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

Vertical assessment of the physico-chemical properties of soils irrigated by Continental Intercalaire waters in the region of El M'Rara (southern Algeria).

Presented by: Chaia Malak

President	**Azouzi Monira**	**MCB**	**University of El Oued**
Examiner	**Djoudi Abdelkader**	**MCB**	**University of El Oued**
Promoter	**Serraye Aicha**	**MCB**	**University of El Oued**

Defended on : ,,,,/06/2026

Academic year: 2025/2026

Dedication

Praise be to God with love, gratitude, and thankfulness; I would not have reached this stage without God's grace and guidance.

I dedicate the fruit of this humble work to those who are the reason for my existence and support in life:

To my dear mother, the source of tenderness and prayer, whose prayers were the source of my strength and tranquility, and who eased my hardships with her patience and kindness.

To my dear father, my support and role model, who taught me that success is only achieved thru patience and hard work, and whose support and encouragement were present at every step of my academic journey.

To my brothers and sisters, who have been my support and strength, and who have shared with me moments of toil.

I dedicate this success to my friends and colleagues Guettouta Imen and Rezzoug Ikram with all my recognition.

To everyone who has been a reason for my support and encouragement, I dedicate this work, hoping that God makes it a beginning of goodness and success.

chaiaa Malak

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

In the arid region of El M'Ghair, the use of thermal waters from the Continental Intercalary (CI) aquifer for irrigation poses major risks of soil degradation. This study aims to evaluate the vertical dynamics of three key parameters of soil salinity: water potential of hydrogen (pH); Electrical Conductivity (EC), and Total Calcium Carbonate content ($CaCO_3$), at three distinct depths: 0-20 cm, 20-40 cm, and 40-60 cm. The analytical results reveal a marked stratification of minerals. The EC shows its highest values in the surface horizon (0-20 cm) between a minimum of 252.22 µs/cm and a maximum of 435.55 µs/cm and an average of 320.38 µs/cm confirming intense evaporation that promotes the accumulation of salt on the surface. Furthermore, the pH results range between 7.43 and 7.66. The $CaCO_3$ results show alkalinity in the deep horizon (40-60 cm), related to the processes of limestone accumulation. This study highlights the need to adjust irrigation water volumes and install an efficient drainage system to limit the salinization of the root horizons of the palm grove.

Keywords: Oued Righ, Continental Intercalaire, irrigated soil, Algeria, Saharan ecosystem.

RÉSUME

Dans la région aride de El M'Ghair, l'utilisation des eaux thermales de la nappe du Continental Intercalaire (CI) pour l'irrigation présente des risques majeurs de dégradation des sols. Cette étude a pour objectif d'évaluer la dynamique verticale de trois paramètres clés de la salinité des sols : le potentiel hydrogène (pH) ; la Conductivité Électrique (CE), et Taux de calcaire total ($CaCO_3$), à trois profondeurs distinctes : 0-20 cm, 20-40 cm et 40-60 cm. Les résultats analytiques révèlent une stratification marquée des minéraux. La CE affiche ses valeurs les plus élevées dans l'horizon de surface (0-20 cm) entre un minimum de 252.22 µs/cm et un maximum de 435.55 µs/cm et une moyenne de 320.38 µs/cm confirmant une intense évaporation qui favorise l'accumulation des sels en surface. En outre, les résultats de pH sont entre 7.43, et 7.66. Les résultats de $CaCO_3$ montrent une alcalinité dans l'horizon profond (40-60 cm), liées aux processus d'accumulation du calcaire. Cette étude met en évidence la nécessité d'ajuster les volumes d'eau d'irrigation et d'installer un système de drainage performant pour limiter la salinisation des horizons racinaires de la palmeraie.

Mots-clés : Oued Righ, Continental Intercalaire, sol irrigué, Algérie, Écosystème saharien.

ملخص:

في المنطقة القاحلة بالمغير، يمكن أن يشكّل استخدام المياه الحرارية المستمدة من طبقة المياه الجوفية القارية (CI) في عملية الري مخاطر جسيمة تؤدي إلى تدهور التربة. تهدف هذه الدراسة إلى تقييم الديناميكية العمودية لثلاثة مؤشرات رئيسية لملوحة التربة، وهي: الأس الهيدروجيني (pH)، والموصلية الكهربائية (CE)، ونسبة الكلس الكلي (CaCO3)، وذلك عند ثلاثة أعماق مختلفة من التربة: 0–20 سم، 20–40 سم، و40–60 سم. كشفت نتائج التحليل عن طباقية معدنية واضحة؛ إذ تسجل الموصلية الكهربائية (CE) أعلى قيمها في الأفق السطحي (0–20 سم) بين حد أدنى قدره 16.83 ملغ/كلغ وحد أقصى يصل إلى 21.25 ملغ/كلغ، وبمتوسط يبلغ 18.38 ملغ/كلغ، مما يؤكد حدوث تبخر شديد يحفز تراكم الأملاح على السطح. علاوة على ذلك، تتراوح قيم الأس الهيدروجيني (pH) بين 7.43 و7.66. وتظهر نتائج الكلس الكلي (CaCO3) قلوية في الأفق العميق (40–60 سم) ترتبط بعمليات تراكم الكلس. وتخلص هذه الدراسة إلى ضرورة ضبط كميات مياه الري وتثبيت نظام صرف زراعي عالي الكفاءة لتصريف فائض مياه هذه الطبقة الجوفية، وذلك للحد من تملح الآفاق الجذرية في واحة النخيل.

.الكلمات المفتاحية: وادي ريغ، القارة الداخلية، التربة المروية، الجزائر، النظام البيئي الصحراوي

TABLE OF CONTENTS

Dedication ....

Acknowledgments ....

TABLE OF CONTENTS...

List of Tables ....

General Introduction ....

General Introduction ....

Bibliography Section ....

Chapter 01

current state of water resources

1.General information on the current state of water resources 4

2. water cycle 4

3. Types of conventional water 6

4.National potable water distribution.. 7

5. Global water distribution 8

6. Water shortage in Algeria 9

7 -Relationship between water and climate change 10

8. Economy on scarcity... 10

Chapter 2

General characters of the Continental Intercalary

1.Continental Intercalary in Southeastern Algeria.. 14

2-1-Quaternary Period 14

2-2-Tertiary Period... 14

2-2-1: Eocene Stage 14

2-2-2-Miocene Stage.. 15

2-3-Secondary Era 15

2-3-1-Lower Cretaceous 15

2-3-1-1-Albian 15
2-3-2-Upper Cretaceous 15
2-3-2-1-Cenomanian 15
2-3-2-2-Sénonian 16
2-3-2-2-1-Senonian Lagunaire 16
2-3-2-2-2- Carbonate Senonian 16
3. Hydrogeological contexte: 17
3-1-Groundwater 19
3-2. Terminal complex Aquifer (TC) 20
3-3- Continental Intercalary (CI) Aquifer 20

Chapter 3: Practical Section

Materials and Methodes

1. Presentation of the study area 24
1.1 Climate of the study region 25
1.2 Pedological characteristics 25
1.3 Hydrogeological context 25
2 .Sampling method 26
2.1 Area selection and disturbed soil sampling 26
3 Sample preparation and conservation 29
4. Used materials 30
4.1 Soil analysis methods 30
5 .Analysis parameters 32
6. Statistical analysis 32
Results and discussions……………………………………………………………………..
General Conclusion……………………………………………………………………..
References....…………………………………………………………………...............………
list of Annex……………………………………………………………………….................

List of figures

Figurer (01): the image illustrates the water cycle and its stages (Administration, 2023).....................5
Figure (02): A hydrogeological profile of south-eastern Algeria,(G.S. Abani & Keltoum, 2023). 18
Figure (03) : Groundwater recharge area and the direction of groundwater flow,(M. Coté, 2006).....19
Figure (04). Location of El-M'Ghair Wilaya in Algeria. Source: adapted map, 2026.........................24
Figure (05). Soil profile opening. Source: fieldwork, 23 April 2026. 26
Figure (06). Soil sampling at depth. Source: fieldwork, 23 April 2026. 26
Figure (07). Sampling depth check. Source: fieldwork, 23 April 2026. 27
Figure (08). Field weighing of soil. Source: fieldwork, 23 April 2026. 27
Figure (09) Sample transfer to a bag. Source: fieldwork, 23 April 2026. 27
Figure (10) Labelled samples before transport. Source: fieldwork, 23 April 2026. 27
Figure (11). sampling os soil depths...28
Figure (12) Core dimension verification. Source: fieldwork, 28 April 2026......................................28
Figure (13) Bulk-density field weighing. Source: fieldwork, 28 April 2026......................................28
Figure (14) Soil sample air-drying. Source: laboratory work, 2026...29
Figure (15) Soil sieving through a 2-mm sieve. 29
Figure (16) Labelled soil samples. Source: laboratory work, 2026. 30
Figure (17) Prepared sample conservation.. 30
Figure (18) Soil suspension preparation. 31
Figure (19) Analytical balance weighing.. 31
Figure (20) Soil extract handling.. 31
Figure (21) Portable pH/EC/TDS 31
Figure (22) : $CaCO_3$ concentration in soil 34
Figure (23): pH concentration in soil 36
Figure (24) : CE concentration in soil 38

List of Tables

Table (01): Water distribution schedule in Algeria (Fanack, 2019). 8
Table (02): Geological context of the Oued Righ,(ANRH, 1993)... 17
Table (03): Hydrogeological formation of the Oued Righ,(ANRH, 1993). 21
Table (04) : the GPS coordinates of the sampling points 47
Table (05) : Soil standards for Potential of Hydrogen.. 47
Table (06) : Soil standards for Electrical Conductivity 48
Table (07): climatic data from the region of El-M'Ghair 49

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 km^2. 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 devoted to a detailed presentation of [missing information].

- The second chapter aims to study the geological and hydrogeological context of the groundwater, and especially the Continental Intercalaire. 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).

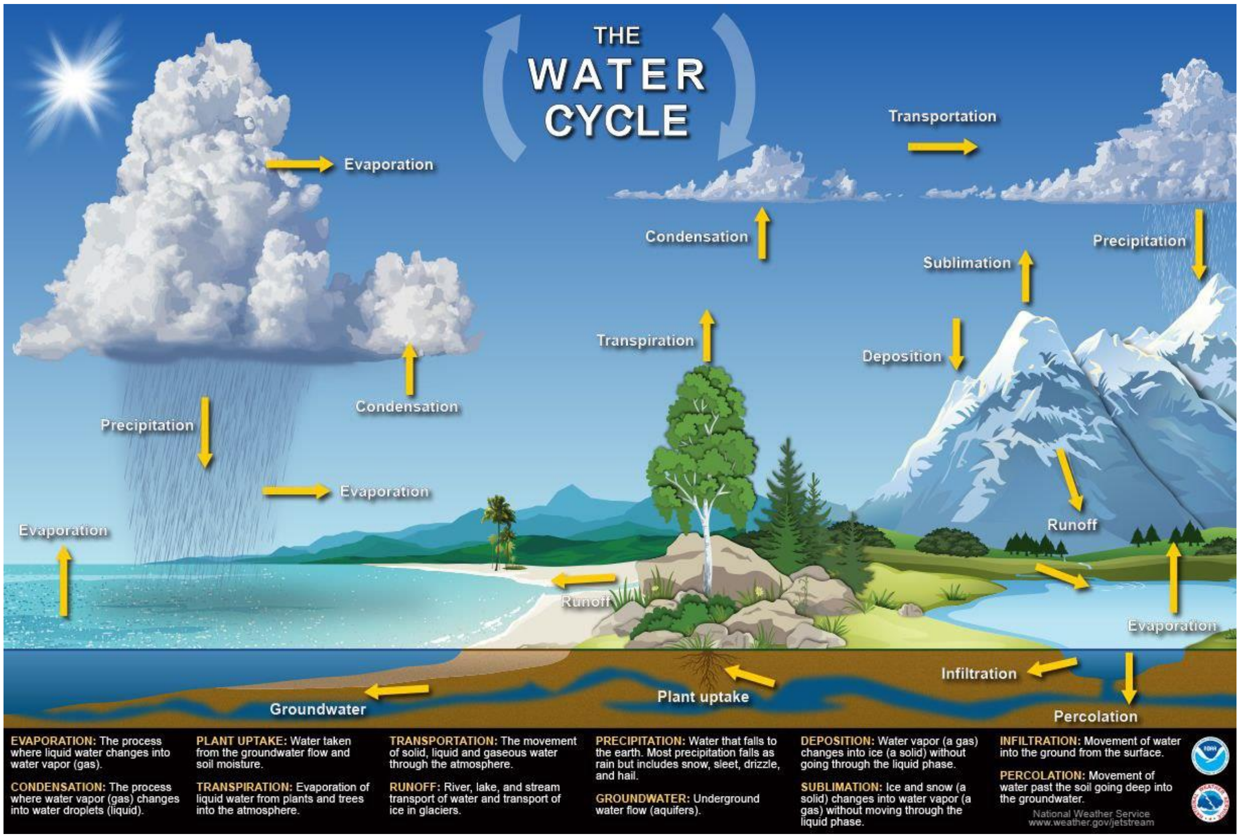
In this context, the first chapter of this study aims to provide an overview of the global distribution of water resources and an understanding of the mechanisms and components of the hydrological cycle, while highlighting the reality of water scarcity and its challenges in Algeria as a case study of 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 (01): Water distribution schedule in Algeria (Fanack, 2019).

National water resource	Size in billion /m³	The area
North and south	11	surface water
North and south	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 (02): 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	1^{st} sand layer (Continental Terminal)
		Semi-permeable
	Pontian	2^{nd} 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

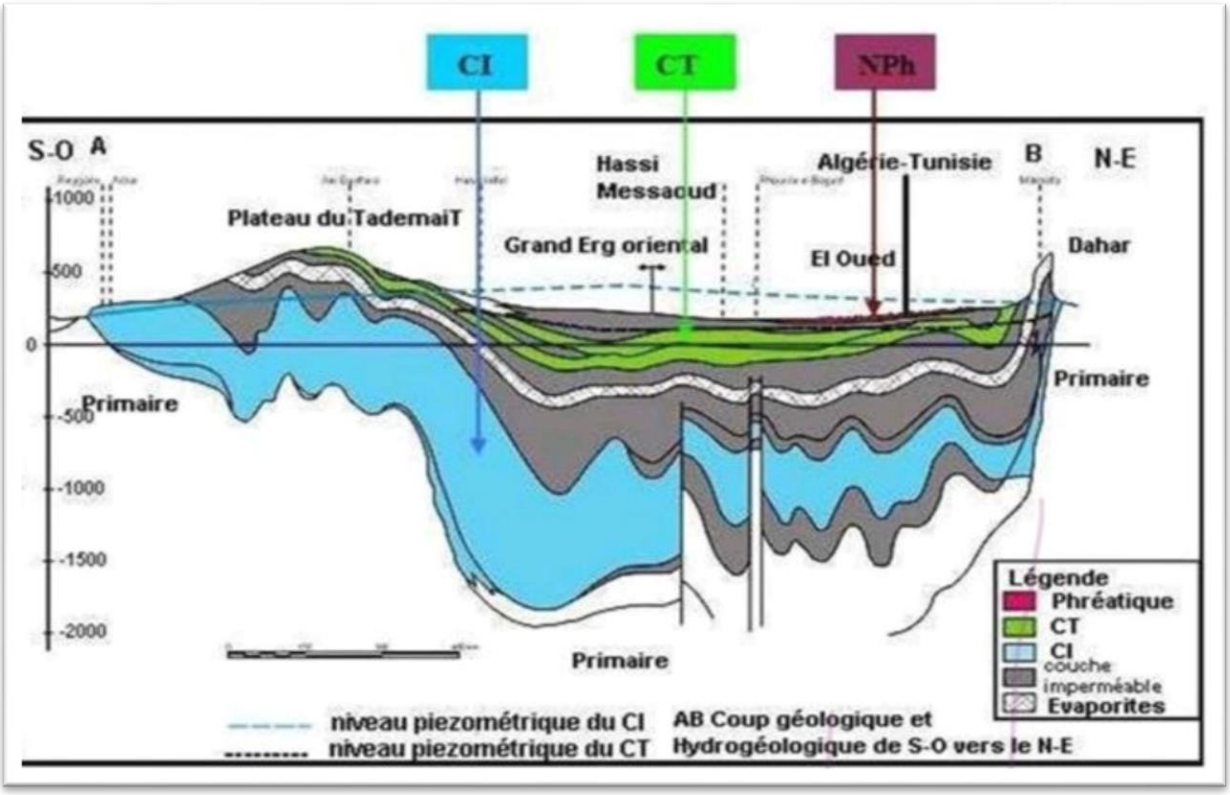


Figure (02): A hydrogeological profile of south-eastern Algeria,(G.S. Abani & Keltoum, 2023).

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.

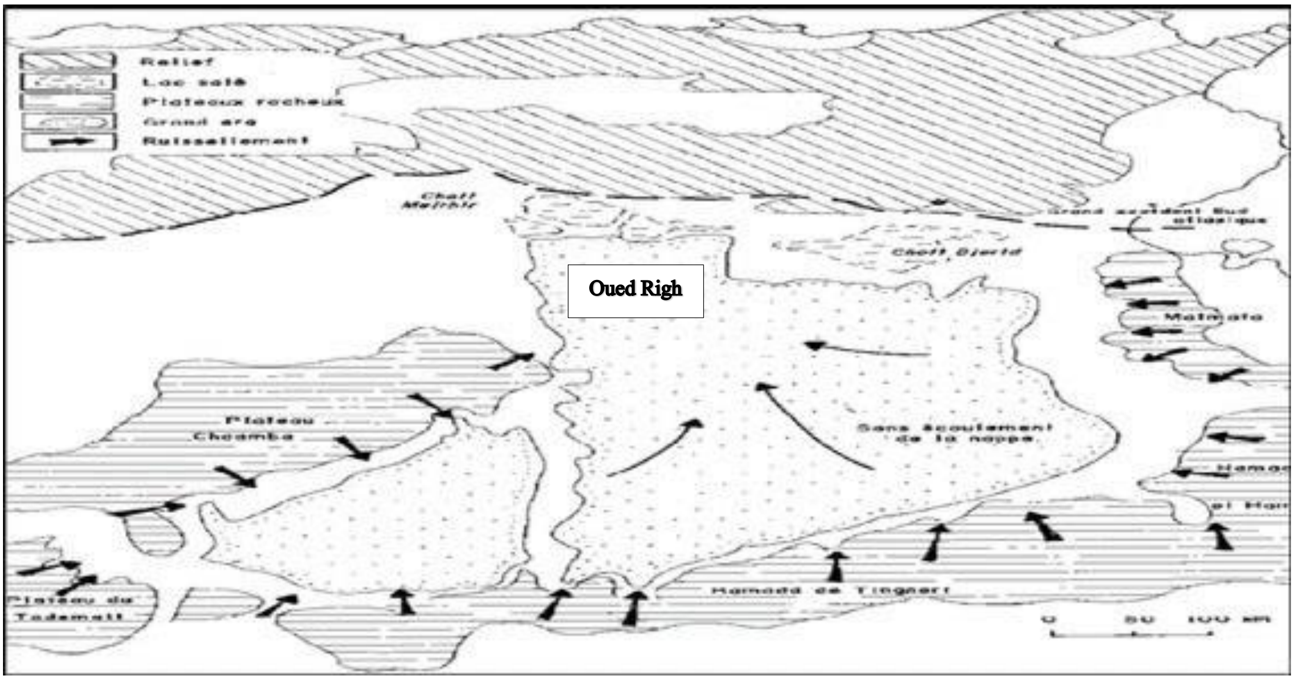


Figure (03) : Groundwater recharge area and the direction of groundwater flow,(M. Coté, 2006).

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 (03): 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. Presentation of the study area

The present study was carried out in El-Merrara Municipality, El-M'Ghair Wilaya, south-eastern Algeria. The study zone belongs to the Saharan agricultural environment of the Oued Righ region, where irrigated agriculture is strongly associated with groundwater exploitation. The selected agricultural plots were chosen to compare soils irrigated with deep groundwater and nearby non-irrigated soils under the same local environmental context.

El-M'Ghair was integrated into the Algerian territorial organization as a wilaya under Law No. 19-12 of 11 December 2019. The investigated area is characterized by oasis-type agriculture, palm groves and cultivated fields distributed within an arid Saharan landscape. In the selected farms, irrigation water is mainly supplied from deep groundwater, corresponding to the Continental Intercalaire aquifer (CI), with a reported depth exceeding 1500 m.

Figure (04). Location of El-M'Ghair Wilaya in Algeria.

Source: adapted map, 2026.

1.1 Climate of the study region

The study region is located in the Algerian Sahara and is therefore dominated by a hot arid to hyper-arid climate. The main climatic constraints are very high summer temperatures, low and irregular rainfall, intense evaporation, and large seasonal variations in water demand. These conditions favor the accumulation of soluble salts in the soil profile when irrigation water contains significant dissolved salts and when leaching is limited.

1.2 Pedological characteristics

The soils observed in the selected fields are typical of Saharan agricultural soils: they are generally light-textured, weakly structured, and poor in organic matter. Their surface condition varies according to irrigation, tillage, salt accumulation and the presence of calcareous or gypsum-related materials. In this context, the comparison between irrigated and non-irrigated soil layers is useful for evaluating the possible impact of long-term irrigation with deep groundwater on soil reaction, salinity, carbonate content and bulk density.

1.3 Hydrogeological context

The agricultural activity of El-Merrara depends largely on groundwater resources. The deep water used for irrigation belongs to the Continental Intercalaire aquifer, a major aquifer system of the Northern Sahara. In southern Algeria, deep sedimentary aquifers are commonly described as fossil groundwater resources with limited modern recharge; therefore, their agricultural use requires careful evaluation of both water quality and soil response.

2 .Sampling method

2.1 Area selection and disturbed soil sampling

A first field trip was conducted on 23 April 2026 in El-Merrara Municipality, El-M'Ghair Wilaya. Four different agricultural fields were selected. In each field, two sampling situations were considered: (i) soil irrigated with deep groundwater and (ii) non-irrigated soil, used as a comparative control. The sampling points were selected randomly within each situation while avoiding visibly disturbed margins, field borders and zones with abnormal accumulation of plant residues.

For each field and each irrigation situation, three successive soil depths were sampled: 0-20 cm, 20-40 cm and 40-60 cm. Thus, each field provided six disturbed soil samples: three from the irrigated part and three from the non-irrigated part. The total number of disturbed soil samples was therefore 24 samples, according to the design shown in Table I.1.

The following figures present the practical work in the studied filed.

Figure (05). Soil profile opening.
Source: fieldwork, 23 April 2026.

Figure (06). Soil sampling at depth.
Source: fieldwork, 23 April 2026.

Figure (07). Sampling depth check.
Source: fieldwork, 23 April 2026.

Figure (08). Field weighing of soil.
Source: fieldwork, 23 April 2026.

Figure (09) Sample transfer to a bag.
Source: fieldwork, 23 April 2026.

Figure (10) Labelled samples before transport.
Source: fieldwork, 23 April 2026.

Figure (11). sampling os soil depths

Figure (12) Core dimension verification.

Source: fieldwork, 28 April 2026.

Figure (13) Bulk-density field weighing.

Source: fieldwork, 28 April 2026.

3 Sample preparation and conservation

After transport from the field, soil samples were spread in a clean and dry place and air-dried at room temperature. The dried samples were gently disaggregated without grinding the mineral particles. Coarse plant residues, stones and visible impurities were removed manually. The samples were then passed through a 2-mm sieve to obtain the fine-earth fraction used for physicochemical analyses.

After sieving, samples were packed in clean labelled paper bags in order to limit contamination and reduce possible changes in sample properties during conservation. Each label contained the field number, irrigation situation, depth and sampling date. The prepared samples were then transferred to the appropriate laboratories for analysis.

Sample preparation and conservation Figuregraphs

. Figure (14) Soil sample air-drying. Source: laboratory work, 2026

Figure (15) Soil sieving through a 2-mm sieve.

Figure (16) Labelled soil samples. Source: laboratory work, 2026.

Figure (17) Prepared sample conservation..

4. Used materials

Field sampling and laboratory preparation required different tools and devices. Field work used a shovel, hand tools, measuring tape, ruler, labelled bags, permanent marker, portable balance, and cylindrical metal cores for bulk density. Laboratory preparation and analyses used a 2-mm sieve, analytical balance, beakers, graduated cylinders, pipettes, filter paper, magnetic stirrer, oven, pH/EC meter and the devices available in the Commerce Laboratory for CaCO3 and bulk density measurements.

4.1 Soil analysis methods

Paramètre	Appareil	Méthode de travail
	Physical analysis	
pH (Potential of hydrogen)	pH-mètre	NF ISO 1039
CE (Electrical conductivity)	Conductimètre	NF ISO 1039
	Chemical analysis	
$CaCO_3$ (Total carbon)	Calcimeter	NF ISO 10693

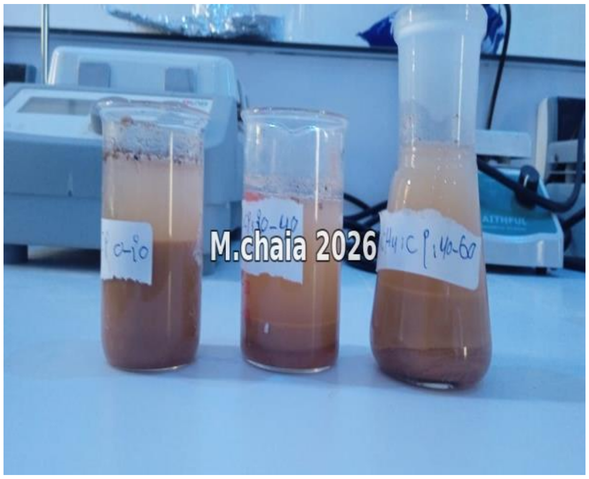


Figure (18) Soil suspension preparation.

Figure (19) Analytical balance weighing..

Figure (20) Soil extract handling..

Figure (21) Portable pH/EC/TDS .

5 .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: pH, CE, $CaCO_3$ are carried out at the analytical laboratories.

The number of samples and the types of analyses and choosen parametres 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.

6. Statistical analysis

The Microsoft Excel software was used to organize, process and visualize the raw data collected during the analyses. The measured parameters (pH, CE, $CaCO_3$) 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.

Results and discussions

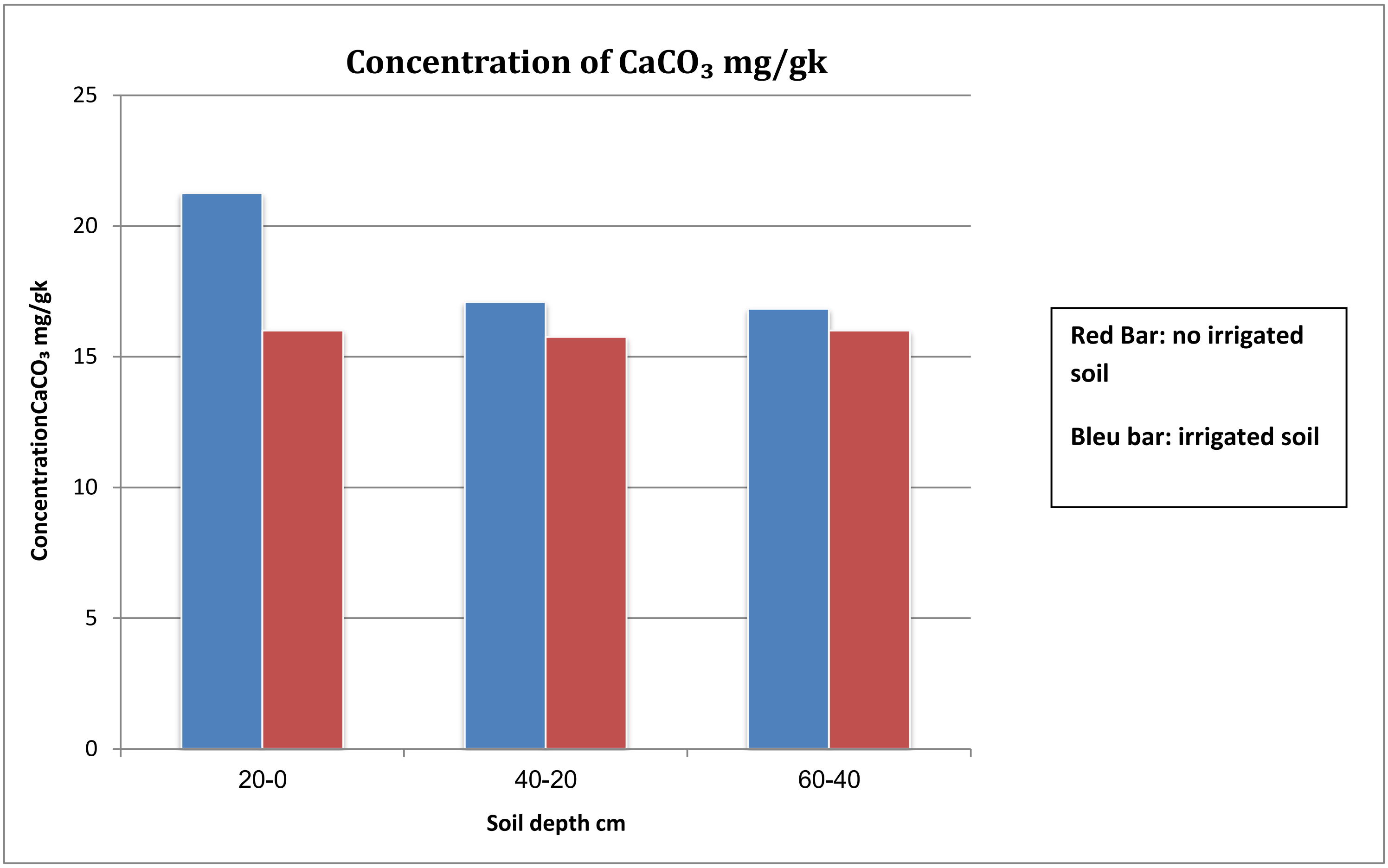


Figure (22) : $CaCO_3$ concentration in soil

The results of the soil analysis, as shown in Figure 5, reveal the following results: Depth 0 to 20 cm: A significant increase in $CaCo_3$ concentration was observed in irrigated soil with an average value of 18.38 g/kg compared to non-irrigated soil with an average value of 15.91 g/kg.

The results showed at depth 20 to 40 cm, the comparison of calcium $CaCo_3$ concentrations in irrigated soil reveals a slight increase over non-irrigated soil we noticed at the depth from 40 to 60 cm, a decrease in the concentration of calcium $CaCo_3$ in soils that received irrigation and those that did not receive irrigation. at this depth, we observed that the minimum concentration was 16.83 g/kg, and the maximum concentration was 21.25 g/kg for the irrigated soil. In addition, for the non-irrigated soil, the minimum concentration was 15.75 g/kg, and the maximum concentration was 16 mg/k

Across all three depth intervals, $CaCo_3$ 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 soils, $CaCo_3$ concentrations display a non-monotonic pattern with depths variable. We observed a moderate concentration at 0–20 cm (≈ 21 mg/kg).Also, we noticed a notable decrease at depth 20–40 cm (≈ 17mg/kg), and a marked increase at the depth 40–60 cm (≈ 16 g/kg), which constituted the lowest value across all depths presented in the figure.

Within the non-irrigated treatment, $CaCo_3$ concentrations are comparatively lower and show less pronounced variation across depths , with 16 mg/kg in the depth 0-20 cm. The depth 20–40 cm Its concentration was 15 g/kg. So, we recorded a slight decrease compared to the surface layer. For the depth of 40–60 cm, we recorded a concentration of 15 g/kg equal to that of the middle and last layers, which represents the lowest value within non-irrigated soil. Furthermore, the largest difference between irrigated and non-irrigated $CaCo_3$ concentrations was observed at a depth interval of 0–20 cm with a difference of about 5.25 g/kg, while the smallest difference was recorded at a soil depth of 40–60 cm.

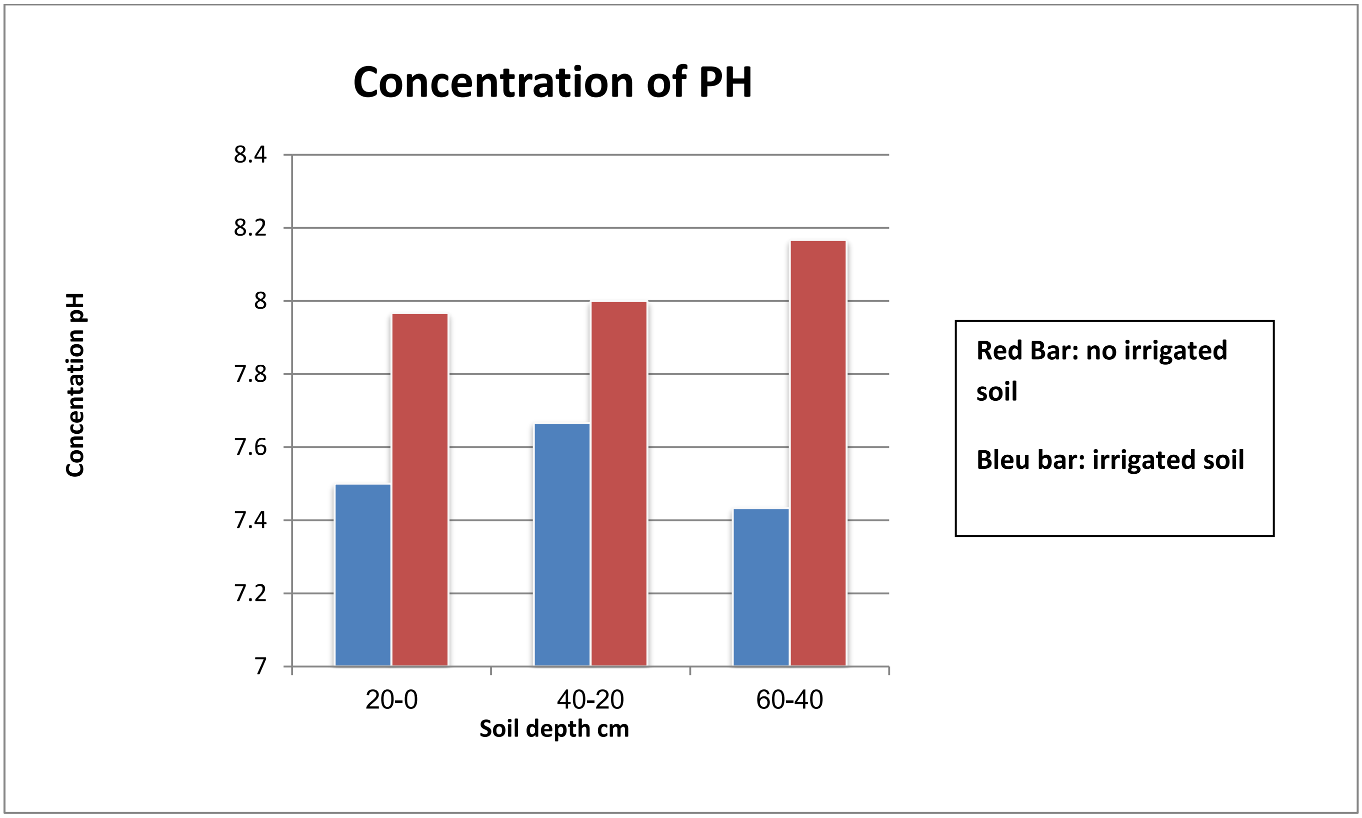


Figure (23): pH concentration in soil

The results of the pH in soil analysis (Figure 6), as shown in Figure, reveal the following results:

Depth from 0 to 20 cm: A significant decrease in pH concentration was observed in irrigated soil with an average value of 7.53 compared to non-irrigated soil with an average value of 8.16. Moreover, at the depth 20 to 40 cm, the pH concentrations in non-irrigated soil reveals a slight increase compared to irrigated soil We saw at the depth from 40 to 60 cm a decrease in the concentration of calcium pH. It was observed in soils that received irrigation and an increase in those that did not receive irrigation.

At this depth, we observed that the minimum concentration was 7.43, and the maximum concentration was 7.66 for irrigated soil. For non-irrigated soil, the minimum concentration was 7.96, and the maximum concentration was 8.16

Throughout all three depth, the pH concentrations in non-irrigated soils consistently exceed those recorded in irrigated soils. This difference is observed at every depth without exception.

In addition, within irrigated treatment, pH concentrations show a non-monotonous pattern with variable depths. Moderate concentration was recorded at 0–20 cm with nearly 7.5. We observed a significant decrease at 20–40 cm (≈7.65), and a slight decrease was recorded at 40–60 cm (≈7.45 g/kg), which constitutes the lowest value across all depths shown in the figure11 In non-irrigated treatment, PH concentrations are relatively larger and show more pronounced variation across depths with 7.9 mg/kg at a depth of 0-20 cm. Depth 20–40 cm and concentration ≈7.95. So we recorded a slight increase compared to the surface layer. For a depth of 40–60 cm, we recorded a concentration of 8.2, an increase in concentration compared to the middle and first layers, which represents the highest value within non-irrigated soil. Furthermore, the largest difference between irrigated and non-irrigated PH concentrations was observed at a depth interval of 40–60 cm, while the smallest difference was recorded at a soil depth of 0-20 cm.

Based on the official classification standards of the USDA, the irrigated Soil were Classified as Slightly Alkaline. And the soil no irrigated Soil were Classified as Moderately Alkaline. This is heavily dominated by active calcium carbonate which naturally locks the pH right around the 8.0 to 8.2.

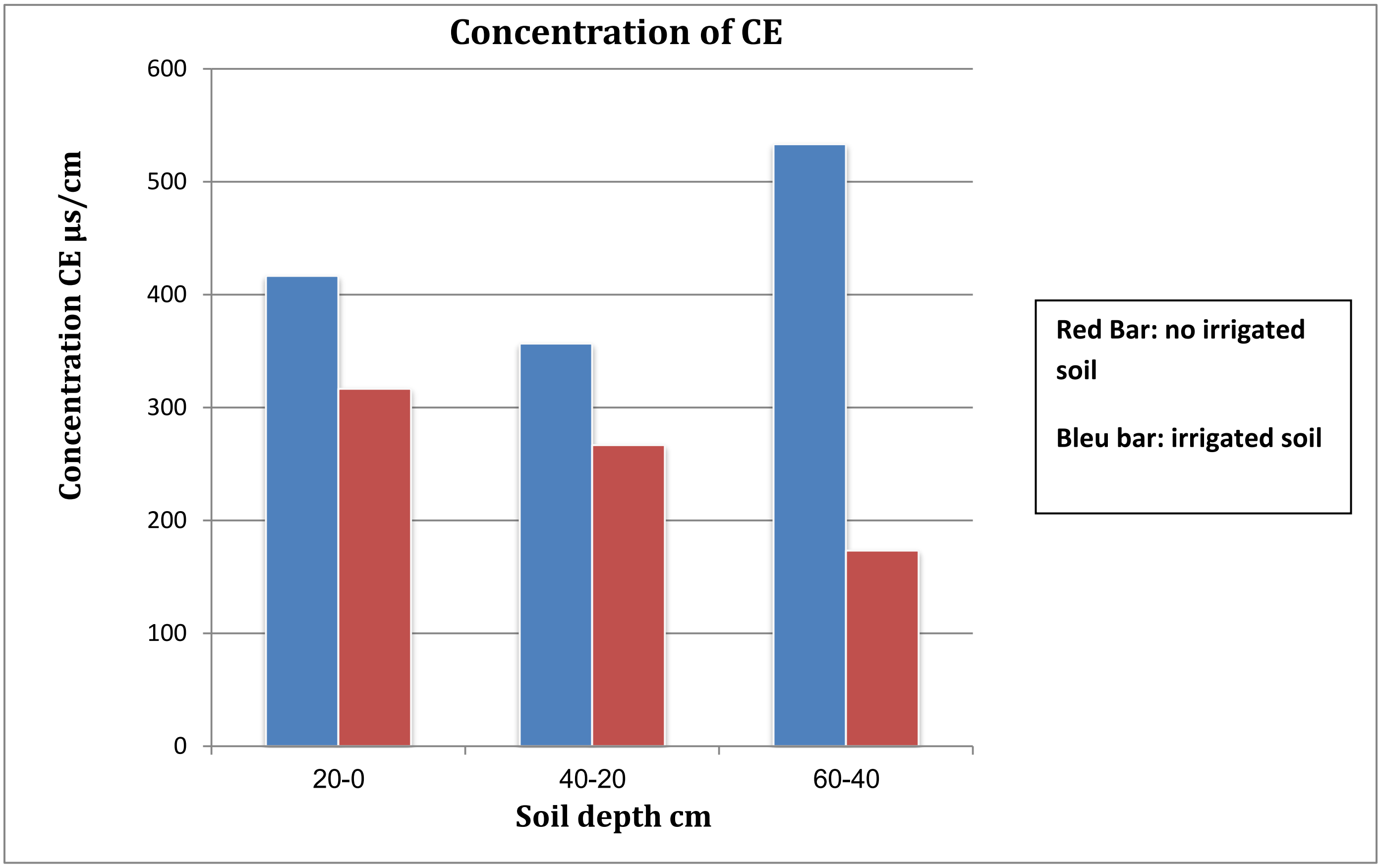


Figure (24) : CE concentration in soil

Our results as shown in Figure 7, reveal the following results: Depth from 0 to 20 cm: A significant increase in CE concentration was observed in irrigated soil with an average value of 435.55 µs/cm compared to non-irrigated soil with an average value of 252.22 µs/cm. Depth 20 to 40 cm: Comparison of CE concentrations in irrigated soil reveals a slight decrease compared to non-irrigated soil Depth from 40 to 60 cm: An increase in CE concentration was observed in irrigated soil compared to non-irrigated soil At this depth, we observed that the minimum concentration was 356.66 µs/cm, and the maximum concentration was 533.33 µs/cm for irrigated soil. For non-irrigated soil, the minimum concentration was 173.33 µs/cm, and the maximum concentration was 316.66 µs/cm Across all three depth periods, CE concentrations in irrigated soil vary consistently with those recorded in non-irrigated soil. This difference is observed at every depth without exception.

In addition, within irrigated treatment, CE concentrations show a non-monotonous pattern with variable depths. A moderate concentration was recorded at 0–20 cm (≈400 µs/cm). We observed a significant decrease at 20–40 cm (≈350 µs/cm), and an increase in concentration was recorded at 40–60 cm (≈525 µs/cm), which constitutes the highest value across all depths shown in Figure

In non-irrigated treatment, CE concentrations are relatively lower and show more pronounced variation across depths of approximately 305 µs/cm) at a depth of 0-20 cm. Depth 20–40 cm and concentration with nearly 260 µs/cm. So we recorded a slight decrease compared to the surface layer .f or a depth of 40–60 cm, we recorded a concentration of(≈ 160 µs/cm), an increase in concentration compared to the middle and first layers, which represents the highest value within non-irrigated soil.

Furthermore, the largest difference between irrigated and non-irrigated CE concentrations was observed at a depth interval of 0–20 cm, while the smallest difference was recorded at a soil depth of 20–40 cm.

Depending to our results compared to the international norms of the United States Department of Agriculture (USDA , we can say that the soil is no saline, making it completely safe and excellent for almost all plants and agricultural crops.

General Conclusion

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. Water from the Continental Intercalaire can have both positive and negative impacts on the soil of El M'Rara.

The current irrigation using Albian borehole water from the 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, resulting in high levels of the following parameters: EC and $CaCO_3$.

The results show that pH values range from a minimum of 7.43, to a maximum of 7.66, at a depth of 0-20cm. The pH and EC coexist because the Saharan climate evaporates water, concentrates salts, and promotes the precipitation of rising limestone.

Our results demonstrate that the electrical conductivity (EC) at a depth of [missing value] cm has a minimum value of 252.22 µs/cm, a maximum value of 435.55 µs/cm , and an average value of 320.38 µs/cm. The variations in EC with depth highlight the dynamics of salt migration. EC at the surface indicates saline upwelling by capillary action, while a concentration at depth indicates leaching induced by water inputs. Ultimately, the increase in EC generates significant osmotic stress for crops, limiting water availability to roots and directly threatening the agricultural sustainability of the Oued Righ area.

The results showed that the $CaCO_3$ concentration were high This element is directly responsible for maintaining a pH generally between 7.5 and 8.5. Limestone acts as a chemical buffer: as long as there is $CaCO_3$ in the soil, the pH remains within alkaline ranges, which directly influences the solubility and availability of nutrients for crops.

Due to the high evaporation typical of the El M'Rara climate, water evaporates rapidly, causing carbonates to precipitate as solid $CaCO_3$. Over time, this can create a limestone crust or a petrocalcic horizon that suffocates roots and blocks water infiltration.

Overall, our results provide constructive information on the use of water from the Continental Intercalaire, particularly in water-scarce areas. They allow for the selection of a specific irrigation environment to maximize the benefits of irrigation and minimize its negative impacts on the soils of the El M'Rara region.

list of Annex

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, namely:

Monitoring the quality of irrigation water and improving the drainage network;

Establishing a monitoring network for groundwater quality;

Store water in open basins to lower its temperature to a level tolerable for the roots of palm trees And underlying crops, ideally below 30C.

References

References

1. Allen, R. G., Pereira, L. S., Raes, D., and Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. Rome: FAO.
2. Bekkari, N. E., Halis, Y., Benhaddya, M. L., and Saker, M. L. (2017). Study of the impact of agricultural activities on the oasis environment of the Oued Righ region. CRSTRA Journal Algérien des Régions Arides, 14, 49-59.
3. Bouchahm, N., Chaib, W., Drouiche, A., Zahi, F., Hamzaoui, W., Salemkour, N., Fekraoui, F., and Djabri, L. (2013). Characterization and mapping of upwelling sites in the Oued Righ region (Algerian Lower Sahara). Algerian Journal of Arid Regions, Special Issue, 76-88.
4. Bouznad, I. E. (2017). Water resources and integrated management in the Oued Righ valley (Northern Algerian Sahara). Doctoral thesis, Badji Mokhtar-Annaba University.
5. British Geological Survey - Earthwise. (2024). Hydrogeology of Algeria.
6. Chemala, O. E. (2006). The status of male date palm trees (Phoenix dactylifera L.) in the Oued Righ region. Engineering thesis, Kasdi Merbah University of Ouargla.
7. Djouadi Bettiche, F. (2011). Research on the human dimension in the conservation of lacustrine ecosystems: the case of Chott Merouane and Oued Khrouf, Meghaier District, El Oued Province, Algeria. Master's thesis, Mohamed Khider University-Biskra.
8. FAO / Global Soil Partnership. Soil bulk density: core method and oven drying at 105 °C.
9. FAO. (2006). Guidelines for soil description. Food and Agriculture Organization of the United Nations.
10. FAO. (n.d.). Management of calcareous soils. FAO Soils Portal.
11. FAO-GLOSOLAN. (2020/2021). Standard operating procedures for soil electrical conductivity and calcium carbonate equivalent.
12. Global Water Partnership. (2000). Integrated Water Resources Management. TAC Background Papers No. 4. Stockholm: GWP.
13. Hammadi, A., Brinis, N., and Djidel, M. (2022). Hydrogeochemical behavior associated with a diverse etiology of high salinity in phreatic water along the Oued Righ valley in the Algerian Sahara. Arabian Journal of Geosciences, 15(12), 1168. https://doi.org/10.1007/s12517-022-10402-0.
14. IPCC. (2013). Climate Change 2013: The Physical Science Basis. Cambridge: Cambridge University Press.

15. Mokhtari, S., Helimi, S., Mihoub, A., and Lakhdari, K. (2016). The Oued Righ River challenged by climate change: what effect on the water needs of the date palm? Agriculture Review, Special Issue 1, 198-204.

16. Official Journal of the Algerian Republic. (2019). Law No. 19-12 of 11 December 2019 amending and supplementing Law No. 84-09 on the territorial organization of the country.

17. Sayah Lembarek, M. (2020). The Oued Righ: Importance, Degradation, and Prospects. Doctoral thesis, Kasdi Merbah University of Ouargla.

18. UNESCO. (1972). Study of the Water Resources of the Northern Sahara. Paris: UNESCO.

19. USDA-NRCS. (2001). Soil Quality Information Sheets: Soil Quality Indicators. Natural Resources Conservation Service.

20. USDA-NRCS. (2011). Soil Quality Indicators: Soil Electrical Conductivity. Natural Resources Conservation Service.

21. USDA-NRCS. (2022). Soil Health - pH. Natural Resources Conservation Service.

22. Zerrouki, F., and Salhi, A. (2017). Hydrogeochemical Characterization of the Continental Intercalaire Aquifer in the Oued Righ Gutter, Northern Sahara. Master's thesis, Department of Earth and Universe Sciences, Abou Bekr Belkaïd University – Tlemcen.

list of Annex

Table (04) : the GPS coordinates of the sampling points

Point	Latitude (N)	Longitude (E)
Irrigated soil	33° 25´ 48.7" N	5° 43´ 00.6" E
Non-irrigated soil	33° 27´ 56.9" N	5° 49´ 54.4" E

Table (05) : Soil standards for Potential of Hydrogen

pH Range	USDA Descriptive Term	Agricultural Implications
< 3.5	Ultra Acid	Severe toxicities; unsuitable for most crops.
3.5 – 4.4	Extremely Acid	Aluminum toxicity heavily restricts root growth.
4.5 – 5.0	Very Strongly Acid	High availability of toxic metals (Al, Mn).
5.1 – 5.5	Strongly Acid	Low phosphorus availability; poor microbial activity.
5.6 – 6.0	Moderately Acid	Suitable for acid-tolerant crops (e.g., potatoes).
6.1 – 6.5	Slightly Acid	Ideal for a high percentage of field crops.
6.6 – 7.3	**Neutral**	**Optimal nutrient availability** and soil biology.
7.4 – 7.8	Slightly Alkaline	Calcium levels are high; minor micronutrient tie-up.
7.9 – 8.4	Moderately Alkaline	Standard calcareous range; iron chlorosis risks.
8.5 – 9.0	Strongly Alkaline	High exchangeable sodium potential (sodic soil risk).
> 9.0	Very Strongly Alkaline	Dispersed soil structure; poor drainage and toxicities.

list of Annex

Table (06) : Soil standards for Electrical Conductivity

EC_{e} (dS/m)	**USDA Salinity Class**	**Crop Growth & Yield Effects**
0 – 2	**Non-saline**	Salinity effects are mostly negligible.
2 – 4	Very Slightly Saline	Yields of highly sensitive crops may be restricted.
4 – 8	Slightly Saline	Yields of many common crops are restricted (defines a saline soil).
8 – 16	Moderately Saline	Only salt-tolerant crops yield satisfactorily.
≥ 16	Strongly Saline	Only a few highly tolerant native plants/halophytes survive.

Table (07): 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