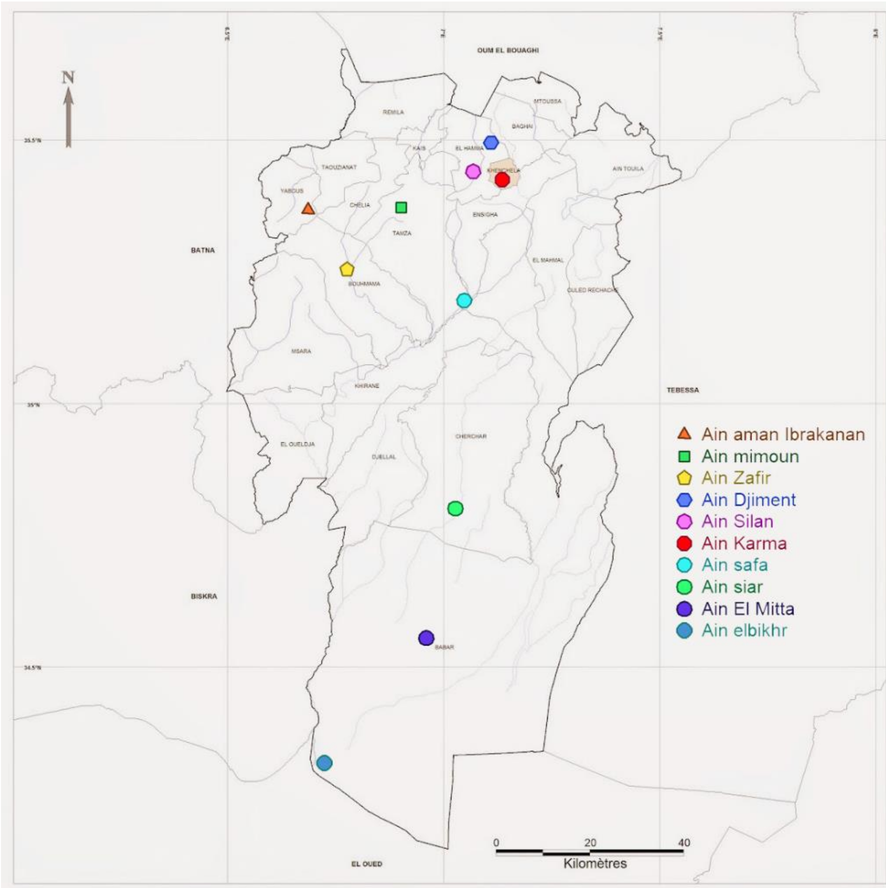


Figure 17: Map of Study Area and Sampling Locations

I.2. Climate context

From the North to the South, the heterogeneity of the relief, geographical location, and lengthening of the North-South territory give great diversity to the climatic aspects. To understand the climatic context of our study area, analysis and synthesis of the climatic data of the three meteorological stations are presented (meteorological stations of Batna, Khenchela, and Biksra).

The analysis of the climatic data of the three meteorological stations from 1991 to 2020 confirms that the climate of the study region reveals a very significant irregularity between its different zones, where it goes from a semi-arid climate in the North to a purely desert climate in the South.

Due to its geographical position and climatic characteristics, the climate in the study area is transitional, presenting a temperate continental climate in the northern part, which includes the coast and the Tell Atlas (hot and dry summers, wet and fresh winters); semi-arid with irregular and low precipitation on a high plateau in the center and arid desert with extremely low annual precipitation beyond the Saharan Atlas. The temperatures range from over 45 °C by day to − 5 °C by night, and annual rainfall ranges from some 200mm, over the entire southern, to levels of 700 to 1200mm in some restricted areas of the high mountains of the northwest massifs.

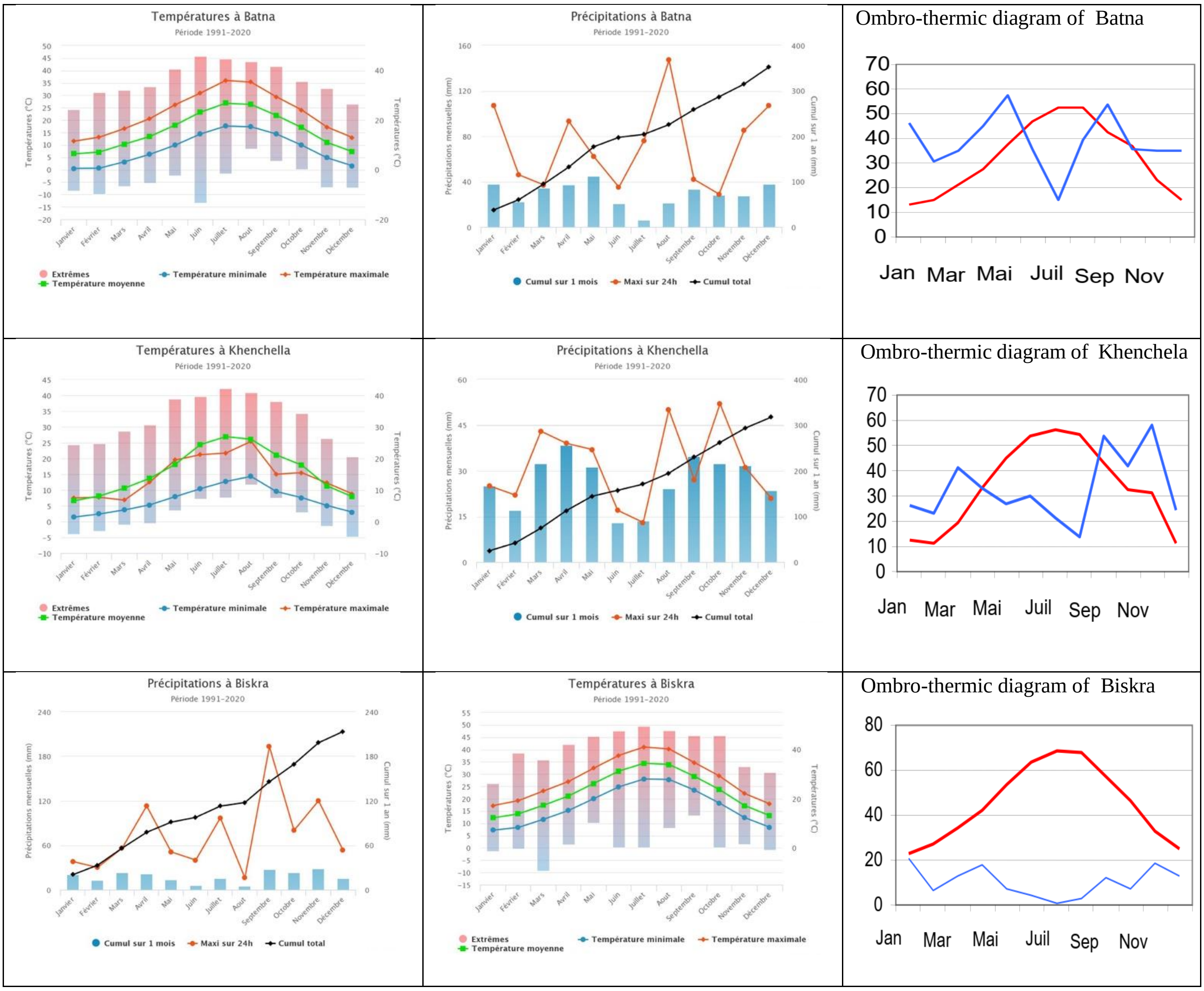


Figure 18: Temperatures, precipitations and climate stages of the Study Area (1991-2020)

I.3. Geology

The geology of the study area is divided into two main structural units: the folded Tellian Domain in the North and the Saharan Platform in the South, separated by the South Atlantic Flexure. The study area (Fig. 19) is delineated by the following features: the Tellian Atlas to the North, large plains in the center, and the Saharan Atlas to the South, and it belongs to the Alpine structural domain. It is characterized by complex geology of over thrusting allochthonous terrains; the geological formations are mainly carbonate and marl

According to works and regional studies (Guiraud,1973 and Villa, 1980), information on the geology of the study area has been identified, represented by Quaternary formations (block Eboulis, limestone), Miocene (white marl sandstone red conglomerates) (Mania, 1978; Marre, 1992) and Cretaceous (marl and chalky limestone). (Fig. 19). The Northeastern part consists of young mountains formed during the Tertiary by the Alpine orogeny. Alpine consists of several structural-sedimentary units, from north to south (Askri et al., 1993).

- The Tellian Atlas is the nappe domain, with mountain basins and a sedimentary column ranging from Jurassic to Miocene. Structural evolution of this part of the north east results from the superposition of several polyphase tectonic events. The first phase (Neo-Cimmerian phase), known in northeastern Algeria, was discovered at the Jurassic- Cretaceous limit and marked by discordances.
- The High Plateaus are the foreland of the Alpine range bearing a thin sedimentary cover. Local distension mechanisms allowed the formation of intra-mountain basins
- The Saharan Atlas was formed from an elongated trough pinched between the High Plateaus and the Saharan Platform. It is followed in the north of Algeria and the Constantine Mounts (Coiffait, 1992; Aris et al., 1998) by a significant compressive tectonic phase during the Miocene, which continues until the Quaternary in Southern Saharan Atlas. The compressive phase is responsible for the structuring of NE-SW folds.

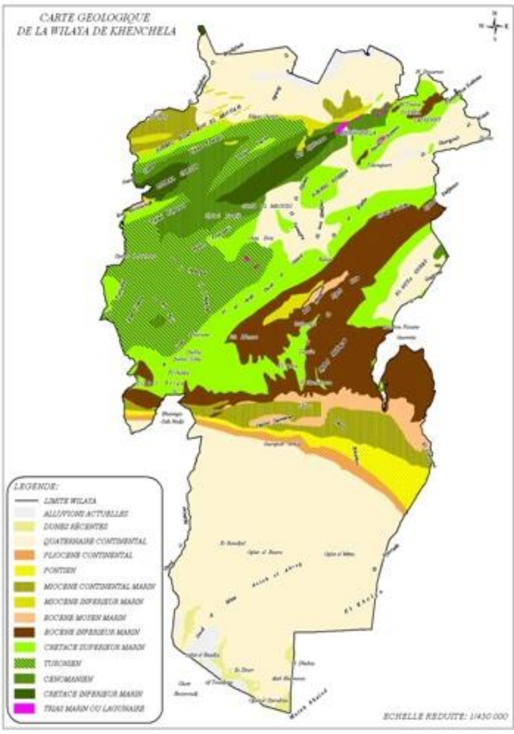


Figure 19: Geological Map of Khenchela Province

I.4. Hydrology

The hydrology of the arid and semi-arid our study area is affected by chronic drought, and climate always has a negative balance that does not justify or clarify the existence of groundwater recharge. Now this charge, even if limited, often exists in these arid regions where the climate can cause irregularity in some years with a few exceptional rainfalls.

From the North to the South, the area of study is characterized by two major drainages composed of three main basins (basin of Oued El-Ma, basin of Oued El-Arab, and basin of Oued Beni Barber) located in the southern part of the studied area (Fig. 20), those in the northern part are less developed:

- The basins of the High Plains of Constantine, which corresponds to the northern part of the wilaya (northern foothills of the Aurès and zone of depressions);
- The basins of the Médjerdah, for the north-eastern part corresponding to the southern slopes of the djebels: Chettaia, Tafrennt, and Bou Tokhma, and, to the northern slopes of the Djebels: Tadilist and Tadjinnart;
- The basins of Chott Melghir, for the middle and southern parts of the wilaya, corresponding to the Aurès massif, the Nemenchas mountains, the valleys of the El Arab and Mellagou wadis, as well as the steppe and pre-Saharan plains of the south. Unlike the first two basins mentioned above, which only affect a small part of the wilaya, this basin covers more than three-quarters of the territory. Regarding the hydrographic network, the wilaya is drained by a few wadis of relative importance and endorheic character, fed by a very dense hairy

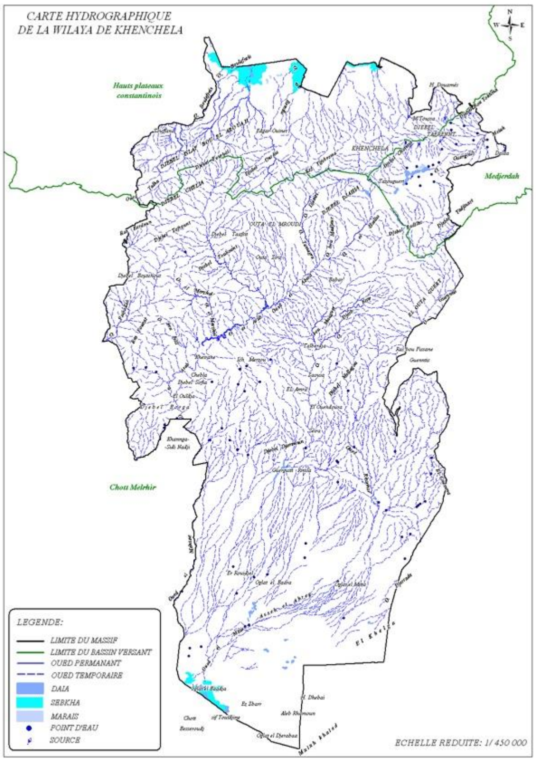


Figure 20: Hydrographical Map of Khenchela Province

VI. Experimental methods

For water analysis and assessment regarding the suitability of water for human consumption, agriculture, and other domestic purposes, specialized sampling and sample handling procedures are required. The site of sampling is selected randomly by considering the physical characteristics, lithology, and climate of the region.

Water Samples from the ten (10) selected sites, namely (Ain Aman ibrakanan (S1), Ain mimoun (S2), Ain Zafir (S3), Ain Djimout (S4), Ain Silan (S5), Ain Karma (S6), Ain safa (S7), Ain siar (S8), Ain El Mitta (S9), Ain Bikher (S10)) were collected during June to August 2022 and taken in pre-cleaned polyethylene bottles (Figure. 21) . Samples were analyzed immediately for parameters, which need to be determined instantly and rest of samples were refrigerated to be analyzed later (Figure. 22).

Figure 21: Pre-clean polyethylene bottles

Figure 22: Refrigerate the water samples

In order to collect data, the experimental work had two parts:

- The fieldwork included the in-field measurement of some parameters such as temperature, pH, and conductivity. As some analyses were done in a lab, samples had to be preserved (Figure. 23).
- The laboratory work: analysis of four major cations, Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}, and four major anions, NO_3^{-}, SO_4^{2-}, Cl^{-}, and HCO_3^{-} in the samples.

Figure 23: Measurment of Field parametrs

II.1. Field Measured Parameters :

In most sampling locations, measurements with a multiparameter were taken before water samples were collected (Figure. 24). Plastic bottles of 0,3 liter capacity with a stopper were used for collecting samples. Each bottle was washed with 2% Nitric acid (Figure. 24). and then rinsed three times with distilled water. The bottles were then preserved in a clean place. The bottles were filled, leaving no air space, and then the bottle was sealed to prevent any leakage. They were stored in a plastic bottle of 0,3 liter and placed in polyurethane insulated coolers, including the date and time sampled (Figure. 22). It also included sampling and preservation of water for laboratory testing purposes.

Figure 24: Washing bottles with 2% Nitric acid

The measured values of the physical parameters were reported immediately in-situ on an Excel Sheet and Hydrochemical Software (Figure. 25).

Figure 25: Reporting of Values of the Physical Parameters.

Ten (10) sampling sites were chosen based on the geographical position and the climatology of the study area. Sampling locations were geographically identified using Global Positioning System (GPS). Samples were collected from June 26, 2022, to August 11, 2022. In (Table. 02) and (Figure. 25). Those chosen stations (their localization) are summarized:

Table 02: Geographic Coordinate of the Sampling Sites.

stations	Geographic coordinate	
	latitude	longitude
Ain aman ibrakanan	35°22'51.92"N	6°38'24.36"E
Ain mimoun	35°24'23.12"N	6°57'57.19"E
Ain Zafir	35°18'25.11"N	6°49'18.81"E
Ain Djiment	35°32'45.26"N	7° 3'1.16"E
Ain Silan	35°26'8.18"N	7° 5'13.63"E
Ain Karma	35°26'11.38"N	7° 8'20.23"E
Ain safa	35°20'9.31"N	7° 2'16.72"E
Ain siar	34°50'20.01"N	7° 1'59.25"E
Ain El Mitta	34°29'0.74"N	7° 3'5.30"E
Ain elbikhr	34°20'34.78"N	6°43'1.92"E

Figure 25: Localisations of water sites.

- **Temperature T (°C)**

The temperature was measured using the multiparameter after a period of time sufficient to permit constant reading. Temperature readings are reported to the nearest 0.1 °C. Temperature is important as it affects most physical, chemical, and biological processes. Temperature differences can determine seasonal variations and distinguish different water sources for mixing purposes.

- **pH value**

The pH parameter was measured in the field using a multiparameter. pH is reported to the nearest 0.1 Standard Unit of pH. After the required warm-tip period, standardize the instrument with a buffer solution of pH near that of the sample and check the electrode against at least one additional buffer of different pH values. Measure the temperature of the water and if temperature compensation is available in the instruments, adjust it accordingly. Rinse and gently wipe the electrodes with the solution.

- **Electrical Conductivity**

Pure water is not a good conductor of electric current rather's a good insulator. An increase in ion concentration enhances the electrical conductivity of water. Generally, the amount of dissolved solids in water determines the electrical conductivity. Electrical conductivity (EC) actually measures the ionic process of a solution that enables it to transmit current. According to WHO standards, the EC value should not exceed 400 µS/cm.

Electrical Conductivities were measured using a multiparameter. Electrical conductivity values are reported in units of µS/cm at 25 °C.

- **Total dissolved solid TDS**

Denotes the various types of minerals present in water in dissolved form. In natural waters, dissolved solids are composed mainly of carbonates, bicarbonates, chlorides, sulfate, phosphate, silica, calcium, magnesium, sodium, and potassium. TDS affects the water supply system (scaling), excessive soap consumption, calcification of arteries, and may cause urinary concretions, diseases of the kidney or bladder, and stomach disorders. According to WHO specifications, TDS up to 500 mg/l is highly desirable, and up to 1500 mg/l is the maximum permissible limit. The degree of groundwater quality can be classified as fresh if the TDS is less than 1000 mg/l; brackish if the TDS is between 1000 and 10,000 mg/l; saline if the TDS varies from 10,000 to 1,000,000 mg/l; brine, if the TDS is more than 1,000,000 mg/l (Todd, 1980).

II.2. Laboratory Measured Parameters

The samples were analyzed for four major cations, Ca2+, Mg2+, Na+, and K+, and four major anions, NO3-, SO42-, Cl-, and HCO3-. Base. The analysis for Physico-chemical parameters in groundwater samples was carried out according to the procedure outlined in standard methods (**APHA, 2012 and BIS, 2012**)1-2 and also prescribed by instrument manufacturers. The methods used are described in Table 3.2 and were determined at the laboratory of quality control and microbiological and physicochemical analysis of water-agriculture-food-soil SID LAB in Khenchela. All samples were first filtered through 0.45-micron paper before analysis.

Table 03: Methods used for the chemical analysis of surface water

Chemicals variables	Methods
Calcium, Ca++(mg/l)	Titration with EDTA
Magnesium, Mg++(mg/l)	Titration with EDTA
Sodium, Na+(mg/l)	Flame photometric
Potassium, K+(mg/l)	Flame photometric
Chlorides, Cl-(mg/l)	Titration with AgNO3
7	U.V. visible Spectrophotometric method
Nitrate, NO_3-(mg/l)	U.V. visible Spectrophotometric method
Bicarbonate, HCO3- (mg/l)	Titration with HCl

- **Calcium (Ca+2):**

Calcium is the 5th most abundant element on the earth's crust and is very important for human cell physiology and bones. Calcium in water has the tendency to react with soap to form a precipitate called soap curd. Calcium is one of the alkaline earth metals which is widely distributed on the earth's crust and is a major constituent of various types of rock, and is present in nearly all water. In the presence of CO2, Calcium Bi-Carbonate can normally be dissolved up to 20 ppm (as Ca) at atmospheric pressure and up to 100 ppm at higher pressure. According to WHO standards, its permissible range in drinking water is 75 mg/l.

- **Magnesium (Mg^{+2})**

Magnesium is another major constituent in groundwater, but its concentration usually is less than Calcium in most natural water; it is the 8th most abundant element on earth's crust and a natural constituent of water. It is essential for the proper functioning of living organisms and is found in minerals like dolomite, magnetite, etc. According to WHO standards, the permissible range of Magnesium in water should be 50 mg/l.

This is probably due to Magnesium being less abundant than Calcium in most of the rocks. It has a longer residence time compared to Calcium and thus precipitates less readily. Magnesium salts are also more soluble in water as compared to Calcium salts.

- **Sodium (Na^+)**

Sodium is a soft, silvery-white, highly reactive metal that is never found in nature in the uncombined state. Sodium, an alkali-metal element, has a strong tendency to exist in the ionic form. In biological systems and even in solids such as sodium chloride, sodium remains distinctly separate from the sodium ion. The sodium ion is ubiquitous in water, most water supplies contain less than 20 mg of sodium per liter, but in some countries, levels can exceed 250 mg/L.

- **Potassium (K^+)**

Potassium is a silver-white alkali that is highly reactive to water. Potassium is an essential element in humans and is seldom if ever, found in drinking water at levels that could be a concern for healthy humans. It occurs widely in the environment, including all-natural waters. Its concentration is quite lower than Na, Ca, and Mg. WHO set the maximum contaminant level at 30mg/L.

- **Chloride (Cl^-)**

Chloride is a common anion found in groundwater. In natural fresh water, a high concentration of chloride is regarded as an indicator of pollution due to the presence of organic wastes of animal origin.

Chloride is mainly obtained from the dissolution of salts of hydrochloric acid as table salt (NaCl) and NaCO2 and added through industrial waste, sewage, seawater, etc. Surface water bodies often have a low concentration of chlorides as compared to groundwater.

High chloride concentration damages metallic pipes and structure, as well as harms growing plants. According to WHO standards, the concentration of chloride should not exceed 250 mg/l.

- **Nitrate ($NO3^-$)**

Nitrate nitrogen (NO3-) is the highest oxidizable form of nitrogen and occurs in trace quantities in surface water but may attain high levels in some groundwater. Nitrate is one of the most important diseases causing parameters of water quality, particularly blue baby syndrome in infants. The sources of nitrate are nitrogen cycle, industrial waste, nitrogenous fertilizers, etc. The WHO allows a maximum permissible limit of nitrate of 5 mg/l in drinking water.

- **Sulphate ($SO4^{-2}$)**

Sulfate is a combination of sulfur and oxygen and is part of naturally occurring minerals in some soil and rock formations that contain groundwater. The mineral dissolves over time and is released into groundwater as water moves through soil and rock formations that contain sulfate minerals. Sulfate is one of the least toxic anions, and WHO (1984) recommended a guideline value of 400 mg/L in drinking water. Sulfate concentration in natural water ranges from a few to several 100 mg/liter, but no major negative impact of sulfate on human health is reported. The WHO has established 250 mg/l as the highest desirable limit of sulfate in drinking water.

- **Bicarbonate (HCO_3^-)**

Bicarbonates are the predominant anions in both surface and groundwater. Mostly, HCO3 ions are soluble in water, and their concentrations in water can be determined through pH. Generally, bicarbonates in groundwater lie under 500 mg/l. Additionally, they influence the hardness and alkalinity of the water. In excessive amounts, bicarbonates, in conjunction with calcium, may cause scale formation in heated waters.

II.3. Data Analysis

- **GIS-Analysis**

Spatial distribution maps of the various Physico-chemical parameters were carried out using Arc Map GIS10.6 software with a spatial analyst module. Kriging interpolation technique was applied in order to interpolate the point data of the Physico-chemical parameters to estimate values between measurements. Kriging is selected because it is an advanced geostatistical procedure that generates an estimated surface from a scattered set of point values (**Azpurua & Ramos, 2010**).

- **Hydrochemical Diagram**

The reactions between aquifer minerals and groundwater control the hydrogeochemical properties of water, and this is useful in understanding the source of groundwater. Major ions are a significant part of the total dissolved solids in groundwater. The concentrations of these ions in groundwater depend on the hydrogeochemical processes taking place in the aquifer system. These processes occur when groundwater reaches equilibrium in major ion concentrations (**Lakshmanan et al., 2003**). For this reason, the investigation of the concentrations of various major ions in groundwater is used to identify geochemical processes.

Facies are recognizable parts of different characters belonging to any geologically related system. Hydrochemical facies are distinct zones that possess cation and anion concentration categories. Dissolved constituents in water can provide indications of its geologic history through which it has passed and its mode of origin within the hydrologic cycle (**Freeze and Cherry, 1979**).

Trilinear Piper diagrams are a visual classification of ion ratios (Piper diagrams). Triangular portions at the bottom of the diagram compare the relative proportion of cations (left side) and anions (right side). The diamond portion above reflects the combined information from the two triangles (**Piper, 1944**). Piper diagrams are useful tools for classifying different water types. In this research, the diagrams will be used to define the different source waters within the system.

The Piper diagrams allow easy and rapid comparison of multiple samples, help visually classify the water rs, and visually identify the mixing and evolution of the groundwater samples (**Garner, 2005**).

Another method of visualizing the chemistry of water samples is the Schoeller– Berkaloff diagram. In this diagram, the concentration of each element is represented with Berkaloff diagram. In this diagram, the concentration of each element is represented vertical lines with a logarithmic scale, and the points obtained are connected by line segments in order to identify the similarities and differences between the samples.

United States salinity laboratory (USSL) diagram: Sodium toxicity is recorded as a result of high sodium in water as Na % and SAR ratios. Typical toxicity symptoms in plants and trees are leaf burn and dead tissue along the outside edges of leaves. The source of Na+ in the groundwater is due to the weathering of feldspar and due to the over-exploitation of groundwater (Hem, 1985b). The measured value of SAR ranges from 0.28 to 8.49. SAR is the combination of Na+ and K+ ion concentrations with Ca2+, Mg2+, Na+, and K+ ion concentrations, which is multiplied by 100. Here, all the ions are represented in meq/l. The geochemical parameters of the water samples are plotted in the USSL diagram (Salinity hazards versus Sodium Hazards, USSL 1954).

Chapter Three:
Results and Discussions

T, pH, EC, TDS, Ca2+, Mg2+, Na+, K+, HCO3−, Cl−, SO42−, and NO−3 were tested in 10 water samples (Table. 04); in the following sections, the hydrochemistry of the groundwater is characterized using maps elaborated by the GIS geostatistics module and Hydrochemical diagrams.

Table 04: Chemical composition of sampled waters (mg/l).

samples	Parameters											
	T	**pH**	**CE**	**TDS**	**Ca++**	**Mg++**	**Na+**	**K+**	**Cl-**	**So4--**	**HCO3-**	**NO3-**
Ain aman Ibrakanan	14	7,51	742	562	76	21	14	3	36	92	244	25
Ain mimoun	17	7,38	751	569	87	25	20	7	52	110	231	18
Ain Zafir	15	7,22	702	544	98	51	8	1	13	55	339	11
Ain Djiment	19	7,91	801	610	62	52	39	3	62	288	288	9
Ain Silan	16	7,01	779	634	73	27	11	2	13	23	331	4
Ain Karma	17	7,34	806	717	53	37	9	1	15	22	339	16
Ain safa	15	7,58	902	684	97	28	16	7	55	140	244	29
Ain siar	21	6,80	2198	2301	322	45	90	8	209	350	270	33
Ain El Mitta	24	6,85	3360	2548	356	65	112	13	230	387	256	42
Ain elbikhr	23	6,75	2457	2579	389	71	111	10	245	401	312	55

IV. Field parameters

- **Temperatures**

The analysis of the results revealed that groundwater samples have temperatures between 14 ◦C (S01) and 24 ◦C (S09), with an average of 18.1 ◦C. The temperature fluctuates temporally and spatially (Table 4 and Figure 27). The South springs samples have the highest mean temperature at 24 °C and the greatest standard deviation. The changes in temperature of these waters correspond to changes in seasonal air temperature. The lower shallow wells have a mean temperature of 14.0 °C; these waters also appear to be seasonally influenced by the air temperature. The temperature of groundwater samples was similar to the air temperature in the study area due to the shallowness of the sampled aquifer. These values reflect the seasonal increase in temperature.

- **pH**

The results presented in Table 4 reveal that the groundwater of Khenchela is neutral to slightly alkaline and contains oxygen. Spatially, the three highest mean pH values are in the waters of Ain Djiment, Ain safa, and Ain Aman Ibrakanan, respectively (Table 4 and Figure 27); this is possibly due to domestic waste from humans or household activity waste generated by industrial and geological conditions such as rocks that affect groundwater conditions. The lowest pH in the lower altitudes in the south region of the study area is about 6,8. In this region pH of the nutrient solution will determine the solubility of nutrients, and the availability of nutrients for plants, in this case, for irrigation. pH was close to neutrality at Ain Silan spring.

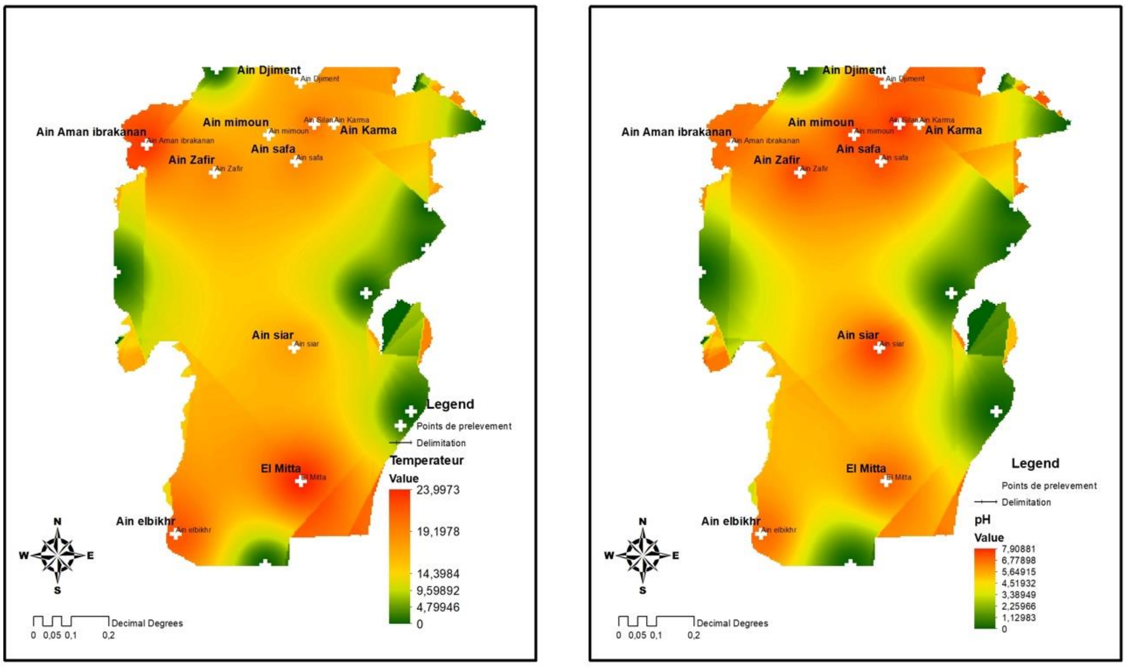


Figure 27: shows the mean Concentration of Temperature and pH in the different sites.

- **Electrical Conductivity**

The measurement of EC is directly related to the concentration of ionized substances in water and may also be related to the problems of excessive hardness and other mineral contamination. Dissolved solids present in natural water consist mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulfates, phosphates, and nitrates of calcium, magnesium, sodium, potassium, iron, and a small amount of organic matter and dissolved gases.

The electrical conductivity can be classified as type I if the enrichments of salts are low (EC: 1500 µS/cm); type II if the enrichment of salts is medium (EC: 1500 and 3000 µS/cm); type III if the enrichments of salts are high (EC 3000 µS/cm; Sarath Prasanth et al., 2012). Figure 27 shows the measured conductivities. The measured values were between around 700 µS/cm minimum and 2400 µS/cm maximum with an average of 1350 µS/cm and characterized by an increase from south to north of our study area (Figure 28) is affected by temperature: the warmer the water, the higher the conductivity and also due to the greater content of salt solubility in this solvent.

According to the classification of EC, water samples of the north region of our study area come under category I, and the water samples of the south region come under category II.

- **Total dissolved solid TDS**

Total dissolved salts in the surface water range from 544 to 2579 mg/l with an average of 1174 mg/l. According to Todd (1980), the water samples of the north region 70 % (7 samples) in the study area are classified as fresh water; in the case of south region water samples, well TDS value ranges from 2198 to 2457 mg/l, (3 samples) are categorized as brackish water. This indicates the influence of rock–water interaction in relation to recharge water. The occurrence of high TDS is due to the influence of anthropogenic sources, such as domestic sewage, septic tanks, and agricultural activities.

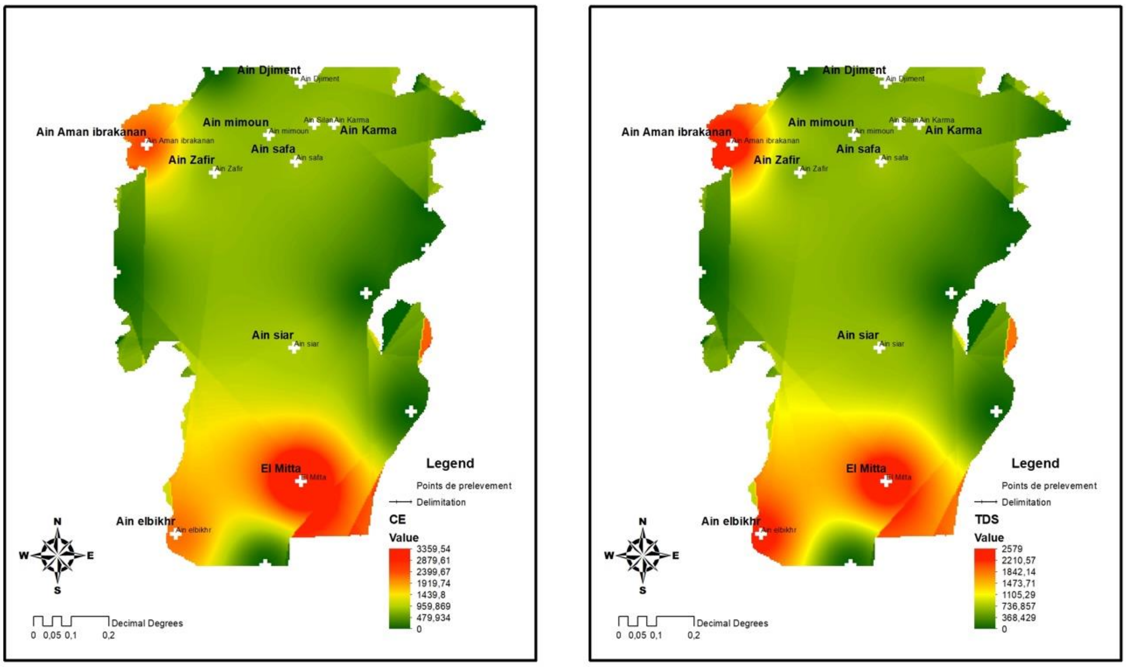


Figure 28: shows the mean Concentration of CE and TDS in the different sites.

V. Hydrochemical analysis

- **Calcium and Magnesium (Ca and Mg)**

Calcium and magnesium are the most abundant elements in the natural surface and groundwater. It exists mainly as bicarbonates and, to a lesser degree, in the form of sulfate and chloride; potential hydrochemical behavior can also estimate from ratios between ions such as Ca2+/Mg2+ **(Han et al., 2009).** In the study area, Ca2+, Mg2+, and HCO3 are dominant ions in groundwater, Ca2+ concentrations vary from 53 to 389 mg/l, and Magnesium content varies from 21–71 mg/l.

Carbonate and silicate weathering controls the presence of Ca2+ and Mg2+ in groundwater. In different studies, Ca2+/Mg2+ ratios of water have been used to make comments about the solubility of calcite and dolomite. In general, if the Ca2+/Mg2+ ratio is equal to 1, the presence of dolomite dissolution is mentioned, and a higher ratio reflects the calcite contribution. A Ca2+/Mg2+ ratio higher than 2 indicates that the calcium and magnesium contribution in groundwater occurs with the dissolution of silicate minerals **(Katz et al., 1998; Han et al., 2009).** All Ca2+/Mg2+ ratio of groundwater in the study area is greater than 2 (Table 4) and indicates that the secondary process providing Ca ions to groundwater is silicate weathering. However, it is seen that calcite and dolomite solubility is dominant in the investigation area.

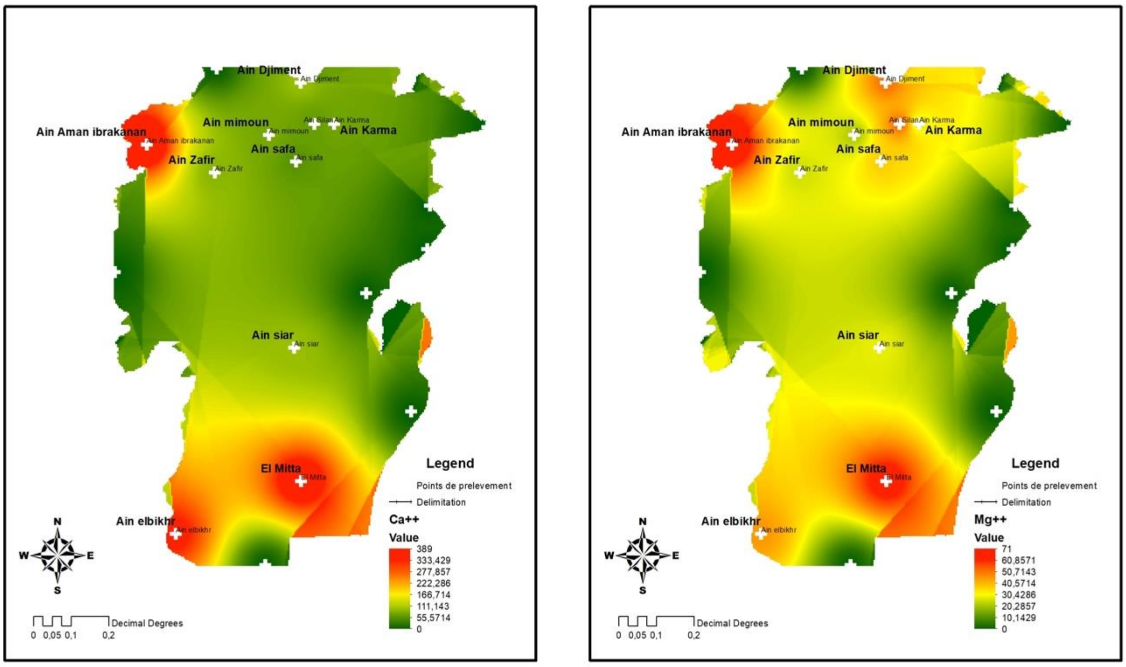


Figure 29: shows the mean Concentration of Calcium and Magnesium in the different sites.

- **Sodium and Potassium (Na and K)**

Sodium is generally found in lower concentrations than Ca2+ and Mg2+ in freshwater. The concentration of Na+ is varied from 8 – 112 mg/l. Accordingly, 100% of the samples had levels of sodium allowed drink. A high level of Na+ intake causes increased blood pressure, arteriosclerosis, edema, and hyperosmolarity. Groundwater with high Na, especially in the south region of the study area content is not suitable for agricultural usage as it tends to deteriorate soil quality. Rock weathering is the primary source of potassium in natural freshwater in the study area. However, other sources of sodium in groundwater are dissolution of halite or from other processes such as silicate weathering reactions, deposition of rock salts, weathering of rocks containing sodium, and its displacement from an absorbed complex of rocks and soils by calcium and magnesium **(Elango et al., 2003; Hussien et al., 2016).**

Potassium levels are lower than Ca, Mg and Na. The concentration of K+ is observed between 1– 13 mg/l. The maximum permissible limit of potassium in drinking water is 12 mg/l. Almost all samples tend to be safe to drink when seen from potassium levels, but there is one sample, Ain El Mitta samples with high levels, which is 13 mg/l. In comparison with Na+, the low concentration of K+ is due to the high resistance of potash feldspars to chemical weathering in the study area, where they attributed low levels of potassium in the region to lack of potassium-bearing rocks in the lithological units and substitution in the crystal structure of some clay materials.

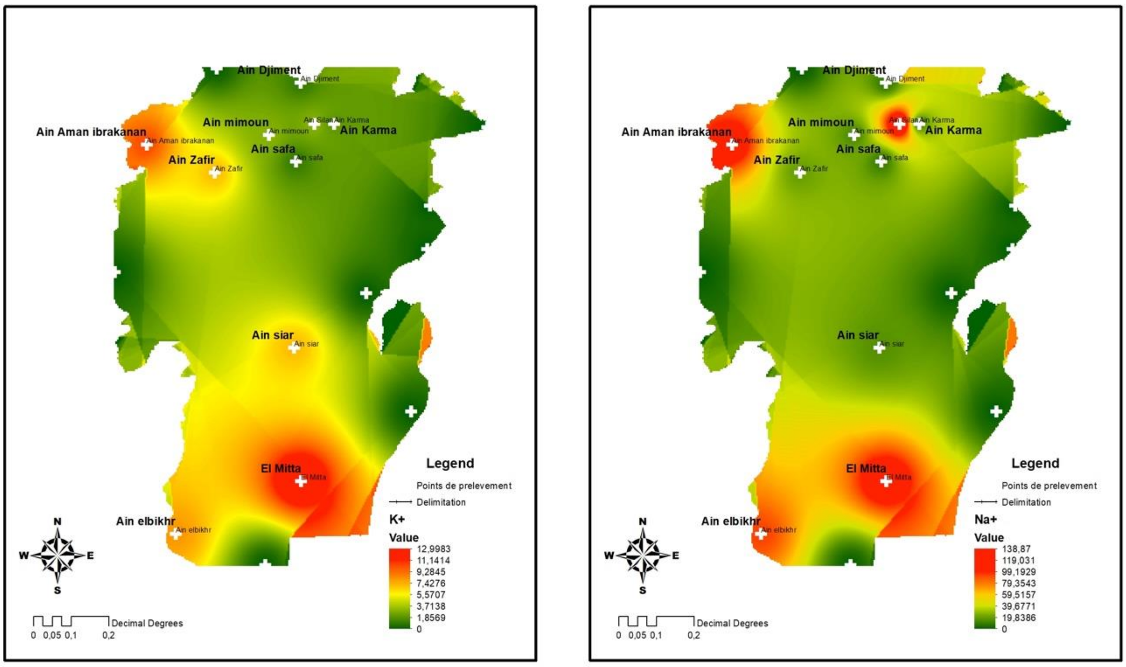


Figure 30: shows the mean Concentration of Sodium and Potassium in the different sites.

- **Bicarbonate and sulfate HCO3- , SO4-2**

Bicarbonate and Sulfate are the most predominant anion. Bicarbonate concentration of natural waters is generally held within a moderate range by the effects of the carbonate equilibrium. Bicarbonate concentration of the water sampled varied between 231to 339 mg/L, with an average mean of 295 mg/L being the most anion predominant. Significant sources of HCO3- in groundwater are calcite and dolomite dissolution. Secondary sources could be from the dissolution of CO2 by anoxic biodegradation of organic matter that originated from domestic septic tanks. However, hydrogen carbonate has no well-known adverse effects; it should not exceed 240 mg/L (WHO, 2004). The higher proportions of bicarbonate in water samples in the south region could be attributed to pollution and dissolution of calcite and dolomite since they have a positive saturation index

Sulfate concentrations vary spatially (Table 4 and Figure 31). The mean water sulfate concentration is 187 mg/L, and all of the groundwater. The north, the center, and the south water samples mean concentrations at 100 mg/L, 150 mg/L, and 300 mg/L, respectively. The primary mineral sources of sulfate ions include evaporate minerals such as Anhydrite, Gypsum, and sulfates of Magnesium and Sodium, and the leaching of fertilizers **(Thivya et al., 2013a)** may also increase the sulfate concentration in groundwater. These dissolved minerals contribute to the mineral content of drinking water **(WHO, 2004).** Sodium, potassium, and magnesium sulfates are all highly soluble in water, whereas calcium and barium sulfates are less soluble. WHO and BIS suggest the maximum permissible limit of SO4 in drinking water is 400 mg/l; all water samples are within the limit (Table 4) The elevated levels of sulfate in groundwater in sites of the south region can be attributed to human economic activities such as using phosphatic fertilizer in agriculture.

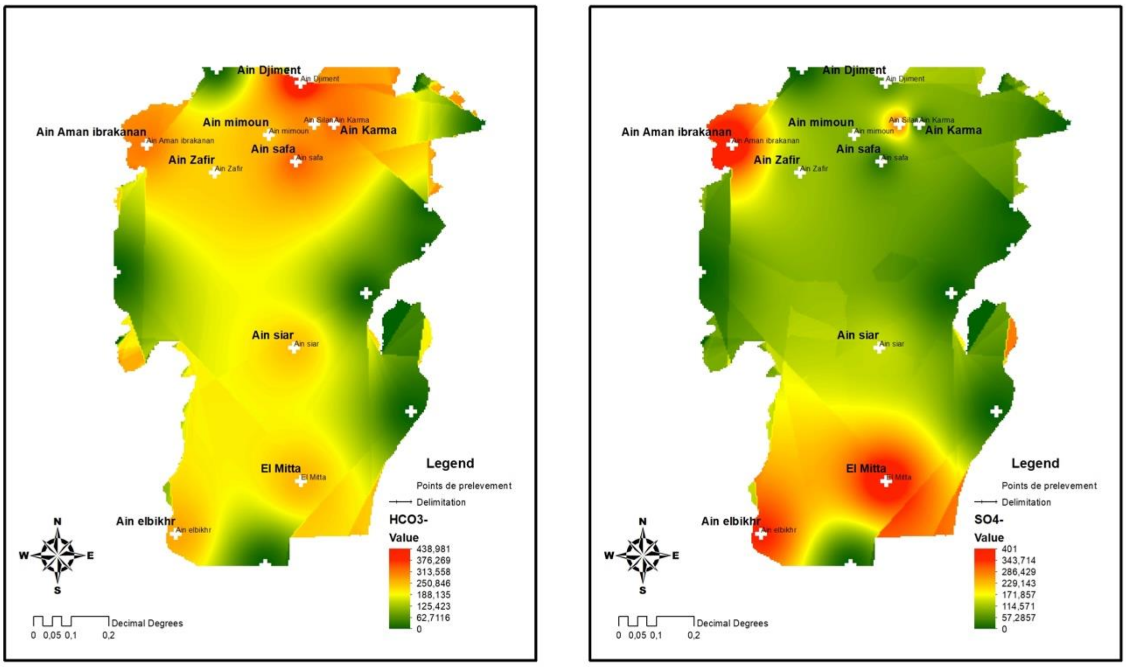


Figure 31: shows the mean Concentration of Bicarbonate and sulfate in the different sites.

- **Chloride (Cl)**

The origin of chloride in groundwater may be from diverse sources such as weathering, leaching of sedimentary rocks and soils, intrusion of saltwater, windblown salt in precipitation, domestic and industrial waste discharges, municipal effluents, etc. In the study area, chloride concentrations are between 13– 245 mg/l. The desirable limit of chloride for drinking water is specified as 250 mg/l.
The atmospheric precipitation, salt deposits dissolution, halite weathering, and evaporite are considered primary lithogenic sources of chloride in the groundwater. The anthropogenic sources are very low effective due to profound groundwater occurrence in a desert region. The distribution map

of chloride ions (Figure. 31) shows a decrease of concentration from south to north in a dilution towards the central portion corresponding with the flow direction.

In a south region, as for irrigation is concerned, chloride is not adsorbed or held back by soils; therefore, it moves readily with the soil–water gets adsorbed by crops, moves in the transpiration stream, and accumulates in the leaves. The high chloride content in water in the Kiambere H.C. borehole (siteA) could be attributed to pollution from the discharge of agricultural and septic tank leakages.

- **Nitrate NO3-**

The nitrate concentration in the study area ranges between 4 and 55 mg/L, with a mean of 24 mg/L. Nitrates concentration in groundwater can be derived from faulty septic tanks, sewage discharge, oxidation of organic materials, and farming and agricultural processes **(WHO, 2011).** The relatively higher nitrate levels in south sites can be attributed to farming and agricultural processes in these areas. A high nitrate concentration in drinking water is toxic and causes blue baby disease/methemoglobinemia in children and gastric carcinomas **(Alam et al., 2012).** *Nitrogen* is a plant nutrient that stimulates crop growth; when applied in excess affects the crop by stimulating growth, delayed maturity, and poor quality of crop yield. The nitrate concentration in surface and groundwater samples is less than the south region's certified limit (45 mg/l). As the phosphate, the average concentration of nitrate in water samples was probably derived from applying phosphate and nitrogen fertilizers in the agricultural fields.

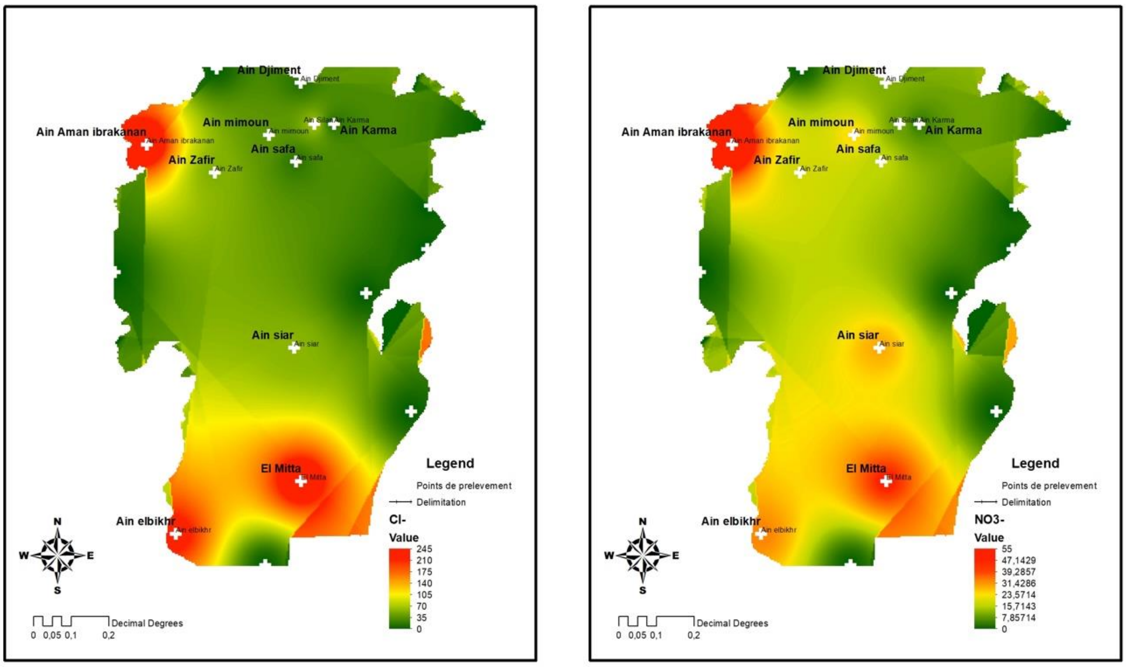


Figure 32: shows the mean Concentration of Chloride and Nitrate in the different sites.

VI. Hydrochemical Facies

Grouping facies of groundwater in the study area based on the results of the Piper diagram analysis (Figure. 33) using data from chemicals laboratory already in the conversion. Hydrogeochemical facies in the study area can be classified into 3 (three) facies, namely; Ca, MgHCO3 facies (calcium, magnesium bicarbonate), and the facies analysis covers the sample (Ain Aman Ibrakanan, Ain Zafir, Ain Silan, and Ain Karma); mixed Ca-Mg-Cl facies (calcium, magnesium chloride) and Ca-Mg-SO4 facies (calcium, magnesium, sulfate), the facies analysis covers the sample (Ain Djiment, Ain safa, and Ain mimoun); Ca-Cl facies (Calcium chloride) facies the facies analysis covers the sample (Ain siar, Ain El Mitta and Ain elbikhr). The hydrochemical analysis results indicate that the origin and geochemical composition of the groundwater in the area are spatially variable because the geologic variations caused spatial variability of the hydrochemical parameters. This variation in the chemical facies can be attributed to the cation exchange process with prolonged water-rock interaction following the groundwater flow direction.

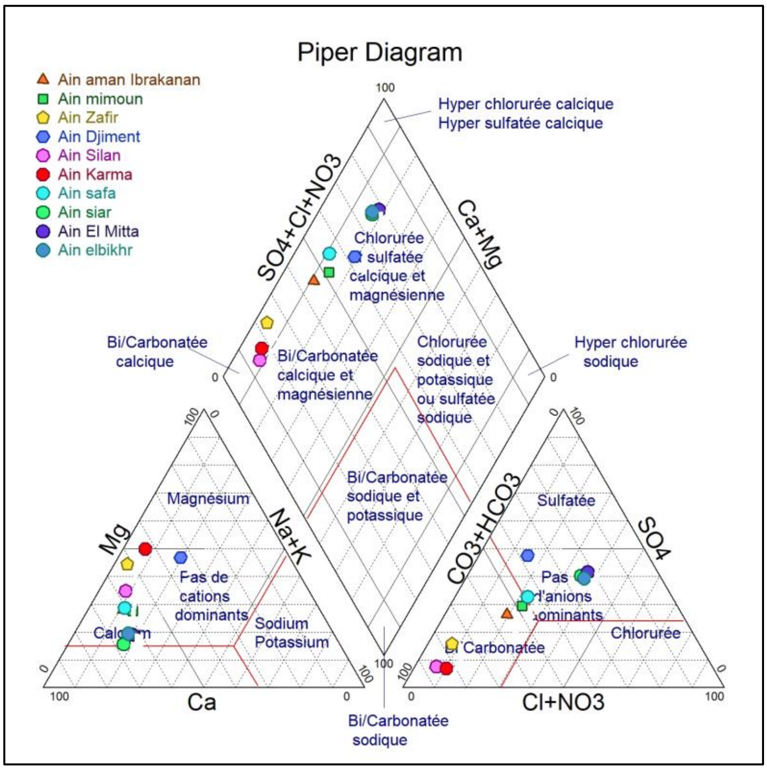


Figure 33: Piper's diagram showing the types of water samples

From the diagram of Schöeller Berkaloff (Figure. 34), we represented each analysis by a broken line, characteristic profile of the concentration of each central ion in solution in water, the six logarithmic scales at equal distance from/to each other, being shifted in order to align the unit values of the milliequivalents of various anions and cations. As shown in the scholler-Berkaloff diagram. The Schoeller–Berkaloff diagrams (Figure. 33) highlight a similar tendency between the primary ions in the analyzed groundwater samples; in particular HCO3 ion is always dominated. Ca, Mg, and Na ions are always the leading group among the cations and reach the highest concentrations. Most often, Ca ion dominates, except in the south part of the study area, where sodium is the dominant cation by weight. These profiles highlight the relationship of water between themselves, which shows the presence of the three facies mentioned in the piper diagram, reflecting the possible mixing of the deep aquifers with the shallow waters. To better characterize the hydrochemical water types and identify the possible hydrochemical processes.

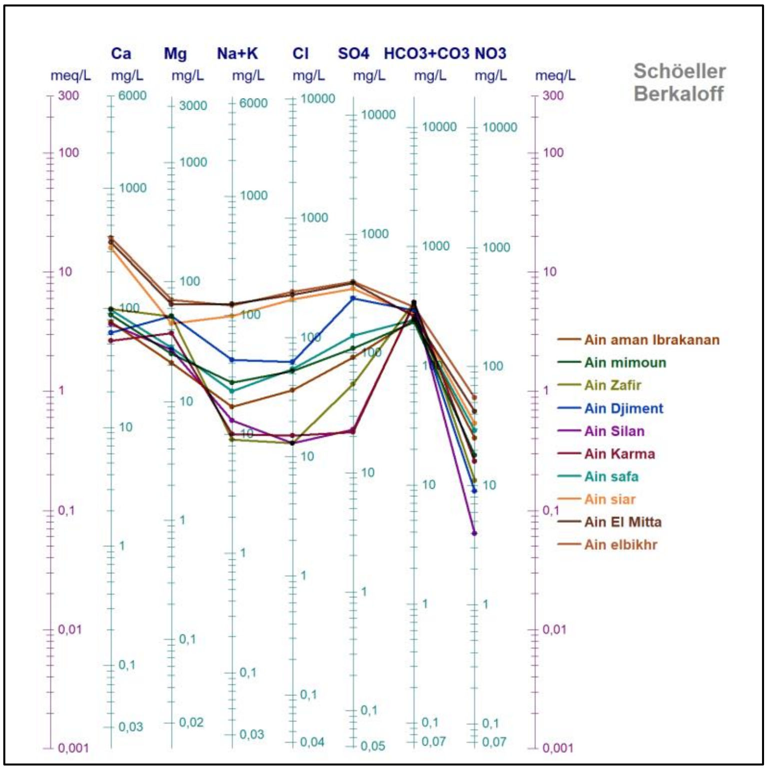


Figure 34: Scoeller-Berkaloff Diagram of water samples

Analysis of Sodicity and Salinity Hazards

Wilcox diagram relating sodium percent and total concentration of the analyzed water samples from the study area, Based on the Wilcox plot, 70% of the groundwater samples of the study area fall in the low and medium to high salinity range while the remaining 30% fall under very high salinity range.

Based on the Wilcox diagram classification, groundwater quality in a significant part of the study area can be considered excellent, eligible, and suitable for irrigation purposes. However, groundwater from the south part of the study area is characterized by high salinity and significant sodicity, which limits irrigation (poor and bad), which can be suitable for plants after special consideration of soil management and maintaining an excellent irrigation system. (Ayenew et al., 2013) Based on Wilcox diagram analysis has also drawn similar conclusions.

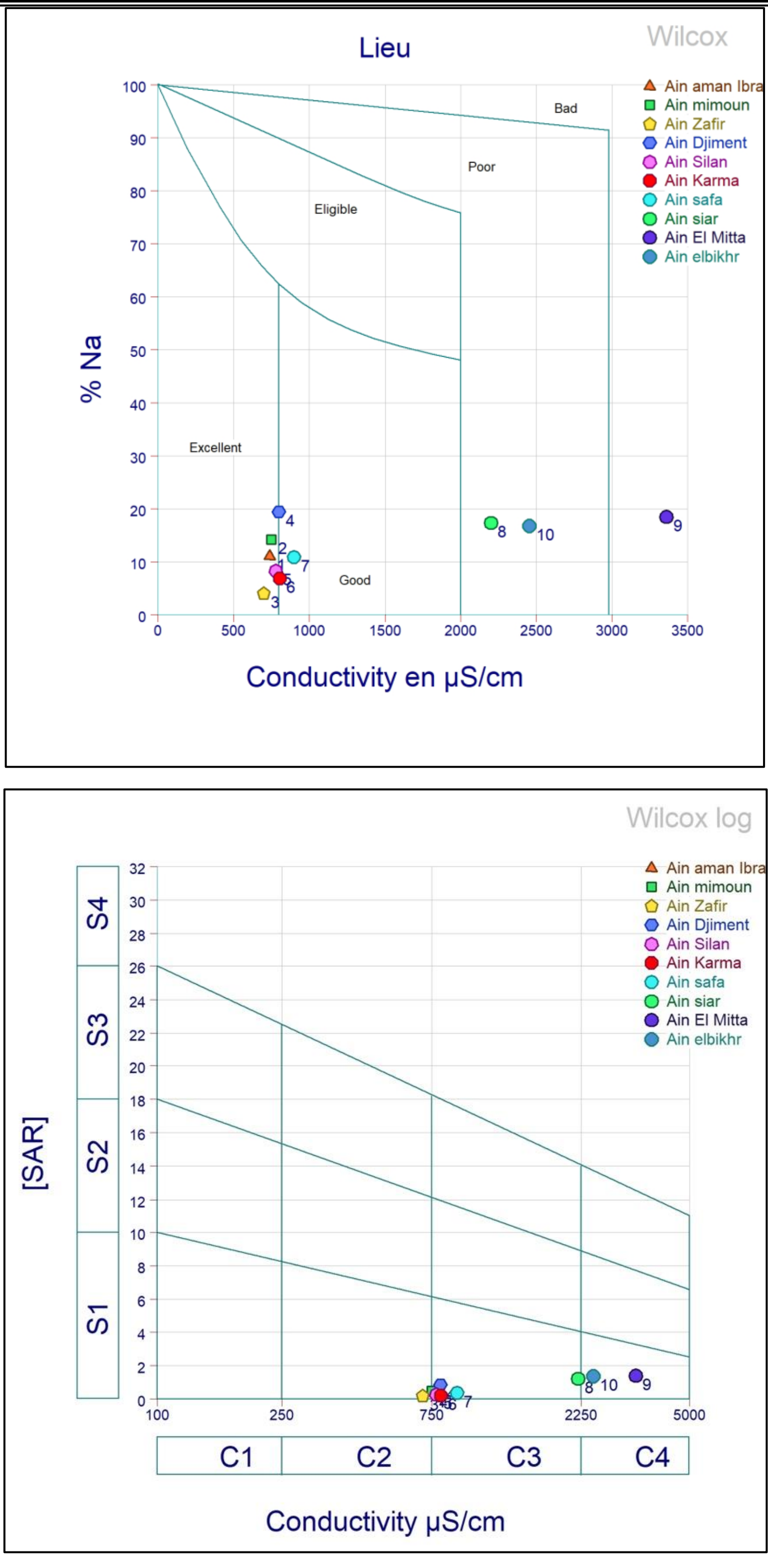


Figure 35: Wilcox and Wilcox log Diagram of water samples

Conclusions and Recommendations

Conclusion

Climate change is already affecting water access for people around the world, causing more severe droughts and floods. Increasing global temperatures are one of the main contributors to this problem. Climate change impacts the water cycle by influencing when, where, and how much precipitation falls. It also leads to more severe weather events over time. Increasing global temperatures cause water to evaporate in larger amounts, which will lead to higher levels of atmospheric water vapor and more frequent, heavy, and intense rains in the coming years.

Typically, policy discussions and scientific studies today omit the important linkages between water quality and climate change, whereas the impacts of climate change on the quality of freshwater systems are likely to be significant. It is evident in our planet weather and climate patterns are changing and will continue to shift, which may increase in return the occurrence of extreme weather conditions and modify the normal balance of water bodies and ecosystems, leading to the degradation of water quality. These changes in water quality not only affect the economic and social welfare but also the sustainability of vital environmental flows, ecosystems and biodiversity.

The literature review indicates that global warming has led to an increase in the average temperature around the globe, which has been heavily impacting on water resources in Algeria especially in Khenchela

In this study the influence of climate change on physico-chemical water quality in north-eastern Algeria is be discussed. Ten (10) sampling sites were chosen based on the geographical position and the climatology of the study area from the second highest peak in Algeria, which reaches 2,328 meters, and El Mitta in the Saharan Atlas, the second lowest point in Algeria, which reaches – 20 m in altitude and a very significant irregularity climate, where it goes from a semi-arid climate in the North to a purely desert climate in the South. In order to collect data, the experimental work had two parts, fieldwork included the in-field measurement of some parameters such as temperature, pH, and conductivity and laboratory work, where we analysied four major cations, Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}, and four major anions, NO_3^-, SO_4^{2-}, Cl^-, and HCO_3^- at the SID LAB laboratory in Khenchela. Meteorological and hydrological data obtained for the last 20 years (1991– 2020) showed an upward trend in the average air temperature and a downward trend relating to the average daily rainfall and water levels in study area.

Spatial distribution maps of the various Physico-chemical parameters were carried out using Arc Map GIS10.6 software, to interpret and classify the waters according to the utility and chemical composition, hydrochemical Diagrams were used. The major ion concentration suggests that predominant samples belong to the suitable category for drinking and irrigation purposes based on WHO standards except in the south part of the study area. Piper diagram showing the samples is falling under classified into 3 (three) facies, namely; Ca-Mg-HCO3 facies, mixed Ca-Mg-Cl facies and Ca-Mg-SO4 facies, Ca-Cl facies. Based on the Wilcox diagram classification, groundwater quality in a significant part of the study area can be considered excellent, eligible, and suitable for irrigation purposes. Changing hydrology is predicted to cause a difference in water discharges between high-latitude areas and low-latitude areas. An increase in precipitation at high latitudes and a decrease in precipitation at low latitudes are expected.

It is important to note that direct and indirect impacts related to climate change affect the physicochemical water quality. A direct effect of climate change on chemical reactions in the sediment and water column is climate warming, since higher temperatures lead to higher rates of biochemical reactions. For instance, nitrification and denitrification are biochemical processes directly related to temperature. Changes in hydrology associated with climate change affect the physico-chemical water quality indirectly. It is expected that increased and more intense precipitation increases nutrients run off from agricultural lands to ground and surface waters. Extreme rain events will lead to increased soil erosion and consequently the water column will become more turbid and more pollutants.

The frameworks and conclusions described in this study will provide valuable, initial information for regional decision makers and water resources managers to understand and assess the impacts of the future climate change on water resources, environment, ecology, and water quality management in North-eastern of Algeria.

Recommendations

Increases in population and anthropogenic activities have heavily influenced water resources and increased water quality. Indeed, various studies have reported that water quality has increased in the last decades, and consequently water-related diseases influence the health of many citizens in Algeria and especially in Khenchela. The following are important recommendations which can be helpful in coping with the consequences of climate change in terms of water-related challenges:

- Due to the shift in seasons, in some locations as a result of climate variability, new water resources have been emerging. However, there is a need to manage and store water for present and future use. For instance, watershed management with dam systems might alleviate drought and floods.

- Adaptation strategies such as protection of water resources and watershed management should be adopted to cope with unforeseen situations and to decrease the water-related disease burden.
- Recourse of water saving techniques, especially in agriculture, such as irrigation drip and controlled suction and choosing crops that consume less water;
- Launching additional drilling programs and rehabilitation of some abandoned wells
- Application of artificial recharge techniques aquifers in the southern regions. These techniques, were applied in the Netherlands, California and Florida and require technology transfer in Algeria, making it possible to store groundwater in winter and river water for use in the summer to be pumped for irrigation and urban consumption.
- Protection of wetlands as places of habitat for local and migrant wildlife species. In Algeria,
- preventive measures to fight against the harmful effects of extreme events, have also been in the centre of attention since the adoption of the law on major natural and technological risks
- The use of non-conventional water resources such as treated wastewater and desalinization
- Environmental education and social awareness play a major role in confronting and controlling water quality and pollution, climate change, energy, biodiversity, food, water-related diseases, and subsequently in improving human health in Algeria.

These recommendations are also valid for many other regions in Algeria and other countries with similar challenges to Algeria.

Key messages

The most important conclusions and key messages presented in this study is that climate change has already started to show impacts on the waters quality in Algeria and on their biodiversity and ecological status, and that these first symptoms will increase over the coming years. These impacts have already clear consequences for water use and for public health. A series of adaptation and mitigation measures are urgently needed to counteract the negative impacts of climate change on Algerian water ecosystems and on the services they provide to human well-being.

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