People's Democratic Republic of Algeria

Ministry of Higher Education

and Scientific Research

University of Echahid Hamma Lakhdar El Oued

Faculty of Natural and Life Sciences

Department of Biology

Master's Thesis

In order obtain a diploma of an Academic

Master

In biological sciences

Specialty: Biodiversity and Environment

Theme

Impact of irrigation by the Continental Intercalaire aquifer on the major ion dynamics of the soils in Oued Righ region

Presented by:

GUETTOUTA Imane & REZZOUG Ikram

President	Touati Tliba. M	**MCB**	**University of El Oued**
Examiner	Khezzani Bachir	**Pr**	**University of El Oued**
Promoter	Serraye Aicha	**MCB**	**University of El Oued**

Defended on: 10/06/2026

Academic year: 2025/2026

Dedication

Praise be to God, by whose grace good deeds are accomplished...

Today, as I turn the page on many long years of study, I finally stand ready to reap the fruits of my hard work and years of effort. Getting here was by no means easy, but by God’s grace, I did it despite everything.

I dedicate this pride:

To the one who supported me with her prayers, love, and endless compassion—my beloved mother. Despite the weight of fatigue, your voice alone was the solace and balm for my soul.

And to the one who was my impenetrable shield and my support, both in private and in public my dear father. May God preserve you, my unwavering pillar and my unyielding comfort.

And to those who opened their doors and hearts to me during my studies: my dear, beloved uncle and my precious aunt. Thank you for your boundless efforts and generosity. May your home always be filled with goodness and blessings.

To my brother and sister, who were always by my side, and to my noble family.

To my lifelong companions, Maryam, Sabrina, and Zainab, and to my friends—and to everyone who shared with me the hardships and the sweetness of this journey.

IKRM

Dedication

God Almighty said: {And their final invocation is: —Praise be to God, Lord of the Worlds.‖} Praise be to God, who has brought me to this point and made the path to completion easy for me.

I dedicate this humble work to those who instilled in me a love of knowledge and learning,

to the inexhaustible source of generosity and my support in times of hardship, my dear father—may God protect him and guide his steps.

To the one who supported me with her prayers and love, my dear mother, may God protect you, watch over you, and grant you continued health and well-being.

To my brothers and sisters, Wafa, Zainab, Amira, Intissar, Abdullah, and Abdulrahman, who shared with me moments of hardship and joy; to my dear uncles, who were a source of support for me on this path; and to all members of my noble family.

To my companions on this journey—friends (both in real life and online) above all, Mr. Abd raouf and the student Meriem Bouyemmout—with whom I shared this journey of struggle and who instilled in me the hope and determination to continue on this path.

To every professor and teacher who has lit the lanterns of knowledge for me, never withholding knowledge or advice from me; may God reward them with all that is good.

IMANE

Acknowledgments

Praise be to God, the Almighty. We praise and thank Him for the strength and patience He has bestowed upon us, and for guiding us in our academic journey.

We extend our deepest gratitude and appreciation to our supervisor, Dr. Aisha Saray, for supervising this thesis and for the guidance, advice, and support she provided us throughout the completion of this work.

We also extend our sincere thanks and appreciation to the Chair of the Examination Committee and the esteemed members of the committee for kindly agreeing to discuss and evaluate this work.

We also extend our deepest gratitude to all the professors and staff of the College of Natural and Life Sciences, and we express our profound gratitude to Mr. Riab Abdulbasit, Head of the Agriculture Department at the Municipality of Al-Marara, and to the entire staff of the Development of Renewable Energy in Arid Regions research unit, led by Dr. Mohammed AL-Tayeb Khalid wasif for their cooperation and valuable contributions.

Finally, we extend our sincere thanks and gratitude to everyone who contributed, directly or indirectly, from near or far, to the completion of this work.

Abstract

Long-term irrigation with highly mineralized water profoundly alters the geochemical balance of soils in the Oued Righ region. This study presents a comparative analysis of the evolution of major ions Ca^{2+}, Mg^{2+}, and SO_4^{2-} between an agricultural soil irrigated with water from the Continental Intercalary (CI) aquifer and a natural, non-irrigated soil. Chemical analyses reveal an increase in calcium concentrations, with a minimum of 26,89g/kg a maximum of 90,67 g/kg and an average of 56,63 g/kg at a depth of 40-60 cm. For magnesium ions, our results show a minimum value of 16,54 g/kg a maximum of 24,22 g/kg, and an average of 20,93 g/kg at a depth of 40-60 cm. Furthermore, the results of the sulfate ion analysis showed a high average value of 0.092 mg/kg in the irrigated soil compared to the control soil. This accumulation is directly linked to the hydrochemistry of the CI water, which is rich in gypsum and soluble salts. The omnipresence of these ions alters the physical structure of the soil and increases the risk of gypsum cementation.

The results highlight the need to implement sustainable management techniques to restore the ionic balance of the root zone in irrigated soils in this region.

Keywords: Continental Intercalary, Saharan ecosystem, Irrigated soil, Major ions, Oued Righ.

ملخص

يؤدي الري طويل الأمد بمياه عالية التمعدن إلى تغيير عميق في التوازن الجيوكيميائي للتربة في منطقة وادي ريغ. يقدم هذا العمل بين تربة مروية بمياه من طبقة المياه الجوفية للحوض القاري SO و Mg و Cat دراسة مقارنة لتطور الأيونات الرئيسية وتربة غير مروية . تظهر التحاليل الكيميائية زيادة في تركيزات الكالسيوم بما لا يقل عن 26.89 ع / كغم. وبحد (CI) الداخلي أقصى 90.67 كغم ومتوسط 56.63 غ / كغم على عمق 40-60 سم لأيونات المغنيسيوم، أظهرت النتائج حد أدنى 16.54 ع كغم، وحد أقصى 24.22 غ / كغم ومتوسط 20.93 غ / كغم على عمق 40-60 سم. بالإضافة إلى ذلك. أظهرت نتائج تحليل أيونات الكبريتات متوسطاً مرتفعا قدره 0.092 ملغم / كغم في التربة المروية مقارنة بـ بالتربة الشاهدة. ويرتبط هذا التراكم ارتباطا مباشرا بالخصائص الكيميائية المائية لمياه طبقة المياه الجوفية للحوض القاري الداخلى الغنية بالجبس والأملاح القابلة للذوبان ويؤدي انتشار هذه الأيونات إلى تغيير البنية الفيزيائية للتربة وزيادة مخاطر التصلب الجبسي. تؤكد النتائج على ضرورة تطبيق تقنيات الإدارة المستدامة لاستعادة التوازن الأيوني في منطقة جذور التربة المروية في هذه المنطقة.

الكلمات المفتاحية المياه الجوفية للحوض القاري الداخلي النظام البيئي الصحراوي، التربة المروية الأيونات الرئيسية، وادي ريغ

.

TABLE OF CONTENTS

CHAPTER 3: PRACTICAL SECTION

MATERIALS AND METHODES

List of figures

List of Tables

General Introduction

General Introduction

Water is a vital element for the survival of all living beings on a global scale, and it is also a major factor in all socioeconomic activity. Water is therefore a precious resource, especially since it is not evenly distributed. Algeria, due to its geographical location, is considered among the countries rich in thermal and mineral waters. Indeed, the Oued Righ region, which is part of the northern Sahara, is known for its hyper-arid climate and its groundwater resources, which are primarily fossil, with low or relatively low renewal rates; namely, the Terminal Complex and the Continental Intercalaire (Zerrouki and Salhi, 2017).

The water resources of the Oued Righ valley are heterogeneous in terms of geological and environmental conditions; it is characterized by a multi-layered groundwater system encompassing the Terminal Complex and the Continental Intercalaire aquifers (Hammadi et al., 2022). The latter constitutes a large groundwater reservoir covering an area of 600,000 km². Given the high temperature of these waters, which are classified as low-energy geothermal waters, their exploitation for both irrigation and domestic needs has generated enormous problems due to the accumulation of scale and obstructions in canals, structures, and hydraulic equipment. The present study aims to understand the effects of groundwater from the Continental Intercalaire on irrigated soils. Based on this approach, the manuscript is organized into three chapters presented as follows:

- The first chapter is: current state of water resources devoted to a detailed presentation of water in the globe and its general cycle and current situation.
- The second chapter shows the general characteristics of the continental intercalary; it studies the geological and hydrogeological context of the groundwater, and especially the Continental Intercalary history and formation. It allows us to identify the different materials and structures of formations likely to be aquifers.
- The third chapter's main purpose is to demonstrate the practical work. First, a description of the region and the study area. Second, a description of the materials and methods used to conduct the study. And third, the results of the work.

Finally, our work concludes with a general summary and some recommendations.

Bibliography Section

Chapter 01

current state of water resources

Water is considered the essential resource for sustaining life and driving sustainable development. Although it is abundant on Earth, freshwater resources suitable for use are facing increasing pressures as a result of hydrological disruptions caused by current climate changes, such as rising temperatures and recurring periods of severe drought.(Roberts, 2022)

The impacts of this crisis are not limited to environmental aspects alone but extend to economic systems, as the agricultural and industrial sectors are directly affected by declining water levels, threatening food security and increasing the financial burdens on nations,(H. Dry, 2016).

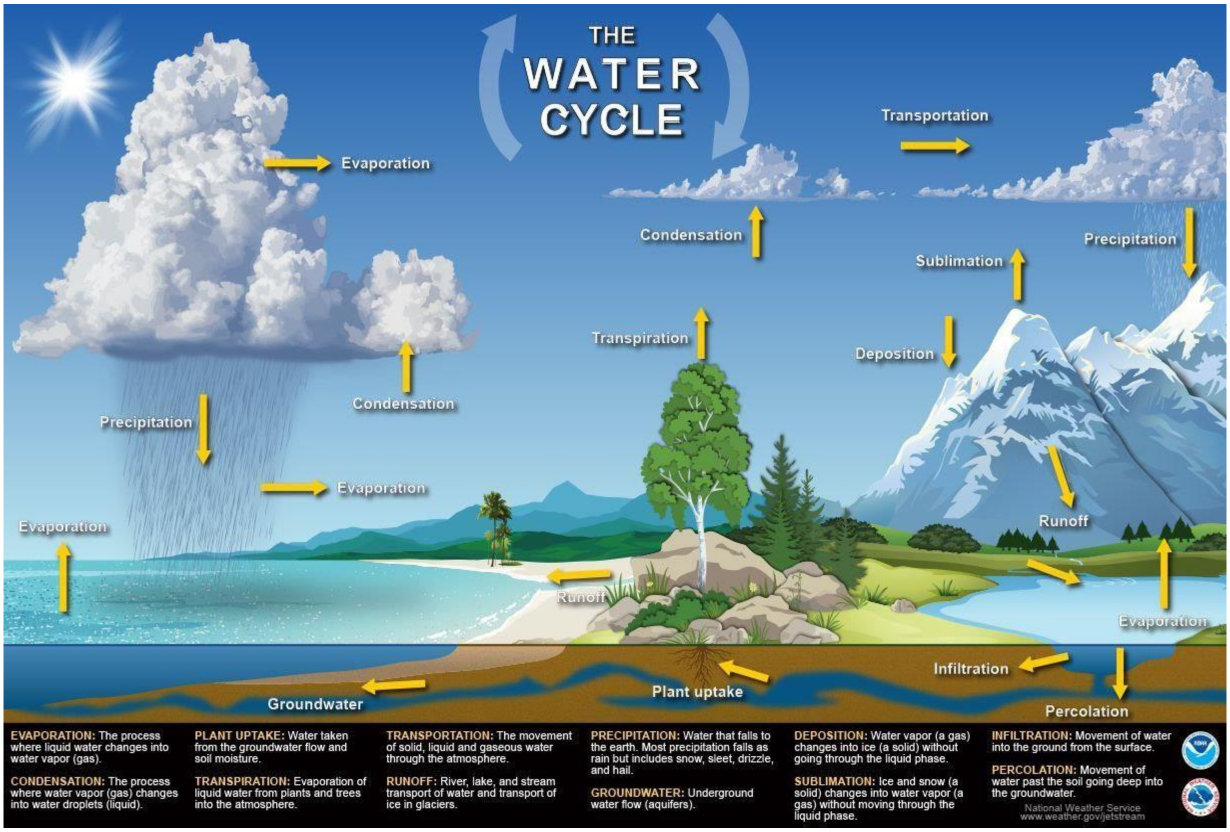
In this context, the first chapter of this study aims to provide an overview of the global distribution of water resources and an understanding of the mechanisms and components of the hydrological cycle, while highlighting the reality of water scarcity and its challenges in Algeria as a case study of countries suffering from the impacts of climate change and water-related economic production.

1. General information on the current state of water resources

The Earth water content is about 1.39 billion cubic kilometers, with the major bulk part of it being about 96.5% in the global oceans. As for the rest, approximately 1.7% is stored in polar icecaps, glaciers, lakes, rivers and permanent snow, and another 1.7% is stored in groundwater. Only a thousandth of 1% of the water on Earth exists as water vapor in the atmosphere,(―State Glob. Water Resour. 2024,‖ 2025).

2. water cycle

Water is one of the main components of life on Earth. The water cycle is the endless process that connects all that water together, encompassing the Earth's oceans, land, and atmosphere, as illustrated in figure (1). This water cycle is closely linked to the exchange of energy between the atmosphere, which determines the Earth's climate and causes many natural climate fluctuations, (H.Nusrat et al., 2022).



Figurer (01): the image illustrates the water cycle and its stages (Administration, 2023)

a) EVAPORATION**:** is the process by which water changes from a liquid to a gas or vapor, and is the main way that water returns to the water cycle, becoming water vapor in the atmosphere. Oceans, seas, lakes, and rivers provide about 90% of the moisture in the atmosphere through evaporation, while the remaining 10% comes from plant transpiration**.(M. Fatnur et al., 2025)**

b) CONDENSATION**: is the process of water changing from a gaseous state** (vapor) to a liquid state. Condensation is important to the water cycle because it forms clouds, which in turn cause vapor to condense into rain or dew, the primary means of returning water to the earth. Condensation is therefore the exact opposite of evaporation. (V.Levizzani & E.Cattani, 2019)

c) FALLING**:** Precipitation is the release of water from clouds in the form of rain, snow, sleet, or hail. It is the primary way by which water in the atmosphere returns to the earth. In addition Most of the water that falls from the atmosphere falls as rain. (Intergovernmental Panel on Climate Change, (IPCC, 2023).

d) TRANSCENDENCE**:** In places with cold temperatures, snow and ice can change directly from a solid state (ice) to a gaseous state (vapor) in a process called sublimation. The most common causes are dry winds and low humidity, (Panayiotis, 2019).

e) LEAKAGE**:** Infiltration is the process by which rainwater is absorbed into the ground. The amount of water absorbed varies depending on the medium into which it is introduced. Rocks, retain much less water than soil. Groundwater can be transported through streams and rivers. However, it is possible for water to sink deeper to the aquifers,(Panayiotis, 2019).

f) SURFACE RUNOFF: If rainwater does not join aquifers, gravity carries it down the slopes of mountains and hills, eventually forming rivers,(M. Fatnur et al., 2025).

3. Types of conventional water

The Natural or traditional water resources consist of rainwater, groundwater, and surface water as follows

A. Surface water:

Surface water accumulates on the ground or in a stream, river, lake, reservoir, or ocean. The total land area that contributes surface runoff to a lake or river is called a catchment area. The volume of water depends mostly on the amount of rainfall but also on the size of the watershed, the slope of the ground, the soil type and vegetation, and the land use. Any changes in the water level of a lake are controlled by the difference between the input and output compared to the total volume of the lake,(S. Bouffier & F.Ortega, n.d.) .

B. groundwater

Groundwater is a major source of drinking water worldwide and is hosted in aquifers. Hydrological recharge of aquifers hugely varies geographically and strongly depends, among other factors, on climate, geology, soil type, vegetation, and land use. Groundwater is recharged from precipitation, which is complemented by natural infiltration by surface water or by artificial recharge. On a global scale, 20% of the irrigation water and 40% of the water used in industry are derived from groundwater. Groundwater within an unconsolidated rock moves only a few centimeters a day, i.e., about 10 m/year. Its velocity largely depends on the steepness of the aquifer slopes and the permeability of the rocks. In consolidated rocks, the water velocity can be many times higher,(L. Abbas, 2022)

C. Water barriers:

These are the water basins, also called mountain lakes, with a storage capacity of rainwater not exceeding one million cubic meters. They are mainly used for irrigation and watering livestock, and they consist of earthen barriers with a height ranging between 5-15 meters, (K.Magharbi, 2016).

4. National potable water distribution

Potable water distribution in Algeria is uneven, with water resources unevenly distributed geographically, concentrated in some areas at the expense of others. Water sources vary between groundwater, dams, and external resources. In quantitative terms, renewable surface water resources shared between the north and south are estimated at about 11 billion m³, while renewable groundwater in the northern regions amounts to approximately 2.5 billion m³. In contrast, the southern regions rely mainly on non-renewable groundwater estimated at around 6.1 billion m³. However, most renewable water resources remain concentrated in the northern regions, which are relatively well endowed compared to the limited availability in the southern regions, which are deserted and arid in nature. This uneven distribution is compounded by the fact that water use by different sectors is also uneven, with the industrial and agricultural sectors consuming the largest share of water, accounting for about 80% of total resources. In addition, about 75% of the water used in the country comes from surface water, while groundwater remains limited and faces significant challenges in terms of demand, pollution, and depletion,(N. Kherbache, n.d.).

Table 1: Water distribution schedule in Algeria (Fanack, 2019).

National water resource	Size in billion /m³	The area
Algeria	11	surface water
Algeria	8.6	groundwater

5. Global water distribution

About 71% of the Earth's surface is water. makes up about 97% of water is in the oceans. The remaining 3% of the water on Earth is freshwater, and it is distributed further through other water bodies. However, not all of that water is available for use; roughly 2/3 of the remaining water is frozen in ice caps and glaciers. Water in this form is useful because it helps to regulate ocean levels and global temperatures. About 1% of the remaining freshwater is available for use and consumption. This water is made up of groundwater and surface water. Ground water is used for drinking and crop irrigation, which makes up about 0.6% of the global water supply. The rest is found as surface water which is made up of streams, rivers, ponds, and lakes. Surface water makes up about 0.3% of all freshwater or 0.009% of all water on Earth. That amount of water is so small, it needs extra care to make sure it stays consumable for living organisms on Earth,(S. Mehdi, 1986).

The distribution of water resources in Tunisia exhibits significant disparities, with most of the surface water (81.2%) concentrated in the northern region, which encompasses a mere 17% of the country's total area. The northern region is endowed with rivers such as the Medjerda, which facilitate enhanced accessibility to water resources for agricultural and urban purposes. Conversely, the southern region predominantly relies on deep, fossil groundwater aquifers, which comprise approximately 60% of the nation's groundwater resources. However, these aquifers are confronted with challenges related to salinity and limited surface water availability. The semi-arid to arid climate is characterized by irregular rainfall, with regions in the north receiving 500–1000 mm annually, while the south receives less than 200 mm. Infrastructure such as dams, reservoirs, and interregional pipelines facilitates the movement of water from areas of surplus to areas of deficit, with a particular emphasis on urban centers and agricultural regions. Salinity levels exhibit regional variation, with groundwater in the southern region frequently characterized by high salt concentrations. This phenomenon restricts the usability of water resources and necessitates the implementation of management strategies to optimize resource allocation,(N. Gaaloul, 2011).

In Morocco, the primary beneficiaries of water distribution are agriculture (80%), industry, and domestic use, with surface and groundwater resources amounting to approximately 22 billion m³ annually. Surface water is concentrated in key basins such as Loukkos, Sebou, and Tangier; however, flows have decreased by over 20% since 1950 due to climate change, overexploitation, and reduced recharge. Groundwater levels are known to decrease at a rate of approximately 2 meters per year. Significant reservoirs are confronted with diminished inflows, a development that has the potential to compromise water security. In order to address these challenges, Morocco is implementing measures to improve efficiency, reduce network losses, and develop alternative sources like desalination and wastewater reuse. The goal of these measures is to balance supply and demand amid increasing climate stresses,(M. Meddi & S.Eslamian, 2021).

6. Water shortage in Algeria

Algeria is facing a water shortage crisis resulting from the impact of several factors that posed a major challenge in the availability and distribution of water resources. The causes of this shortage are:

Climatic drought

Climate drought is a primary cause of water scarcity in Algeria, where the country experiences severe hydrometeorological conditions due to its geographical location within a semi-arid and arid region. Since 1975, Algeria has experienced a 30% deficit in rainfall, a situation that has recently been exacerbated by a severe drought over the past three years. This ongoing drought has precipitated a decline in dam reserves and the depletion of groundwater resources. High temperatures also play a significant role, with 85% of total annual rainfall being subject to evaporation. Projections indicate that this trend will persist, with a further decline in rainfall ranging from 5% to 13% by the year 2025, thereby exacerbating the water deficit,(F. Abdessalam et al., 2025; ZERDOUMI & ABRAMOV, 2023).

Limited and unbalanced water resources

Algeria has limited natural water resources, amounting to about 19.2 billion cubic meters per year, unevenly distributed, The flow of rivers is irregular, and renewable surface water makes up only a fraction of the total, restricting supply,(A. Oulmane et al., 2022).

Population growth:

Population growth and urbanization have increased demand, while poor sector management and loss of infrastructure (notably a leakage rate of up to 30 percent in water distribution networks) exacerbate shortages. Rural areas are particularly affected, with lower connection rates and more frequent service interruptions,(S.BOUCHENTOUF & K.BENABDELI, 2021).

Pollution:

Pollution from industrial, household, and agricultural sources reduces the amount of potable water and exacerbates the shortage. Limited wastewater treatment capacity leads to the discharge of untreated water, contaminating natural water sources and reducing the availability of reusing water,(F. Abdessalam et al., 2025).

Overexploitation of groundwater:

The excessive extraction of groundwater poses a grave threat to its long-term sustainability, particularly in arid and semi-arid regions. The present-day supply of potable water is predominantly derived from groundwater, which currently supplies more than 55% of drinking water. This fact underscores the critical concern of groundwater depletion. The ongoing extraction process has been shown to exceed natural recharge, particularly during extended periods of dry conditions. This has resulted in a decline in piezometric levels and the potential for resource exhaustion,(W.M. Edmunds et al., 2003).

7 -Relationship between water and climate change

The nature of the relationship between climate change and water is complex, as climate change significantly affects the water cycle through several mechanisms such as rising temperatures and increased weather events, heat waves, heavy rains, floods and droughts, and this affects water distribution, availability and dynamics globally,(S.M. Dunn et al., 2012).

Long-term data and climate models (such as SIMEP) have also shown that climate change has brought noticeable changes in hydrological patterns including increased frequency, intensity, and duration of weather events, as well as increased variability and unpredictability of the water cycle, Climate change also promotes hydrological changes through,(K. Diao et al., 2016).

Rising global temperatures that increase evaporation rates and changes in precipitation patterns. Seasonal changes in dry summers or harsh winters threaten the stability of water supplies and exacerbate water scarcity,(K. Diao et al., 2016).

In addition, human activities, such as greenhouse gas emissions and the habitual irrational consumption, are also exacerbating these impacts and increasing variability and unpredictability in water cycles,(G. Konapala et al., 2020).

8. Economy on scarcity

In the recent years, Algeria has witnessed a significant decline in water levels, which has affected many aspects, including the economy, through several channels, most notably the deterioration of the agricultural sector due to its huge dependence on water for irrigation and crop production, leading to a decline in agricultural production.

Also, the Water scarcity also contributes to the deterioration of industries that require large amounts of water, limiting their production capacity and increasing operating costs. In addition, water scarcity can lead to the deterioration of infrastructure and health services,(H. Mezouane et al., 2025).

Chapter 2

General characters of the Continental Intercalary

Chapter 2 General characters of the Continental Intercalary

1. Continental Intercalary in Southeastern Algeria

The Continental Intercalary (CI) aquifer, located in southeastern Algeria, is among the world's most extensive fossil aquifers, encompassing an area of over 600,000 square kilometers. The Lower Cretaceous period is the time frame from which it originates, extending from the Triassic base to the upper Albian stage, with some reaches extending up to the Santonian. The water bodies under consideration are located at depths more than 1000 meters, particularly within the confines of the Illizi basin. The temperature of these bodies is notably high, reaching approximately 60°C, and they are characterized by a substantial mineralization, predominantly of a sulfate-rich nature. The recharge of this aquifer is predominantly reliant on residual meteoric water and lateral inflows from surrounding piedmonts and older aquifers. The region's mineral wealth, coupled with its depth and temperature, poses significant challenges to the extraction process. These challenges, however, do not negate the importance of this vital resource in the region's economic landscape,(F. Maioua, 2025).

The Paleozoic marine terrain forms the base of the sedimentary sequence, consisting of saline aquifers and overlying hydrocarbon deposits. Overlying these, in a non-conformable relationship, are formations from the Mesozoic and Cenozoic eras, which may exceed 3,000 meters in thickness in the center of the basin. The Quaternary period is represented mainly by dune sands, which sometimes reach thicknesses of several tens of meters. The following sections detail the geological areas and strata that have been identified .

2-1- Quaternary Period

The Quaternary consists of wind-blown sandy deposits that give rise to dunes, which in turn form the western edge of the Great Eastern Erg. In the northern part of the region, the chotts are gradually disappearing beneath the dune sands (Table 2). It is at this level that the water table is encountered. The stratigraphic columns of certain boreholes show that the average thickness of this aquifer is approximately 60 meters ,(M.L. Zidane & M.Soufi, 2018).

2-2- Tertiary Period

The Tertiary Period is represented mainly by formations dating from the Paleogene and Neogene epochs. The notable geological stages in this period are:

2-2-1 : Eocene Stage

This stage consists of clays and marly limestones, with occasional gypsum and gravel. The lower part of this stage is carbonate, while the upper part is characterized by clays of lagoon to shallow marine origin. The thickness of this horizon varies between 150 and 200 meters (Table 2). The fine-grained nature of these sediments reflects calm sedimentation, conducive to the accumulation of clay-marl layers that act as impermeable layers within the aquifer system (M.L. Zidane &M. Soufi, 2018).

2-2-2- Miocene Stage

(Bel & Demargne, 1966)cv b noted that this stage lies in unconformity with both the Primary Series on the one hand and the Lower Cretaceous, Turonian, Cenomanian, and Eocene on the other. Most borehole sections capturing this horizon show that the Mi-Pliocene consists of a sequence of alternating sandy and sandy-clayey layers with gypsum intercalations and overlying sandstone (Table 2). The grain-size variability of these deposits reflects contrasting hydrodynamic episodes, with phases of erosion and deposition. Across the entire eastern Sahara, this horizon is subdivided as follows:

- Clayey layer: It is thin and occurs only in the central part of the eastern Sahara.
- Sandstone-sandy layer: this is the thickest compared to the others; its thickness remains nearly uniform throughout the entire Eastern Sahara. It is in fact at this level that the main aquifer horizon, also known as the terminal complex (TC), is found.

2-3- Secondary Era

According to (Rolland, 1890), this era—also known as the Mesozoic Era—spans the period from 145 million years ago to 66 million years ago. It consists of two main periods and geological stages based on the age of the rocks. The following are distinguished:

2-3-1- Lower Cretaceous

This period is dominated by continental and coastal formations. Its deposits are associated with fluvial and deltaic environments and consist of the Berriasian, Valanginian, Hauterivian, Barremian, Aptian, and Albian stages. We will focus on the Albian (Table 3).

2-3-1-1- Albian

This geological stage is characterized by alternating layers of marl, sandstone, sand, and, above all, limestone, often associated with interbeds of chert and clay, which are residues of limestone weathering (Moullade et al., 1998; Foucault; Raoult, 2005). Its lower boundary is defined by the top of the Aptian bar, while its upper boundary is marked by the gradual appearance of clay-carbonate facies (Ferry, 2017).

2-3-2- Upper Cretaceous

The deposits from this period are predominantly marine and rich in marine fossils. The geological stages of this interval are: Cenomanian, Turonian, Coniacian, Senonian, Campanian, and Maastrichtian. The following are explained:

2-3-2-1- Cenomanian

Drilling in the region indicates that the Cenomanian consists of alternating layers of dolomites, dolomitic limestones, dolomitic marls, clays, and anhydrites, (ANRH, 1993). This facies gives this stage a semi-permeable character, making it a natural protective barrier that isolates deep aquifers, (Karpoff, 1952). Regarding its stratigraphic boundaries, the base is marked by the appearance of evaporites and dolomites, while the upper part is characterized by the appearance of limestones and evaporites, signaling the transition to the Turonian, (Fabre, 1976).

2-3-2-2- Sénonian

According to (Bouselsal, 2016), most geological studies conducted across the Algerian Sahara reveal that the Senonian consists of two facies-wise very distinct units: one corresponds to the lagunal Senonian at the base, the other to the carbonate Senonian below ,(R. Karpoff, 1952).

2-3-2-2-1- Senonian Lagunaire

The boundary of this stage is clearly defined and characterized by an evaporitic facies containing clays that are easily distinguishable from those of the Turonian. It also consists of anhydrite, dolomitic limestone, clays, and, most notably, massive salt beds nearly 150 meters thick. The upper boundary of this formation coincides with the Turonian at the end of the anhydrite intercalation. Its thickness ranges from 270 m to 300 m.

2-3-2-2-2- Carbonate Senonian

This second substage consists of dolomites, dolomitic limestones with marly clay interbeds, and largely of fissured limestones and vacuolar dolomites (Table 2). Its thickness sometimes exceeds 200 meters. It should also be noted that there is lithological continuity between the carbonate Senonian and the Eocene, both of which contain limestones of the same nature with the presence of nummulites.

Table 2: Geological context of the Oued Righ,(ANRH, 1993).

Geological	Geological stage	Hydrogeological characteristics
The Quaternary era	-	Shallow aquifer (groundwater table)
		Substrate (Waterproof)
The Tertiary era	Mio-Pliocene	1st sand layer (Continental Terminal)
		Semi-permeable
	Pontian	2nd sand layer (Continental Terminal)
	Middle Eocene	Substratum
	Lower Eocene	Limestone layer
The Secondary era	Carbonate Senonian	-
	Lagunina Senonian	Substratum
	Cenomanian	Substratum
	Albien	**Albian aquifer (Continental Intercalary)**

3. Hydrogeological contexte:

La région wad rig se caractérise, sur le plan hydrogéologique, par la présence de deux principaux systèmes aquifères : le Continental Intercalaire et le Complexe Terminal (Figure 2), tous deux recouverts par une nappe superficielle libre communément désignée sous le nom de nappe phréatique

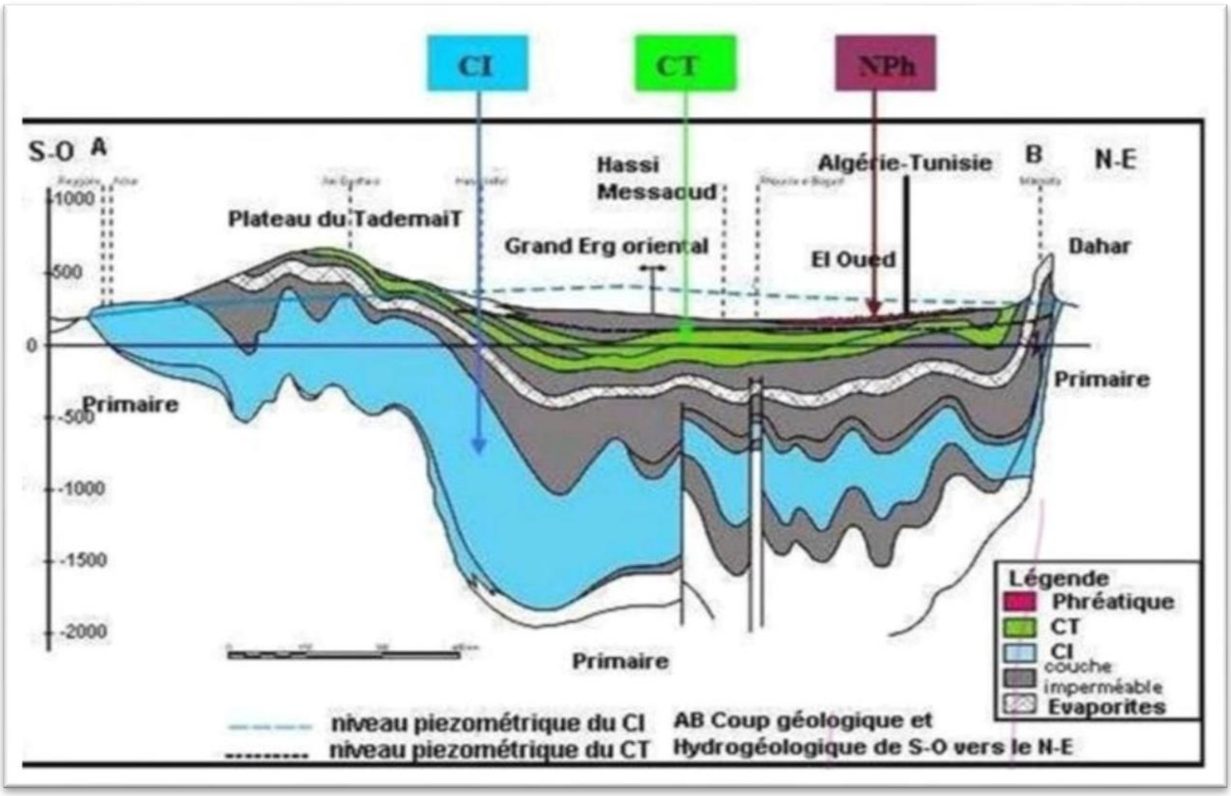


Figure 2: A hydrogeological profile of south-eastern Algeria,(G.S. Abani & Keltoum, 2023).

According to the hydrogeological studies conducted by the UNESCO team as part of the study of aquifers in the Northern Sahara, and the schematic cross-section shown in Figure 3, which was created based on borehole cross-sections.

The following aquifers were identified:

3-1- Groundwater

Table The groundwater table extends throughout the Wad Rig region and corresponds primarily to the upper part of the continental formations that were established at the end of the Quaternary period. It lies at depths generally ranging from 0 to 60 meters. Due to its importance, this aquifer constitutes the main water resource for irrigating palm groves; it is exploited notably through a network of traditional wells, the number of which is estimated at approximately 31,000 authorized wells. Water flow within this aquifer remains relatively rapid on a regional scale, particularly in areas where clay lenses are present. Except for the chott areas, the unconfined aquifer is present throughout the El-Oued region. According to Marc Cote (1998), this aquifer is primarily replenished by water used by the population, and its ultimate source is the deep aquifers of the Terminal Complex (TC) and Continental Intercalary (CI) shown in Figure 3.

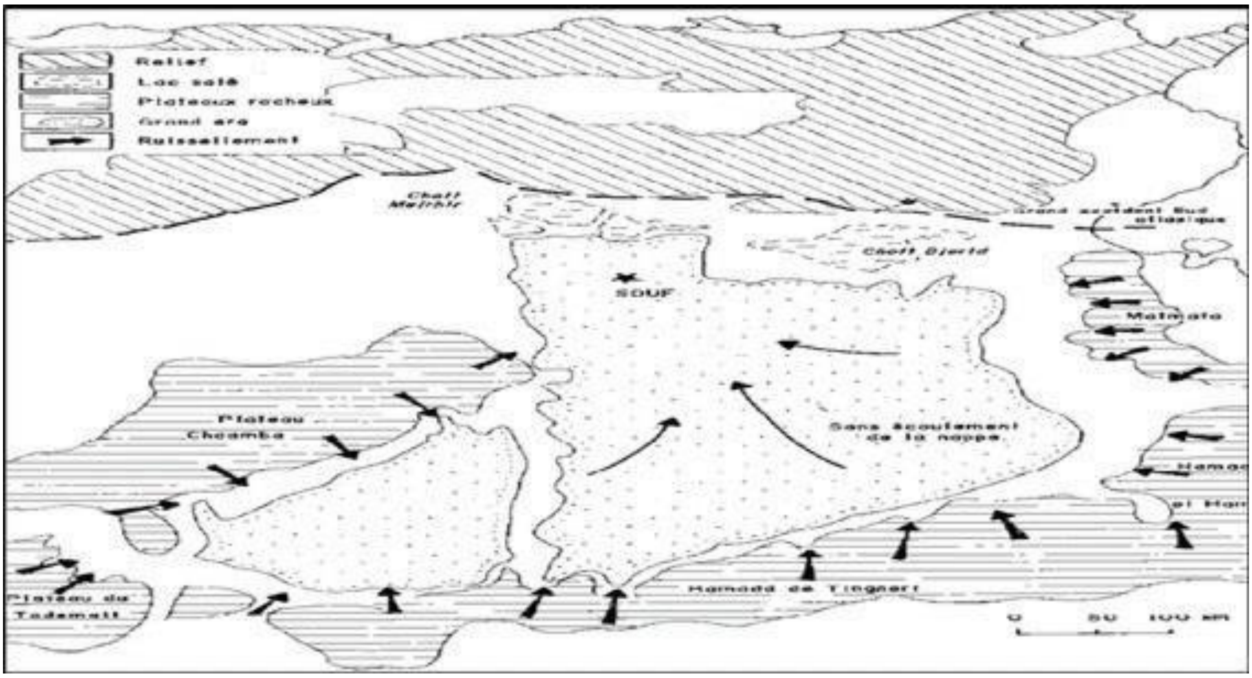


Figure (03) : Groundwater recharge area and the direction of groundwater flow,(M. Coté, 2006).

3-2. Terminal complex Aquifer (TC)

According to Boualem B. and Belksier M. (2018), the Terminal Complex aquifer encompasses the permeable strata of the carbonate Senonian and the Miocene-Pliocene. In fact, it is possible to distinguish three aquifers there, separated locally by semi-permeable or impermeable horizons. These three aquifers are represented by the Miocene-Pliocene sands (the first sand aquifer, CT1), by the sands, sandstones, and gravels of the Pontian (the second sand layer CT2), and by the fissured limestone and dolomite , at a depth of approximately 250 m and extending down to 700 m.

3-3- Continental Intercalary (CI) Aquifer

The Continental Intercalary aquifer comprises continental deposits laid down primarily during the Early Cretaceous period(Table 3) , deposited between two major marine sedimentary cycles: a regression during the Early Cretaceous and a transgression during the Late Cretaceous. This aquifer extends stratigraphically from the base of the Triassic to the top of the Albian stage, sometimes extending into the Late Santonian (Sahri, 2022). As shown in Figure 10, the CI is among the largest fossil aquifers in the world, with a surface area of over 600,000 km² and a local thickness of over 1,000 m (Sahri, 2022; Djehiche et al., 2017) .

The CI or Albian aquifer is very large; its water flows at ground level in the southern part at Tinhert and Tadmait and plunges to depths of over 1000 m in the eastern erg: Oued Righ and Oued Souf. The CI water, which reaches temperatures of around 60°C at the outlet of artesian wells, is unsuitable for direct irrigation ,(U.Setif et al., 2016).

This multi-layered aquifer, sealed at the surface by clay and anhydrite layers, currently functions with residual recharge from Quaternary geological events, estimated at approximately 2.5 billion m³/year, and remains in equilibrium thanks to slow lateral recharge from the surrounding piedmonts (Benammar et al., 2015).

Furthermore, the main recharge zones are located in the southern foothills of the Saharan Atlas, in the northwest region, at Tinrhert in the south, at Dahar in the east, as well as at Jebel Nafusa and Jebel Hassawna, where the CI aquifer also receives inputs from Cambrian-Ordovician aquifers (Benammar et al., 2015; Sahri, 2022).

Vertical transfers from the CI to the Terminal Complex are also suspected locally in areas exhibiting fractures, such as Amguid-El Biod, while elsewhere, the clay-anhydrite cap provides a near-perfect seal between the two aquifers (Djehiche et al., 2017). This aquifer has been exploited since at least the 10th century through the construction of foggaras on the banks of the Tademaït ((UNESCO, 1972); Benammar et al., 2015).

In this chapter, we have presented and analyzed in detail the geological and hydrogeological context of the Wad Rig region, with a particular focus on the characteristics and extent of the intercalated continental aquifer (CI). This analysis has provided a better understanding of the stratigraphic structure, the lithological nature of the formations, and the hydrodynamic conditions influencing groundwater flow and storage in the region. The following chapter will be devoted to the experimental part of our study. It will address, on the one hand, the description of the equipment and methodology used for sampling and data analysis, and, on the other hand, the presentation and interpretation of the results from the field investigations,(ANRH, 1993).

Table 3: Hydrogeological formation of the Oued Righ,(ANRH, 1993).

Geological ear	Geological stage	Hydrogeological characteristics
The Quaternary period		Shallow aquifer (groundwater table)
		Substrate (Waterproof)
The tertiary period	Miocene-pliocene	1st sand layer (Continental Terminal)
		(Semi-permeable)
	Pontian	2nd sand layer(Continental Terminal)
	Middle Eocene	Substratum
	Lower	Limestone layer
The Secondary era	Carbonate Senonian	
	Lagunina Senonian	Substratum
	Cenomanian	Substratum
	Albien	Albian group(continental Intecalary)

Chapter 3: Practical Section

Materials and Methodes

1. Introduction to the study area

The wilaya of El M’Ghair, located in southeastern Algeria, covers an area of approximately 8,835 km². It occupies a strategic position in the Oued Righ region, in the heart of the northern Sahara, and is located at the geographical coordinates 33.95° N latitude and 5.92° E longitude. (figure 4)

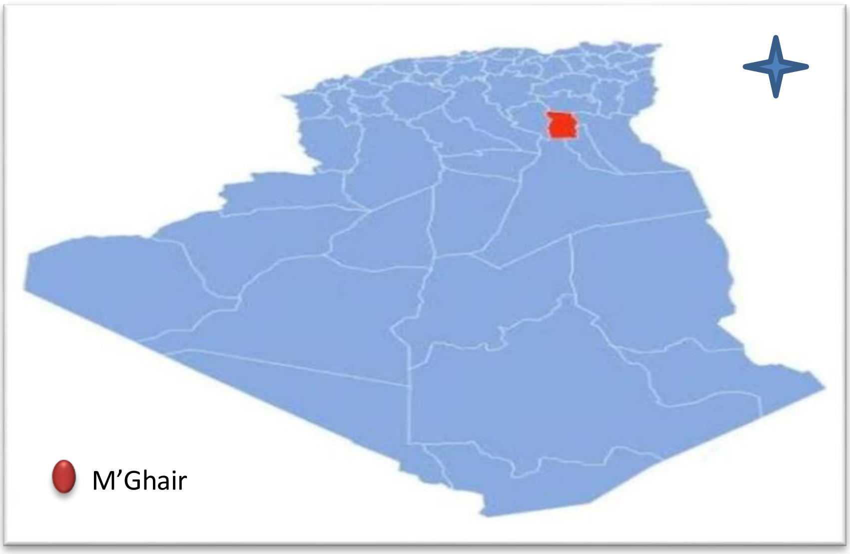


Figure 04: Location of the study area (Wikipedia, 2026).

Location and characteristics of the study area:

- To the north, it borders the province of Biskra.
- To the east, it borders the province of El Oued.
- To the west, it borders the province of Ouled Djellal.
- To the south, it borders the provinces of Touggourt and Ouargla.

1-1- Climat of the study region

The El M'Ghair region is characterized by a hot desert climate.Throughout the year, the region experiences elevated temperatures, with monthly averages ranging from 10.7°C in January to 33.6°C in July.

During the summer months, maximum temperatures can reach up to 49°C, while minimum temperatures typically remain above 0°C. In contrast, during the winter season, minimum temperatures can drop to below 0°C, although this is not a common occurrence. Precipitation levels are notably low, with an annual average of approximately 42 millimeters.

Most of the precipitation occurs during the months of November and December, with amounts of 27.8 millimeters and 9.3 millimeters, respectively. From June through

August, precipitation levels are virtually negligible, with amounts approaching 0 millimeters.
The annual temperature range is approximately 22.9°C, reflecting a significant variation between maximum and minimum temperatures. The aforementioned climate engenders considerable challenges with regard to the effective management of water resources and the adaptation of agricultural practices. (Yousfi.F, 2025)

1-2- Soil characteristics

He soils of the Oued Righ Valley are a prime example of desert soils in the northeastern Algerian Sahara, within the "Lower Sahara" basin. From a physicochemical perspective, these soils are characterized by distinct alkaline properties, along with high electrical conductivity levels resulting from the proximity of shallow groundwater and fluctuations in its levels.(A. Boudoukha & Athamena, 2016)
From a mineralogical perspective, the dominant feature of these soils is the marked predominance of gypsum, which forms a hard crust. The clay mineral group consists primarily of illite, associated with high potassium content, and fibrous attapulgite, part of which is believed to be wind derived,(Z .Mansouri et al., 2022).
From an agricultural perspective, these soils present a significant edaphic challenge; while the lower topographic levels allow for the cultivation of date palms due to the ease of controlling the thickness of the gypsum crust, the higher, pastoral-type levels remain suitable only for herbaceous plants because of the continuity and density of the gypsum formations, (B et al., 2025)

1-3- Hydrogeology

The Wadi Righ region is characterized by a unique and exceptional hydraulic setting in the heart of the Algerian desert, where its water system is based on a striking paradox that combines vast groundwater reserves with complex chemical and technical challenges in management. Hydrologically, the region relies entirely on a system of superimposed aquifers, ranging from the surface and Miocene layers belonging to the ―Terminal Complex‖ (Complex Terminal)—primarily used for irrigating oases—down to the extreme depths of the ―Continental Intercalary‖ (Continental Intercalaire) or Albian aquifer, which extends beyond 1,500 meters. The latter represents the sole lifeline for supplying the population with potable water through strong flows and high pressures; however, this water flows at very high temperatures (ranging between 55 and 60 degrees Celsius) and is laden with extremely high levels of salinity and calcium hardness, exceeding international standards by several times,(Q.Bawaya, 2004).
The region experiences interactions between groundwater and rock layers, which affect water quality and distribution; it is considered a major source of water, primarily for agricultural use, despite the significant challenges it faces in terms of water quality and climate change,(A. Kadri et al., 2022).
The groundwater is characterized by high salinity, with the majority of samples classified as Na-Cl type, while a slightly smaller proportion are of the $Na\text{-}SO_4$

(sulfate) type. The calcium and magnesium content remains high, with calcium concentrations ranging between 257.47 and 289.93 mg/L, and magnesium between 192 and 224.60 mg/L, reflecting chemical interactions with the subsurface rocks, particularly ion exchange processes and the dissolution of calcium- and magnesium-rich rocks. The study also revealed high sulfate concentrations, with a maximum content of 2,290 mg/L, likely resulting from interactions with sulfate-bearing rocks or other geological processes, such as sulfide oxidation and evaporation. High levels of calcium and magnesium increase water salinity, which may negatively impact water use in agriculture, as sulfates and calcium contribute to increased salinity and soil fertility degradation, necessitating careful assessment prior to use. Overall, the results indicate that high coastal salinity and geological rock interactions make it difficult to sustain water use in agricultural activities without appropriate treatment or effective water management strategies (Miloudi.Z et al., 2022).

2- Sampling method

2-1- Area selection and sampling

The study was installed in El-M'Ghair, exactly in the area of El Merrara, to test the effects of irrigation by water from the Continental Intercalaire (CI) on the soil. We have chosen the area of El Merrara because intensive farming and use of deep waters of the Continental Intercalary (CI) are particularly representative of the local irrigation practices (Figure 5).

Figure 05: Map of soil sampling points (red points) in El Merrara region (Google Maps, 2026).

The sampling strategy is based on a direct comparative approach: we collected samples of continuously irrigated soil from this deep aquifer, as well as samples of non-irrigated soil, acting as a control.

The soil samples were weighed, about 500 g for each sample; so from the non-irrigated soil, and the soil irrigated with Continental Intercalary water (CI). According to Figure 5 and 6 the samples were taken at 3 depths (0-20 cm, 20-40 cm, 40-60 cm). Then, the samples are dried in the open air and screened to 2 mm; afterwards, they are transported in cardboard bags to the laboratory for the chemical analysis (Figure 5).

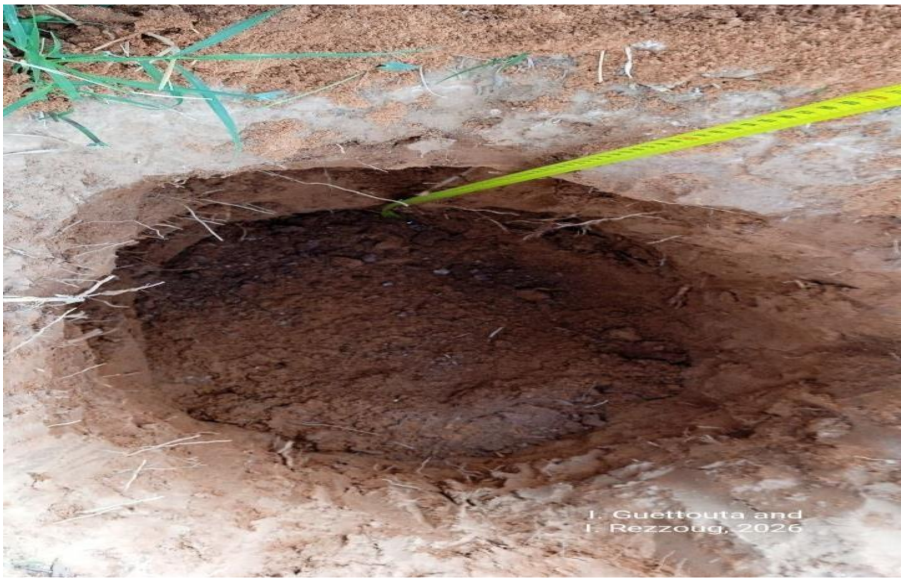


Figure (6): Collection of soil samples at different depths

Figure (7): labeling, storage and preservation Soil sample

Figure (8): Shovel for taking samples

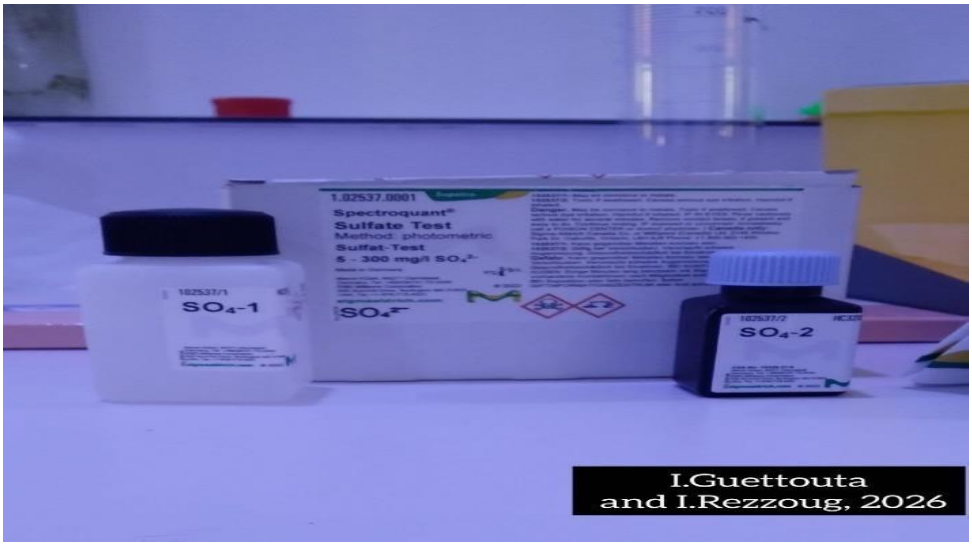


Figure (9): Sulfate detector

3- Used materials

We used different devices and tools on the spot for our own research analysis; Figure, from 8 to 12 present some of the devices and analytical tools that have been used. The following tables show the parameters, devices, and analysis methods that were followed for the water and soil analysis.

3-1 : Soil analysis methods

The following table shows the parameters ; the divise qnd the work methods used in the study :

Table 04: The analyses methods used in the experimental study .

parameter	Device	Work Method
Determination of soluble anions		
SO_4^{-2}	UV-visible spectrophotometer	Mohr's method (Argentometric Titration) NF ISO 10304-1
Determination of soluble cations		
Mg^{2+}	AAS	NF X31-108
Ca^{2+}		

Figure (10): UV-Visible spectrophotometer

Figure (11): Atomic Absorption Spectrometer (AAS)

Figure (12): Filtration of soil solution samples

4- Analysis parameters

Sample preparation for analysis is carried out in the laboratory of Research unit, Development of Renewable Energies in Arid Zones in the University of El Oued, and in the El Oued Operational Fraud Repression Laboratory. The parameters for SO_4^{-2}, Mg^{2+}, Ca^{2+}, are carried out at the analytical laboratories.

The number of samples and the types of analyses and chosen parameters were performed under the conditions of the laboratories. The study was restricted by the offer of reagents, equipment, and supplies provided in the laboratory.

Despite experiencing technical limitations regarding laboratory infrastructure and field-testing equipment, this research incorporates a broader range of complementary parameters. These additions enhance the scientific value and data depth for the investigated ecological sector.

5- Statistical analyses

The Microsoft Excel software was used to organize, process and visualize the raw data collected during the analyses. The measured parameters (SO_4^{-2}, Mg^{2+}, Ca^{2+}) were recorded in structured tables and then processed to obtain averages, minimums, maximums of data, and graphical representations. So, the Excel software allowed to visually compare the two types of soils studied, observe general trends, and judge the dispersion along the depths.

The next part will treat the results of our research in detail.

Results and discussions

In this section of results and discussion, we have tried to describe our analytical results using graphs for each parameter studied. The analyses were performed at the 3 soil depths: 0-20 cm, 20-40 cm, 40-60 cm.
In the results of our study, we agree with the view of (Rassoul et al., 2026), who noted that a study of soil salinity responses to irrigation with thermal Continental Intercalary (CI) water.
Soil salinity is determined by the ionic composition of the soil solution. Some soils contain a liquid phase that is very rich in dissolved salts, giving them often unfavorable properties, especially for the plants that grow in them (Terchi, 2014).

Figures13 to15 present our result in detail for the soils analyzed.

1-Calcium (ca^{+2}) dynamics in the soil

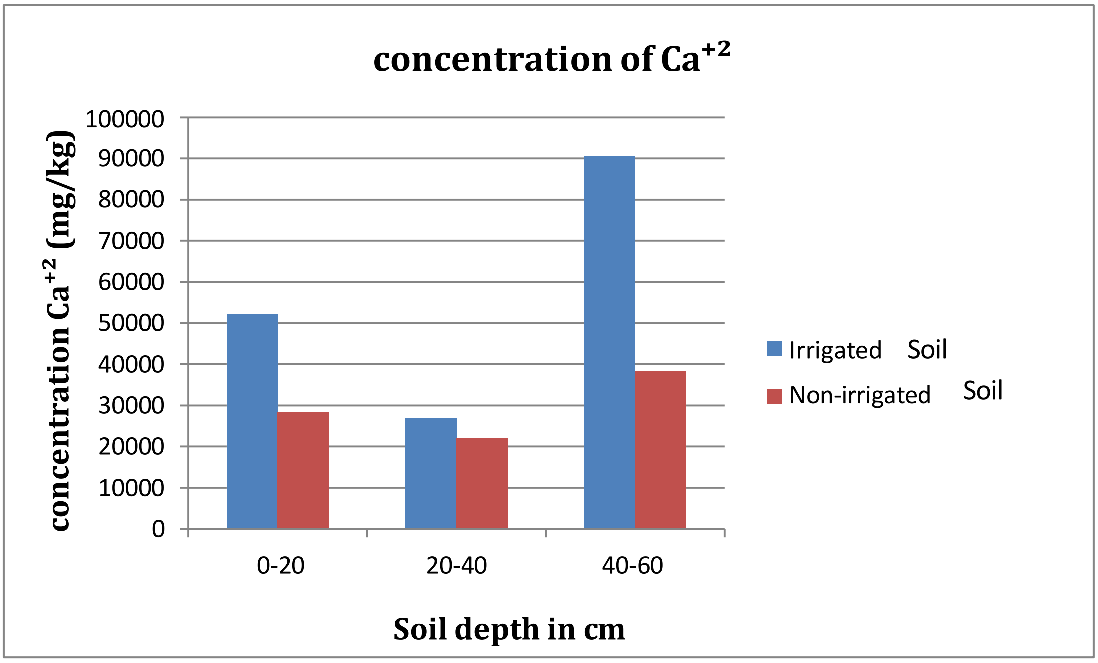


Figure 13: Ca^{+2} concentration in deferent soil depths

The results of the soil analysis, as illustrated in Figure 13, reveal the following findings:
Depth from 0 to 20 cm: A important increase in calcium (Ca^{+2}) concentration was observed in irrigated soil with a mean value of56.63 g/kg compared to non-irrigated soil with a mean value of29.64 g/kg.
Depth from 20 to 40 cm: A comparison of the calcium (Ca^{+2}) concentrations in irrigated and non-irrigated soils reveals that they are nearly identical with a mean value of26.89 g/kg.
Depth from 40 to 60 cm: A considerable increase in the calcium (Ca^{+2}) concentration was observed in soils that received irrigation and in those that did not receive

irrigation. We noted in this depth that the minimum concentration wasg 26.89 /kg, and the maximum concentration was 90.67g/kg for the irrigated soils. For the no irrigated soils, the minimum concentration was22.07 g/kg, and the maximum concentration was 38.46 mg/k

Across all three depth intervals, Ca^{2+} concentrations in irrigated soils consistently exceed those recorded in non-irrigated soils. This differential is observed at every depth without exception.

In addition, within the irrigated treatment, Ca^{2+} concentrations display a non-monotonic pattern with depths variable. A moderate concentration is recorded at 0–20 cm (≈ 53 g/kg). we noticed a notable decrease is observed at 20–40 cm (≈ 30 g/kg), and a marked increase is recorded at 40–60 cm (≈ 90 g/kg), which constitutes the highest value across all depths presented in the figure 11.

Within the non-irrigated treatment, Ca^{2+} concentrations are comparatively lower and show less pronounced variation across depths with 30 g/kg in the depth 0-20 cm. The depth 20–40 cm had a concentration of ≈ 25 g/kg. So we recorded a slight decrease relative to the surface layer. For the depth 40–60 cm, we logged a concentration of 42g/kg and an increase relative to the two lower layers, representing the highest value within the non-irrigated soils.

Furthermore, the largest difference between irrigated and non-irrigated Ca^{2+} concentrations is observed at the 40–60 cm depth interval with a difference approximately of 48 g/kg, whereas the smallest differential is recorded at the 20–40 cm soil depth.

While the overall mineral enrichment of our profiles aligns with the dynamics described by Chachoua (2018) and Marlet et al. (2009) in the irrigated perimeters of the Lower Sahara

Indeed, the thermodynamic solubility limits of gypsum typically inhibit dissolved calcium to much lower baselines. Consequently, our result confirms the extreme mineral saturation driven by the Albien CI groundwater.

2- Magnesium (Mg^{+2}) dynamics in the soil

In Figure 14 we present the variation of the magnesium in deferent soil depths. We observed that in the depth from 0 to 20 cm, there was an increase in the concentration of Mg^{+2} in irrigated soil compared to non-irrigated soil.

In the irrigated soil, the maximum concentration value was 2,42 g/Kg. The minimum concentration value was1.65g/Kg.

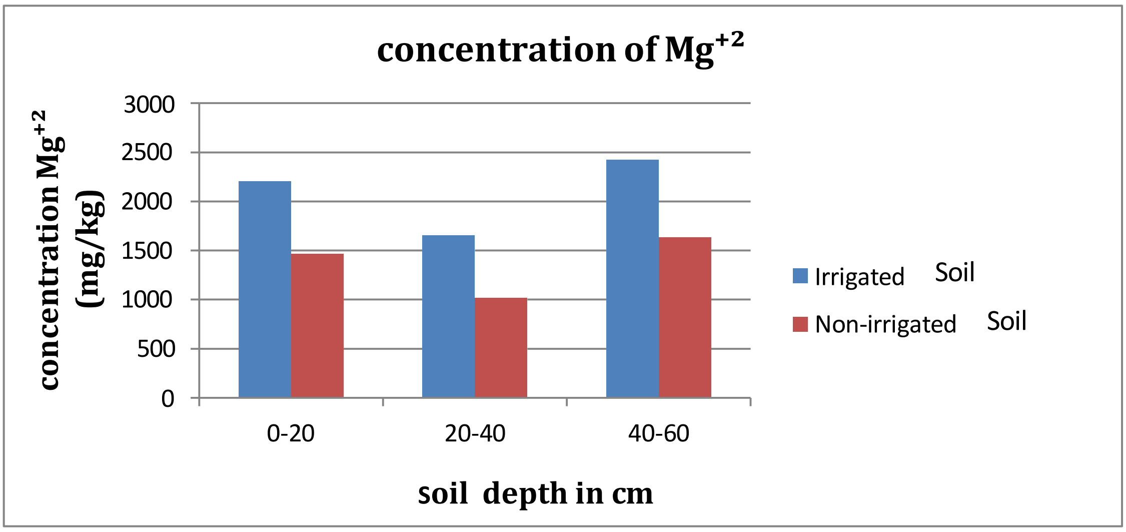


Figure 14: Mg^{+2} concentration in deferent soil depths.

In Figure 14 we present the variation of the magnesium in deferent soil depths. We observed that in the depth from 0 to 20 cm, there was an increase in the concentration of Mg^{+2} in irrigated soil compared to non-irrigated soil.

In the irrigated soil, the maximum concentration value was 2,42 g/Kg. The minimum concentration value was1.65g/Kg.

For the non- irrigated soil in this depth, a minimum concentration value was 1.01 g/kg, and a maximum value was 1.63g/kg, with a mean of 2,09 g/kg.

Moreover, in the depth of 40 to 60 cm, the Mg^{+2} concentration is high in irrigated soil compared to control soil with a maximum concentration value of 2.53g/Kg. And a minimum concentration value of2.23 g/Kg, and a mean value of minimum0.0015 g/Kg.

Likewise, in the depth of 40 to 60 cm, we registered that in irrigated soil, the concentration becomes very high compared to non-irrigated soil.

We observed that the concentration of Mg^{+2} has increased in the irrigated soil at depth

40-60 cm, compared to other depths. The maximum concentration value was 2,42 g/Kg, and the minimum concentration value was 2,60 g/Kg, and a mean value of minimum 2,09 g/Kg.

In the same depth for the non-irrigated soil, we recorded a maximum concentration value of 1.01g/kg, and a minimum concentration value of 0.0003 g/kg, with a mean value of 0.33g/kg.

Across all three depth, Mg^{+2} concentrations in irrigated soils consistently exceed those recorded in non-irrigated soils. This differential is observed at every depth without exception.

Within the irrigated soils, Mg^{+2} concentrations display a moderate concentration at the depth 0–20 cm, and a notable decrease is observed at the depth 20–40 cm (≈1,55 g/kg). Also, we saw a marked increase at the depth 40–60 cm (≈2,40 g/kg) which constituted the highest value across all depths presented in the study figure.

The Mg^{+2} concentrations in the non-irrigated soil are comparatively lower and show less variation across depths 0–20 cm. But at the depth 20–40 cm, we saw a noticeable decrease compared to the surface depth 0–20 cm.

The depth 40–60 cm presented a slight increase compared to the two shallower depths, representing the highest value within the non-irrigated soils.

The biggest difference between irrigated and non-irrigated Mg^{+2} concentrations was observed at the depth 40–60 cm with around 2,40 g/kg difference.

This Mg concentration can pose severe agronomic risks, including structural soil degradation through clay dispersion, intense osmotic stress on crops (Rengasamy, P., & Marchuk, A., 2011).

3- Sulfates (SO_4^{-2}) dynamics in the soil

The analysis results of the sulfates are shown in figure 15, We registered at the depth 0 to 20 cm that the concentration of SO_4^{-2} is high in irrigated soil compared to non-irrigated soil with a mean value of 0.090244 mg/kg.

In irrigated soil under depth 20 to 40 cm, the concentration of SO_4^{-2} is very high compared to non-irrigated soil with a mean value of 0.090244mg/kg. We had the same findings at 40 to 60 cm with a mean value of 0.090244 mg/kg.

We noted that SO_4^{-2} salt is present in high concentrations at all depths of irrigated soil compared to the depths of non-irrigated soil.

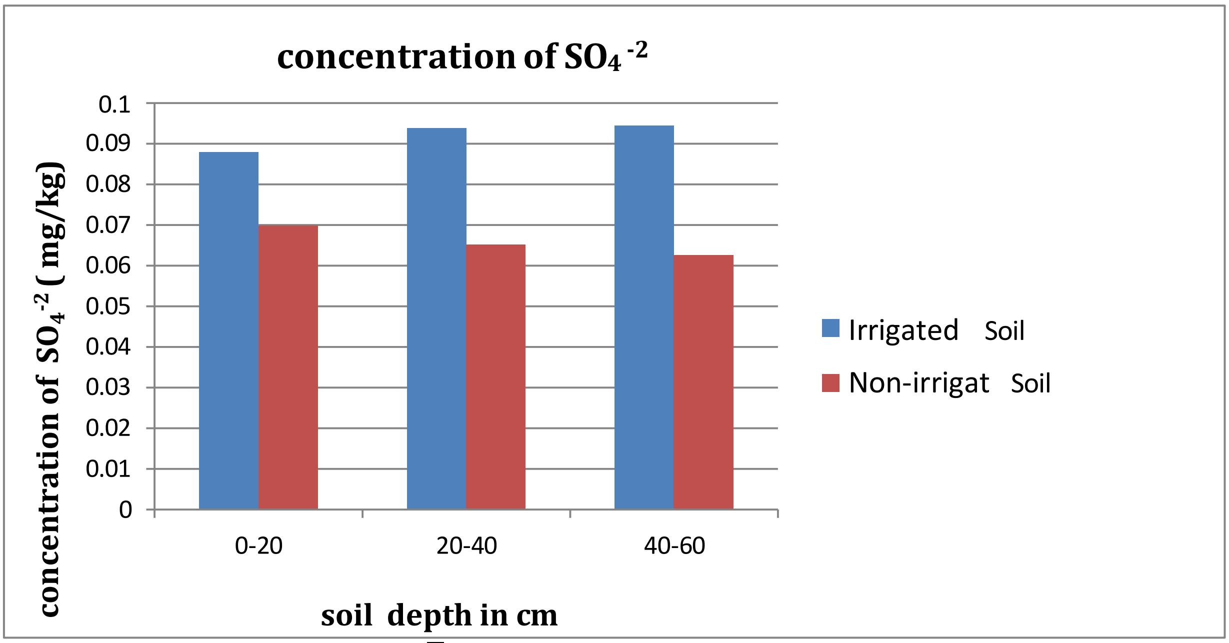


Figure 15: SO_4^{-2} concentration in deferent soil depths.

In the same figure 15; and for the irrigated soils we noticed that at depth of 0–20 cm, we had a maximum concentration value of 0.092044 mg/kg, and a minimum concentration value of 0.087867 mg/kg. And we observed at 20–40 cm depth, the results showed a maximum concentration value of 0.092044 mg/kg, and a minimum concentration value of 0.087867 mg/kg.

And at the depth 40–60 cm, we noted a maximum concentration value of 0.0944 mg/kg, and a minimum concentration value of 0.087867 mg/kg. These values constituted the highest value across all depths presented in the study figure (figure 13).

for the not irrigated soils we noticed that at depth of 0–20 cm, we had a maximum concentration value of0.069867 mg/kg, and a minimum concentration value of 0.062533 mg/kg. And we observed at 20–40 cm depth, the results showed a maximum concentration value of 0.069867 mg/kg, and a minimum concentration value of 0.062533, mg/kg.

And at the depth 40–60 cm, we noted a maximum concentration value of 0.069867mg/kg, and a minimum concentration value of 0.062533mg/kg. These values constituted the lowest value across all depths presented in the study figure (figure 13).

The major difference between SO_4^{-2} concentrations in irrigated soil is observed at the depth **2**0–**4**0 cm with a difference of **0.092** mg/kg, while the smallest difference is recorded at the depth of 0–20 cm.

GENERAL CONCLUSION

This research allowed us to conduct an in-depth analysis to address our research question regarding the effect of water from the deepest aquifer of the Continental Intercalaire (CI) on irrigated soils. We focused on the critical case of the El M'Rara region in Algeria.

Irrigation has a crucial effect on irrigated soils. The waters of the Continental Intercalaire can have both positive and negative impacts on the soil of El M'Rara.

The current irrigation with Albian borehole water from CI in the El M'Rara region also has a negative impact on the soil, causing salinity problems when it exceeds the needs of irrigated crops due to high levels of these salts: Ca^{2+}, Mg^{+2} and SO_4^{-2}.

The salts most concentrated in the irrigated soils of the El M'Rara region are Ca2+ ions at a depth of 40-60 cm.

However, in our study, soils irrigated with CI water in the El M'Rara region showed a higher accumulation of Mg^{+2} salt at a depth of 40-60 cm compared to the depth of 0-20 cm. Furthermore, the results showed a higher accumulation of SO_4^{-2} salt at a depth of 40-60 cm. compared to the depth of 0-20 cm .

Sulfate ions introduced by irrigation water from the Continental Intercalaire play a major role in the geochemical dynamics of the soils of El M'Rara. Under the influence of intense evapotranspiration, these ions preferentially combine with calcium to precipitate as gypsum. Overall, our results provide constructive information on the use of water from the Continental Intercalary, particularly for water-scarce areas. They allow, in particular, the selection of a specific irrigation environment to maximize the benefits of irrigation and reduce its negative effects on the soils of the El M'Rara region.

At the end of this work, we deemed it useful to formulate some recommendations, given the constraints related to the use of water from the Continental Intercalaire, including the cooling of this water and its suitability for irrigation, particularly:

*Controling the quality of irrigation water and improve the drainage network,

*Activating the groundwater quality monitoring network.

*Store the water in open basins to lower its temperature to a level tolerable for the roots of palm trees and underlying crops (ideally below 30°C).

References

References

1. Abani, H. S., & Keltoum, Z. (2023). *Etude gé* **363 ,00** ث الاقتصاديت المتقذمت, .
   https://doi.org/10.38170/1993-010-001-023

2. Bel, F., & Demargne, F. (1966). *Etude hydrogéologique du Continental Terminal*.
3. BOUCHENTOUF, S., & BENABDELI, K. (2021). Water resources and food security in Algeria: Diagnosis and new strategy proposition. *African Journal of Agricultural Research*, *17*(3), 414–424. https://doi.org/10.5897/ajar2020.15125
4. Boudoukha, A., & Athamena, M. (2016). *CARACTÉRISATION DES EAUX THERMALES DE L ' ENSEMBLE SUD SÉTIFIEN . Est algérien*. *25*(March), 103–118. https://doi.org/10.7202/1011602ar
5. Bouffier, S., & Ortega, F. (n.d.). *L ' eau dans tous ses états Perceptions antiques.*
6. Bouselsal, B. (2016). *Evolution hydrogéologique, hydrochimique et impact du phénoméne de remontée des eaux dansla nappe du complexe terminal de la région de souf (sahara.septentrional , Algérie*. Université Kasdi Merbah - Ouargla, Algéria.
7. Diao, K., Sweetapple, C., Farmani, R., Fu, G., Ward, S., & Butler, D. (2016). Global resilience analysis of water distribution systems. *Water Research*, *106*, 383–393. https://doi.org/10.1016/j.watres.2016.10.011
8. Dry, H. qnd. (2016). High and Dry:Climate Change ,Water ,and the Economy. *World Bank Group*.
9. Dunn, S. M., Brown, I., Sample, J., & Post, H. (2012). Relationships between climate, water resources, land use and diffuse pollution and the significance of uncertainty in climate change. *Journal of Hydrology*, *434–435*, 19–35. https://doi.org/10.1016/j.jhydrol.2012.02.039
10. Edmunds, W. M., Guendouz, A. H., Mamou, A., Moulla, A., Shand, P., & Zouari, K. (2003). Groundwater evolution in the Continental Intercalaire aquifer of southern Algeria and Tunisia: Trace element and isotopic indicators. *Applied Geochemistry*, *18*(6), 805–822. https://doi.org/10.1016/S0883-2927(02)00189-0
11. Fanack. (2019). *Water resources in Algeria -Water Fanak.*
12. Fatiha, M. (2025). *Gestion et optimisation des ressources en eau face aux défis climatiques Présenté par les étudiantes : Maioua fatiha Devant le jury compose de : Président : Examinateur :*
13. Fatnur, M. A., Achmad Abu Bakar, Muhammad Irham, & Dina Arbiyah. (2025). The

Process Of Rainfall From The Perspective Of Tafsir Ilmi By The Kemenag RI And Science. *ARRUS Journal of Social Sciences and Humanities*, *5*(1), 828–836. https://doi.org/10.35877/soshum3477

14. Gaaloul, N. (2011). Water resources and management in Tunisia. *International Journal of Water*, *6*(1–2), 92–116. https://doi.org/10.1504/IJW.2011.043319
15. Google Maps. (2026). *EL Mghaire, Algeria*. Google Maps. https://maps.app.goo.gl/tADoUddJeEgB1WNb8?g_st=awhttps://maps.app.goo.gl/tADoUddJeEgB1WNb8?g_st=aw
16. Hydrauliqurs, A. N. des R. (1993). *éTUDE HYDROGéOLOGIQUE DE LA Région d'El Oude*.
17. Intergovernmental Panel on Climate Change (IPCC). (2023). Water Cycle Changes. In *Climate Change 2021 – The Physical Science Basis*. https://doi.org/10.1017/9781009157896.010
18. Kadri, A., Baouia, K., Kateb, S., Al-ansari, N., Kouadri, S., & Khedher, K. M. (2022). *Assessment of Groundwater Suitability for Agricultural Purposes : A Case Study of South Oued Righ Region , Algeria*.
19. Karpoff, R. (1952). Sur le crétacé supérieur du shara algérien. *Comptes Rendus de l'Académie Des.Sciences(C.R.Acad.Sci.)*, *234*(26), 3.
20. Kherbache, N. (n.d.). Water policy in Algeria: Limits of supply model and perspectives of water demand management (WDM). *Desalination and Water Treatment*, *180*(October), 141–155. https://doi.org/10.5004/dwt.2020.25009
21. Konapala, G., Mishra, A. K., Wada, Y., & Mann, M. E. (2020). Climate change will affect global water availability through compounding changes in seasonal precipitation and evaporation. *Nature Communications*, *11*(1), 1–10. https://doi.org/10.1038/s41467-020-16757-w
22. Laid, Z. M., & Mohamed, S. (2018). *Etude hydrogéologique et hydrochimique de l ' aquifère de Complexe Terminale (CT) de*.
23. Levizzani, V., & Cattani, E. (2019). Satellite remote sensing of precipitation and the terrestrial water cycle in a changing climate. *Remote Sensing*, *11*(19). https://doi.org/10.3390/rs11192301

24. Lina Abbas. (2022). **006كليت العلوم الذقيقت و علوم الطبيعت و الحياة جامعت محمد خيضر بسكرة ..**

25. Magharbi, K. (2016). Economie des ressources en eau en Algérie Etude analytique des ressources en eau (potentiel et défis). *Revue Les Cahiers Du POIDEX*, *4*(6), 103–120. https://www.asjp.cerist.dz/en/article/30157
26. Marc Coté. (2006). *Guide d'Algérie paysages et patrimoine*. Saide Hannachi, Média-plus.
27. Meddi, M., & Eslamian, S. (2021). Uncertainties in Rainfall and Water Resources in Maghreb Countries Under Climate Change. In *African Handbook of Climate Change Adaptation: With 610 Figures and 361 Tables*. https://doi.org/10.1007/978-3-030-45106-6_114
28. Mehdi, S. (1986). *Solar Desalination*. 317–321.
29. Mezouane, H., Hank, D., & Delli, R. (2025). Agricultural Water Management under Water Scarcity in Algeria: Practices and Future Perspectives. *The Open Agriculture Journal*, *19*(1), 1–15. https://doi.org/10.2174/0118743315442659251120053241
30. Nusrat et al. (2022). هنذست كيميائيت جامعت حمت لخضر الوادي كليت التكنولوجيا.
31. Oulmane, A., Kechar, A., Benmihoub, A., & Benmehaia, M. A. (2022). Assessment of surface water management institutions: a case of public irrigation schemes in northern Algeria. *Water Policy*, *24*(2), 229–241. https://doi.org/10.2166/wp.2022.025
32. Panayiotis. (2019). *Encyclopedia of Ecology | ScienceDirect*. https://www.sciencedirect.com/referencework/9780080454054/encyclopedia-of-ecology#book-description%0Ahttps://www.sciencedirect.com/referencework/9780444641304/encyclopedia-of-ecology
33. Qais, B. (2004). معالجت عسرة مياه طبقت البيان حوصلت تجريبيت و امكانيت استغلال النتائج في منطقت وادي ريغ. جامعت ورقلت.
34. Rassoul, Y., Berreksi, A., Maza, M., Belkhiri, L., Bendif, H., Ali, M. A. M., & Mouni, L. (2026). *Assessment of the Impact of Thermal Springs on Surface Water Quality in the Soummam Watershed (Algeria)*. 1–30.
35. Roberts, D. C. (2022). *Climate Change 2022 : Impacts , Adaptation and Vulnerability Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. https://doi.org/10.1017/9781009325844.Front
36. Rolland, G. (1890). *chémin de fer transsaharien: Géologie du sahara algérien et aperçu*

géologique sur le sahara occidental. Imprimerie Nationale.

37. Setif, U., Adil, M., Samia, H., & Sakher, M. (2016). *REVUE AGRICULTURE Appréciation d ' une méthode pour l ' estimation des besoins en eau d ' une culture cultivée dans un milieu salin (cas du palmier dattier) Evaluation of method for estimating water requirements of crops grown in saline environment (case of date palm) Key words : 1*, 189–197.
38. State of Global Water Resources 2024. (2025). In *State of Global Water Resources 2024* (Issue 1362). https://doi.org/10.18356/9789263113801
39. Terchi, S. (2014). *Etude de l'impact de la qualite des eaux d'irrigation sur la fertilite du sol, la plante et le rendement des systemes d'irrigation*. ECOLE NATIONALE SUPERIEURE D'HYDRAULIQ-ARBOUI Abdellah.
40. UNESCO. (1972). *Etude des ressoursces en eau du shara septentrional (Algérie, Tunisie) : Rapport sur le résultas du projet(Conclusions et recommandations)*.
41. Wikipedia. (2026). *Carte géographique de la commune de M'ghir,Algérie*.
42. ZERDOUMI, I. E., & ABRAMOV, V. Y. (2023). Climate change and scarcity of water resources in Algeria. *NEWS of the Ural State Mining University*, *1*(1), 7–12. https://doi.org/10.21440/2307-2091-2023-1-7-12
43. Zina, M., Youcef, L., Saber, K., Nadir, A.-A., Hadee, M. N., S.Mashaan, N., A.Eldirderi, M. M., & KHEDHER, K. M. (2022). *Hydro-Geochemistry and Groundwater Quality Assessment of Ouargla Basin, South of Algeria*.

LIST OF ANNEXES

Table 5: the GPS coordinates of the sampling points

point	**Latitude (N)**	**Longitude (E)**
Irrigated soil	33° 68´ 48.7'' N	5° 40´ 12.6'' E
Non-irrigated soil	33° 39´ 56.9'' N	5° 39´ 44.4'' E

Table 6: climatic data from the region of El-M’Ghair

Parametres	Jan	Feb	Marc	Apr	May	Juen	Jul	Aug	Semp	Oct	Nov	Dec
Average Temperature (°C)	10.7	13.1	16.7	20.7	25.7	30.7	33.6	33.2	28.6	22.9	15.8	11.4
Minimum temperature (°C)	5.5	7.2	10.2	13.8	18.5	23.1	25.8	25.9	22.2	16.7	10.3	6.2
Maximum temperature (°C)	17	19.6	23.2	27.3	32.5	37.8	40.8	40.3	35.2	29.5	22.3	17.6
Precipitation / Rain (mm)	17	5.7	8.9	12.5	6	16.5	4.5	4.6	12.6	7.1	27.8	9.3
Humidity(%)	62%	51%	44%	39%	34%	30%	28%	30%	41%	49%	57%	63%
Rainy days (d)	2	2	3	2	2	1	1	1	2	2	2	2

Data: 1999 – 2008 Minimum temperature °C, Maximum temperature °C, Precipitation / Rain mm, Humidity, Rainy days