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Department of Water Engineering

With a view to obtaining the **Master's** degree in:

Water engineering

Theme:

Mapping and Characterization of Groundwater in the Plain of Ain Azel, Setif, and its Suitability for Consumption And irrigation

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Gratitude

Above all, we would like to thank **Almighty God** for all the blessings He has given me to do this work.

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Dedication

I dedicate this humble work:

To my mother and father.

To my brothers Hamza, Younes, Salah.

To my sister Nowara.

To two best friends of the world (KERKAR Yacine, FENICHI Mohamed Nadji)

To MY FRIENDS (Gaya et the whole family SAIDI, Mouloud, Moustapha, Salah, Haithem, Ali, Abed star, Ouchen Aymen).

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AMINE

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I Dedicate this Modest Work:

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For their support, their patience, their encouragement throughout my academic and academic career, I hope that they will find in this work all my gratitude and all my love.

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To all those I love.

I dedicate this memory.

NADJI

ملخص

تعد المياه الجوفية الملجأ الاول لسقي الأراضي الزراعية لسكان منطقة عين ازال الواقعة جنوب ولاية سطيف، وفي السنوات الاخيرة عرفت المنطقة موجة جفاف حادة ونقص كبير في كمية الامطار المتساقطة، وهذا أدى الى تراجع في مستوى المياه الجوفية في المنطقة.

الهدف الاول من هذه الدراسة هو معرفة نوعية وصلاحية المياه الجوفية لمنطقة عين ازال بالنسبة للشرب والسقي، اعتمادا على نتائج التحاليل الفيزيائية والكيميائية التي اجرتها مديرية الموارد المائية لولاية سطيف على المياه الجوفية الميوبليوكواترنارية بالمنطقة. وتم إجراء الدراسة من خلال فحص نتائج التحليل الكيميائي لعينات مياه الابار باستخدام المخططات الكيميائية (بايبر وشولر) والطرق التحليلية باستخدام (ستيف وويلكوكس)، وتحليل معايير السقي. واظهرت النتائج ان اغلبية الابار صالحة للاستعمال البشري والسقي باستثناء البعض منها التي تجاوزت قيمها معايير الشرب والسقي الموصى بها

الهدف الثاني من الدراسة هو معرفة كيفية توزيع العناصر الكيميائية والفيزيائية في سهل عين ازال ومقارنتها مع المعايير المحلية بالنسبة للصحة العامة والسقي. ولضمان هذا اعتمدنا على برنامج Arc GIS لرسم الخرائط. واستنادا على الخرائط تمكنا من معرفة توزيع وتمركز جميع عناصر المياه في منطقة دراستنا.

الكلمات المفتاحية: المياه الجوفية، الخرائط، مؤشر الجودة، عين ازال.

Résumé

Les eaux souterraines constituent le premier refuge pour l'irrigation des terres agricoles pour les habitants de la région d'Ain Azel, située au sud de la wilaya de Sétif. Ces dernières années, la région a connu une grave sécheresse et une diminution significative des précipitations, ce qui a entraîné une baisse du niveau des eaux souterraines dans la région.

Le premier objectif de cette étude est de déterminer la qualité et l'aptitude des eaux souterraines de la région d'Ain Azel à la consommation et à l'irrigation, sur la base des résultats d'analyses physiques et chimiques réalisée par la Direction des Ressources en Eau de la Wilaya de Sétif dans la nappe aquifère Mio-Plio-quaternaire de la région. L'étude a été menée en examinant les résultats de l'analyse chimique d'échantillons d'eau des forages à l'aide de diagramme chimiques (Piper et Schuller) et de méthodes d'analyse utilisant Stiff et Wilcox, et en analysant les indices d'irrigation. Les résultats ont montré que la majorité des forages sont conforme à l’usage humain et à l’irrigation, à l’exception de Certains d'entre eux qui ont des valeurs dépassant les normes de consommation et d'arrosage recommandées.

Le deuxième objectif de l'étude est de connaître la répartition des éléments chimiques et physiques dans la plaine d'Ain Azel et de les comparer aux normes internationales et locales en matière de santé publique et d'irrigation. Pour garantir cela, nous nous sommes appuyés sur le logiciel de cartographie Arc GIS. Grâce aux cartes, nous avons pu connaître la répartition et la concentration de tous les paramètres el les indices de l’eau dans notre zone d'étude.

Mots-clés : Eaux souterraines, cartographie, indices de qualité, Ain Azel.

Abstract

Groundwater constitutes the first refuge for the irrigation of agricultural lands for the inhabitants of the Ain Azel region, located in the south of the wilaya of Sétif. In recent years, the region has experienced severe drought and a significant decrease in precipitation, which has led to a decline in groundwater levels in the region.

The first objective of this study is to determine the quality and suitability of groundwater in the Aïn Azel region for consumption and irrigation, based on the results of physical analyzes and chemicals carried out by the Water Resources Directorate of the Province of Sétif in the Mio Plio quaternary aquifer of the region. The study was conducted by examining the results of chemical analysis of well water samples using chemical tables (Piper and Schuller) and analytical methods using (Stiff and Wilcox), and analyzing the irrigation indices. The results showed that the majority of boreholes are suitable for human use and irrigation, except that some of them have values that exceed the recommended consumption and watering standards.

The second objective of the study is to know the distribution of chemical and physical elements in the Ain Azal region and to compare them to international and local standards in public health and irrigation. To ensure this, we relied on ArcGIS mapping software. Thanks to the maps, we were able to know the distribution and concentration of all water elements in our study area.

Key words: Groundwater, cartography, quality index, Ain Azel.

Summary

Chapter II: Hydrology and hydrogeology of the study area

Chapter III: Water suitability for consumption and irrigation

Chapter IV: Groundwater quality mapping

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List of abbreviations

Al: Aluminum.

Cl^-: Chlorides.

Ca^{2+}: Calcium.

° C: Degree Celsius.

CE: Conductivity.

CO_3^{2-}: Carbonate.

Cu: Copper.

RPD: Water Resources Directorate.

Fe^{2+}: Iron.

H_2O: Chemical formula of the water molecule.

HCO_3^-: Bicarbonate.

IB: Ionic balance.

IC: Larson saturation index.

IL: Langelier Index.

IR: Ryznar saturation index.

IQE: Water quality index.

IP: Permeability index.

Kc: Correction coefficient as a function of altitude.

K: Monthly post adjustment coefficient.

K +: Potassium.

KR: Kelly's report.

Mg/l: Milligram per liter.

Mm: Millimeter.

Mn: Manganese.

Mg^{2+}: Magnesium.

Na%: Percentage of sodium**.**

NTU: Unit Turbidity nephelometry.

NO_2^-: Nitrite.

NO_3^-: Nitrate.

Na +: Sodium.

WHO: World Health Organization.

OH^-: Hydroxyl.

P_m: Average monthly precipitation.

P: Average annual precipitation.

Pb: Lead.

PH: Hydrogen potential.

PHs: Hydrogen saturation potential.

PO_4^{3-}: Phosphate.

RSBC: Residual sodium bicarbonate.

SO_4^{2-}: Sulphate.

SAR: Sodium risk index.

SSP: Percentage of soluble sodium**.**

TAC: Complete Alkalimetric title.

TDS: Solid on total.

TH: Hydrometric title.

T °: Temperature.

Zn: Zinc.

λ: Temperature-dependent parameter.

General introduction

General introduction

The importance of groundwater in Algeria is essential, especially in a context where precipitation is often rare and unpredictable. Fresh water sources, such as the Continental Intercalative and the Northern Sahara Terminal Complex, are aquifers that are used for drinking water supply, agricultural irrigation and industry. However, increasing demand for water has led to intensive exploitation of underground reserves, leading to problems such as decreasing groundwater levels, salinization and deterioration of water quality. To address these challenges, Algeria is focusing on implementing sustainable management strategies, such as regulating the exploitation of wells, promoting more environmentally friendly agricultural practices and diversifying sources of energy. water supply.

Groundwater in Algeria plays an essential role in agricultural irrigation and human consumption. They contribute to food supply and provide a drinking water resource in regions where water supply systems are restricted. However, overexploitation has led to difficulties such as decreasing groundwater levels.

Groundwater is very important for drinking water supply and agricultural irrigation in the wilaya of Sétif in Algeria. The Ain Azel plain, in the wilaya of Sétif, is rich in lead and zinc mines, which in turn contain large quantities of groundwater. This posed a major obstacle to mining: several drillings were carried out to reduce the piezometric level in order to continue mining and provide the region with drinking and irrigation water.

This may pose a major threat to people and agriculture. This situation prompts us to ask ourselves: “Is there a danger of mining pollution and degradation of the water quality of the aquifer?” ". Therefore, this research is of great importance, as it will assess the quality of groundwater in the Ain Azel plain region and provide a reference for future studies.

Our dissertation makes a contribution to understanding the hydrochemistry of the Mio-Plio-Quaternary aquifer of the Ain Azel area in this context. The main objectives to be achieved are the assessment of water quality and its ability to be used in different ways.

To finish this dissertation, we completed a four-month internship at the Water Resources Directorate of the State of Sétif, with the aim of acquiring information and facilitating our work.

The Water Resources Department is a national agency whose mission is to preserve and guarantee the rational use of water resources and to enforce regulations on hydraulic management. An office dedicated to underground resources is at the Water Resources Directorate. **[1]**

In order to achieve your objective, your work will be organized into a general introduction and four chapters followed by a general conclusion.

- In the first chapter, we will present an overview of natural water sources, discussing groundwater quality and various criteria for groundwater pollution.
- The geological framework in which we examined the lithology and structure of the terrain is discussed in the second chapter, which focuses on the analysis of climatic parameters. We will also present the hydrogeology of the Mio-Plio-Quaternary aquifer in our study region.
- The objective of the third chapter is to measure the quality and suitability of groundwater in the Ain Azel region for drilling for consumption and irrigation, according to the results of physical and chemical analyzes carried out by the Directorate of Water Resources of the Province of Sétif in 2018. We will use diagram design software for drinking water and irrigation. We will also use The capacity of water to be used for agricultural irrigation in the study area is assessed using essential indices such as SAR, SSP, PI, KR, MR, RSBS and IQE.
- The fourth chapter aims to map the various key elements present in the groundwater of the study region using Geographic Information Systems (GIS) based software, namely ArcGIS.
- Finally, we will conclude in general, in which we will highlight the results we have achieved.

Chapiter I:

Bibliographic research

I.1. Introduction

Water, also known as H_2O, is a molecule composed of two hydrogen atoms and one oxygen atom. It can occur in liquid, solid or gaseous form in different environments and plays a crucial role in life. Groundwater refers to water found beneath the Earth's surface in aquifers and water tables. This groundwater is often caused by rainwater entering the ground. They play a crucial role in supplying wells, springs and regulating watercourses. Groundwater also plays an essential role in many regions for the supply of drinking water. **[2]**

In this chapter, we will give an overview of natural water sources, mentioning Groundwater Quality, and the different criteria of groundwater pollution.

I.2. Natural water sources

There are different natural water reserves: groundwater (infiltration, aquifers), stagnant surface water (lakes, dam reservoirs) or flowing water (rivers, rivers) and sea water. **[3]**

I.2.1. Sea water

The balance between evaporation, rainfall and river inputs on the one hand and water exchanges with other seas or oceans to which they are connected on the other hand is responsible for the salinity observed in the different oceans or seas of the world. It therefore varies considerably. **[4]**

I.2.2. Surface water

Surface waters are surface waters, i.e. rivers, lakes, ponds, oceans and other bodies of water visible on the Earth's surface. Elements such as precipitation, evaporation and runoff influence these waters, and they play a vital role in the hydrological cycle. **[5]**

I.2.3. Underground waters

Below the earth's surface, groundwater tends to descend, depending on the slope of the water table. Like surface water, it flows into streams, lakes and oceans, where it eventually becomes suspended. However, groundwater flow in aquifers beneath watersheds does not always match surface flow. Groundwater can therefore move in directions different from those visible on the surface.

There are three main types of aquifers:

- ✓ Unconfined aquifers (unconfined aquifers);
- ✓ Confined aquifers (confined aquifers);

- ✓ Partially confined or semi-confined aquifers. **[3]**

I.2.3.1. Types of tablecloths

1) Free tablecloth:

The free layers are in contact with the atmosphere. This contact is evaluated based on chemical and geological criteria. It should be noted that a free aquifer is not necessarily exposed to air at the surface, but rather resides in soil that contains air, also known as "unsaturated soil.». Rainwater feeds this aquifer over the entire surface of the aquifer and its level fluctuates under the action of gravity. It is imperative to extract the water by pumping, because it is never under pressure. **[6]**

It is common for unconfined aquifers to be close to the ground surface and therefore more easily accessible. In an aquifer topped by an unsaturated zone, an aquifer is said to be free if its surface can rise and fall freely depending on the inflows and outflows of water. The water table is a free surface water table exploited by a simple well. The surface of unconfined, or unconfined, aquifers corresponds to the level of the water table. **[6]**

- **Water table:**

The water table consists of groundwater that lies at a shallow depth. The water table is formed from the accumulation, in all available and interconnected spaces, of infiltrations from the upper layers, above an impermeable layer which prevents any deeper infiltration. The highest level the water reaches defines the free surface, which represents the level at which water stabilizes in wells reaching the water table. **[6]**

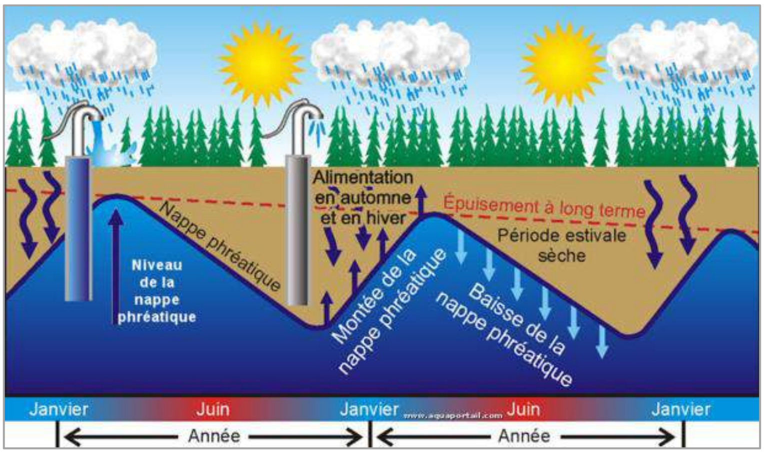

Figure I. 1 : Water table **[7]**

➢ **Alluvial layer:**

An alluvial aquifer is a particular type of free aquifer. These sheets pass through the sediments of the rivers, creating a body of water in the alluvium sites. An alluvial layer is generally linked to a watercourse until it meets an impermeable geological barrier. Part of the water infiltrates to recharge the aquifer when the river level rises rapidly, such as during a flood. **[6]**

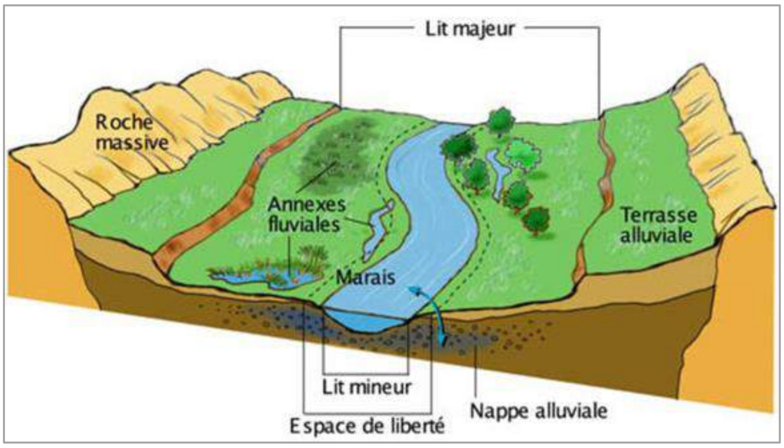

Figure I. 2 : Alluvial sheet **[8]**

➢ **Perched tablecloth:**

A perched aquifer is a specific type of unconfined aquifer. This term is used to describe an aquifer that lies above another free aquifer and can recharge it through drainage. In some cases, there may exist locally in the aquifer material a layer of aquiclude, such as a layer of clay, which acts as a barrier to water, thus allowing the accumulation of a lens of water in the vadose zone. **[6]**

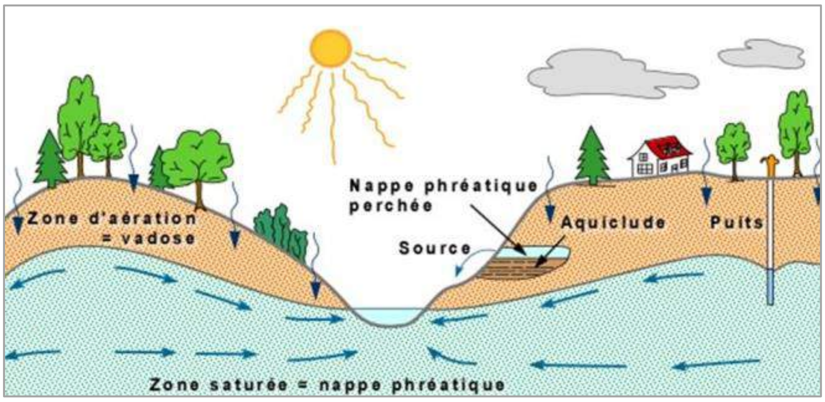

Figure I. 3 : Perched tablecloth **[9]**

2) Captive tablecloth:

The captive layers are located below the surface and are not in direct contact with the air. The adjective "captive" is used to describe an aquifer covered by an impermeable geological layer. Being captive, the waters can flow out if a drilling is carried out. A confined or confined aquifer is generally overlain by a poorly permeable or impermeable formation, resulting in higher than atmospheric pressure on the pore water. When vertical drilling is carried out in such an aquifer through this impermeable layer, water can rise above this layer or gush out. **[6]**

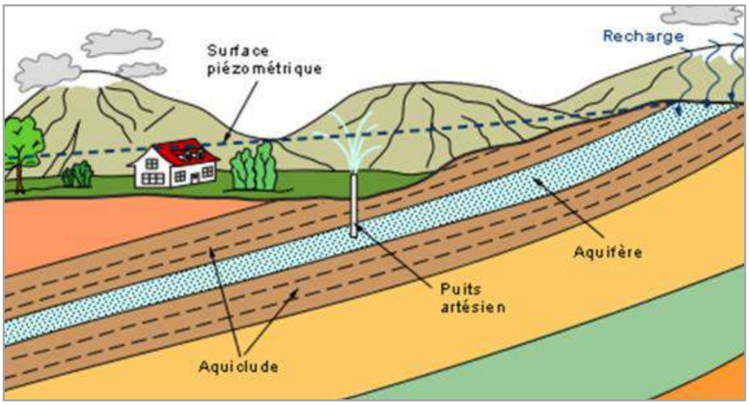

Figure I. 4 : Captive tablecloth **[7]**

3) Partially confined or semi-confined aquifers

They have similarities to confined aquifers, except that the aquitards surrounding them are more permeable and allow the passage of a significant amount of water. They are generally located at greater depths in the ground. The deeper a confined or partially confined aquifer is buried, which provides increased protection against contamination for this aquifer and its water. In a confined aquifer, the movement of water is referred to as artesian flow, while in an unconfined aquifer it is gravity flow. **[6]**

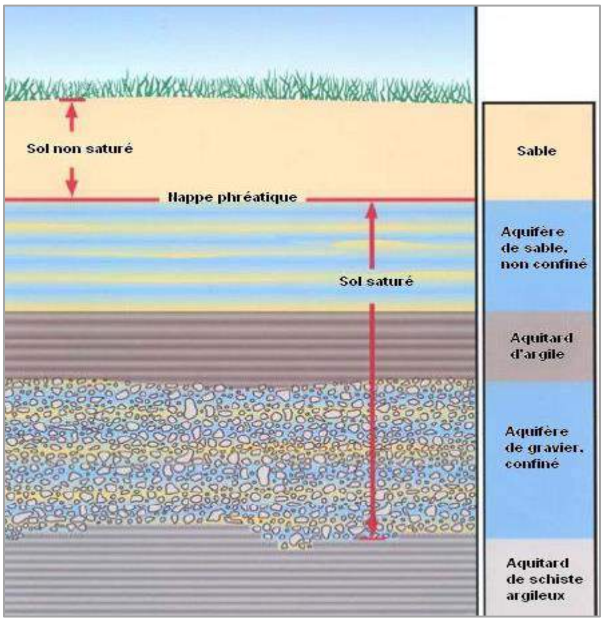

Figure I. 5 : Different aquifers **[10]**

I.3. hydrological cycle

The concept of the hydrological cycle encompasses the processes of circulation and renewal of water on the Earth's surface. According to this definition, the mechanisms that govern the hydrological cycle occur collaboratively. There is therefore no starting point for the hydrological cycle. The elements that make up the water cycle are: (Precipitation, Evaporation, Transpiration, Prevents interception, Runoff or surface runoff, Depression storage, Infiltration, Percolation). **[11]**

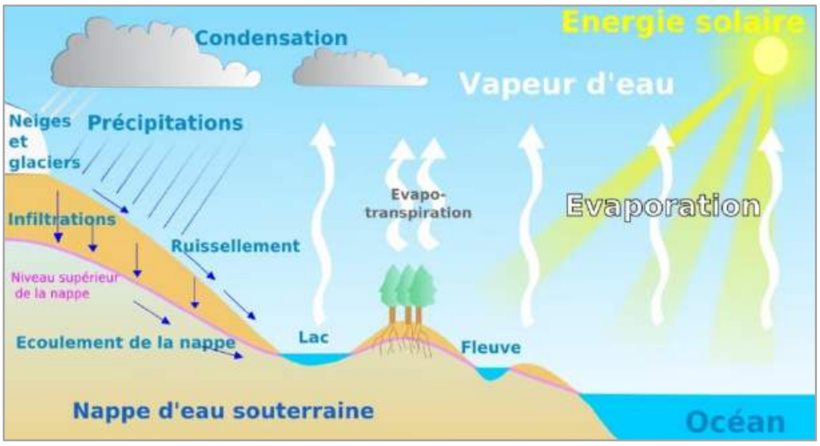

Figure I. 6 : Water cycle **[12]**

I.4. Groundwater quality

Groundwater quality is the result of natural mineralization processes (biogeochemical background) as well as human contributions (pollution).

Groundwater acquires physicochemical properties as it passes through different parts of the water cycle. **[13]**

I.4.1. Groundwater potability parameters

I.4.1.1. Physical parameters

a. Hydrogen potential pH:

The concentration of H+ ions in water is measured by pH (hydrogen potential), which represents the balance between acid and base on a scale of 0 to 14.7, which corresponds to neutral pH. This parameter influences numerous physicochemical balances and is influenced by numerous elements. Hydrogen has a potential energy of 6 to 8.5 in natural waters. **[14]**

b. Temperature:

The increase in water temperature leads to an acceleration in the metabolic activities of aquatic organisms. This parameter is influenced by the ambient temperature and the discharge of thermal wastewater. **[15]**

Thermal power plants constitute the main source of thermal pollution for surface water (70 to 80%), while the rest is associated with the metallurgical, chemical, food industries, etc. **[16]**

c. Hardness:

The hardness or hydrometric titer of water corresponds to the total concentration of metal cations, excluding concentrations of alkali metals and hydrogen ions.

Hardness is mainly caused by calcium and magnesium ions, sometimes with iron and aluminum ions. The quantity of CaCO3 is expressed in milliequivalents. **[17]**

Table I. 1 : Relative degree of water hardness depending on the quantity of calcium carbonate **[18]**

Hardness (Mg / L $^{-1}$in $CaCO_3$)	**Relative degree of hardness**
0 < TH < 50	Very sweet
50 < TH < 100	Sweet
100 < TH < 200	Moderately sweet
200 < TH < 300	Hard
300 and more	Very hard

d. Electrical conductivity:

Water conductivity corresponds to the ability of water to pass through the water column between two metal electrodes, inversely to resistance.

The unit of conductivity varies depending on the total concentration of the ions, their mobility, their valence, their relative concentration and the temperature. For water, we generally use micro siemens per centimeter (μS\cm). **[19]**

Table I. 2 : Relationship between conductivity and mineralization of water **[20]**

Conductivity (μS/Cm)	**Mineralization of water**
EC < 100	Very weak
100 < EC < 200	Weak
200 < EC < 400	Average
400 < EC < 600	Emphasis on average
600 < EC < 1000	Important
EC >1000	High

e. Turbidity:

The opacity of a cloudy medium is the opacity of a liquid, which is the reduction in the transparency of a liquid due to the presence of insoluble substances. The presence of fine suspended matter in the water is responsible for this situation, such as clay, silt, silica particles and microorganisms. A small part of the turbidity can also be attributed to the presence of colloids of organic or mineral origin. **[21]**

Table I. 3 : Class of usual turbidities (NTU, nephelometry, turbidity) **[22]**

NTU<5	Clear water
5<NTU<30	Slightly cloudy water
NTU>50	Troubled Water
NTU>200	Most surface waters in Africa reach this level of turbidity

f. Alkalinity:

The presence of bases in water is responsible for its alkalinity. It is generally caused by hydrogen carbonate, carbonate and hydroxide in natural water. **[23]**

I.4.1.2. Chemical parameters

a) Major ion concentration:

- **Calcium (Ca^{2+}):** Calcium is a divalent ion (Ca^{2+}) that often comes from the dissolution of minerals such as calcite in rocks. It is important for many chemical reactions in water and can influence water hardness.
- **Magnesium (Mg^{2+}):** Magnesium is another divalent ion (Mg^{2+}) that also comes from the dissolution of minerals, particularly minerals such as magnesite. It also contributes to water hardness.
- **Sodium (Na^{+}):** Sodium is a monovalent ion (Na^{+}) that may be present in water due to geological processes or the influence of human activities, such as irrigation with salt water.
- **Potassium (K^{+}):** Potassium is a monovalent ion (K^{+}) that comes from the dissolution of minerals such as potash. Its concentration in water can vary depending on the geological characteristics of the region.
- **Chloride (Cl^{-}):** Chloride is a monovalent ion (Cl^{-}) that can be present in water due to natural processes such as rock erosion, as well as the influence of human activities such as use of de-icing salts.
- **Sulfate (SO_4^{2-}):** Sulfate is an anion (SO_4^{2-}) that comes from the dissolution of sulfide minerals. It may also be present in water due to human activity, such as acid my drainage.
- **Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^{-}):** Carbonate (CO_3^{2-}) and bicarbonate

(HCO_3^-) are anions that can be present in water due to the dissolution of atmospheric carbon dioxide, forming acids carbon dioxide which then reacts with the minerals in the rocks. **[24]**

a) Concentration of minor ions and heavy metals:

- **Iron (Fe):** Iron is an essential element for many biological reactions, but high concentrations can cause taste, odor and color problems in water. Water quality standards set limits for iron due to its adverse effects.
- **Aluminum (Al):** Aluminum can occur naturally in water, but high concentrations can result from industrial processes. Excessive levels may be associated with health problems and adverse environmental effects.
- **Manganese (Mn):** Although manganese is an essential element, high concentrations in water can cause cosmetic problems, such as black or brown discoloration and material deposit in water pipes.
- **Copper (Cu):** Copper is an essential trace mineral, but excessive concentrations can cause health problems, including gastrointestinal upset. It can also be toxic to aquatic life.
- **Zinc (Zn):** Zinc is a trace element necessary for life, but high concentrations can be toxic. Input sources include industrial waste and urban runoff.
- **Lead (Pb):** Lead is a toxic heavy metal, and even low concentrations can be dangerous to your health. Lead exposure is associated with neurological problems, particularly in children. **[25]**

b) Nutrient concentration:

- **Nitrate (NO_3^-):** Nitrates often come from agriculture and can contaminate water sources. High levels of nitrates can be harmful to health, especially in infants, due to conversion to nitrites.
- **Nitrite (NO_2^-):** Nitrites can be formed by the decomposition of nitrates. High levels of nitrites are toxic and can cause methemoglobinemia, also known as blue sickness in infants.
- **Phosphate (PO_4^{3-}):** Phosphates often come from agricultural and urban sources. High levels of phosphates can lead to algae blooms and water quality problems. **[26]**

I.5. Requirements for the quality of water intended for human consumption

Potability standards for drinking water in Algeria were defined by (JORA 2011) concerning the characteristics of prepackaged drinking water and presentation conditions. We have divided these standards into 4 categories:

- ✓ Organic characteristics;
- ✓ Physic-chemical characteristics;
- ✓ Unwanted products;
- ✓ Toxic products. **[27]**

Table I. 4 : Physic-chemical standards for groundwater **[27]**

Physic-chemical parameter	Unit	Algerian Standard
Temperature	˚C	25
pH	/	6.5-9
Electrical conductivity	µs/cm	2800
Turbidity	NTU	5
Dissolved oxygen	Mg. L^{-1}. O^{2}	5
Chlorides	Mg. L^{-1}	500
Total hardness	Mg. L^{-1}in $CaCO^{3}$	200
Calcium	Mg. L^{-1}	200
Magnesium	Mg. L^{-1}	150
Nitrate	Mg. L^{-1}	50
Nitrite	Mg. L^{-1}	0.1

I.6. Groundwater pollution

I.6.1. Causes of groundwater pollution

I.6.1.1. Natural causes

Biodegradable parts of plants and animals mix with water and cause pollution. Bank erosion has caused sedimentation, and this silt is sometimes harmful to aquatic life. Many natural salts and other substances mix with rainwater and eventually fall into rivers and ponds. **[28]**

I.6.1.2. Anthropogenic causes

The main source of pollution comes from human activities. Industrial, agricultural and household waste, as well as the abuse of fertilizers, pesticides, and other chemicals, contribute significantly to this anthropogenic pollution. This contamination has serious repercussions on water quality, making it extremely harmful to both humans and aquatic life. **[28]**

I.6.2. Sources of pollution

The main causes of water pollution include untreated industrial waste, solid waste from urban and commercial areas, municipal sanitation waste, animal feces, use of pesticides and fertilizers, radioactive waste, soil erosion, and riparian areas of rivers. Even the heated water emitted by engines contributes to water pollution. **[28]**

I.6.2.1. Main pollutants

- ✓ Organic liquid discharge;
- ✓ Non-organic waste;
- ✓ Nutrients;
- ✓ Synthetic compounds;
- ✓ Inorganic chemicals;
- ✓ Silt and sedimentary deposits. **[28]**

I.6.3. Type of water pollution

These causes can be divided into two main divisions, namely:

I.6.3.1. Physical pollution

This pollution is mentioned when the environment is altered in its physical structure by different elements. It includes mechanical pollution (solid waste), thermal pollution (heating of water by factories) and atomic pollution (radioelements from nuclear weapons explosions, residues from nuclear installations and consequences of declared nuclear accidents). **[29]**

I.6.3.2. Chemical pollution

It comes from the discharge of industrial waste containing significant quantities of chemical substances, some of which do not degrade. **[30]**

I.6.3.3. Biological pollution

It is a natural process where pollution is caused by the presence of different microorganisms such as bacteria, viruses, parasites, fungi, planktonic blooms, etc. As a general rule, the different types of pollution mix and interact with each other. In fact, there is never a discharge from a single source and the sewers expel waste of different types. **[30]**

I.7. Protection of groundwater resources

It is necessary to implement measures to preserve the quality and quantity of groundwater, as well as to ensure their long-term sustainability. In general, this involves managing human and industrial activities to reduce the risks of contamination and depletion of groundwater and aquifers. Regular monitoring of water quality, adoption of sustainable agricultural and industrial practices, regulation of potentially polluting activities, public awareness and adoption of water treatment technologies are the main strategies for protecting resources in groundwater. **[30]**

I.8. Conclusion

In conclusion, this literature search highlights the crucial importance of natural water sources and groundwater in the hydrological cycle and for global water security. We explored the different types of aquifers, notably groundwater aquifers and alluvial aquifers. Additionally, we examined groundwater quality in detail, highlighting key quality parameters and indicators, as well as potential sources of contamination.

Finally, we identified the different criteria for groundwater pollution. These criteria provide valuable guidance for assessing and monitoring groundwater quality, as well as for designing appropriate protection and restoration measures.

Chapiter II :

Hydrology and hydrogeology of the study area

II.1. Introduction

Land geology is a key factor to consider when studying the chemical composition of groundwater, as it directly influences the processes that determine the quality and composition of that water.

This chapter presents the geographical location, hydrography, climatic and geological framework of the study environment. These elements will help place the aquifer system in the regional context and gather the data necessary to understand the issues addressed during the study. The hydrogeological study makes it possible to complete and confirm geological predictions. This study is crucial to gain an in-depth understanding of the hydrogeological characteristics of various present-day aquifers.

II.2. Presentation of the wilaya of Sétif

The wilaya of Sétif, located in eastern Algeria, extends over an area of 6,549 km² in the high plateau region. Its geographical position is advantageous, being close to several large cities. It is approximately 300 km from the capital Algiers, 120 km from Constantine, and approximately 110 km from the coastal towns of Bejaia and Jijel. In addition, it is 120 km south of the town of M'Sila. The wilaya of Sétif is limited by the wilayas of Bejaia and Jijel to the north, the wilaya of Mila to the east, the wilayas of Batna and Msila to the south and the wilaya of Bordj-Bou-Arreridj to the west. **[1]**

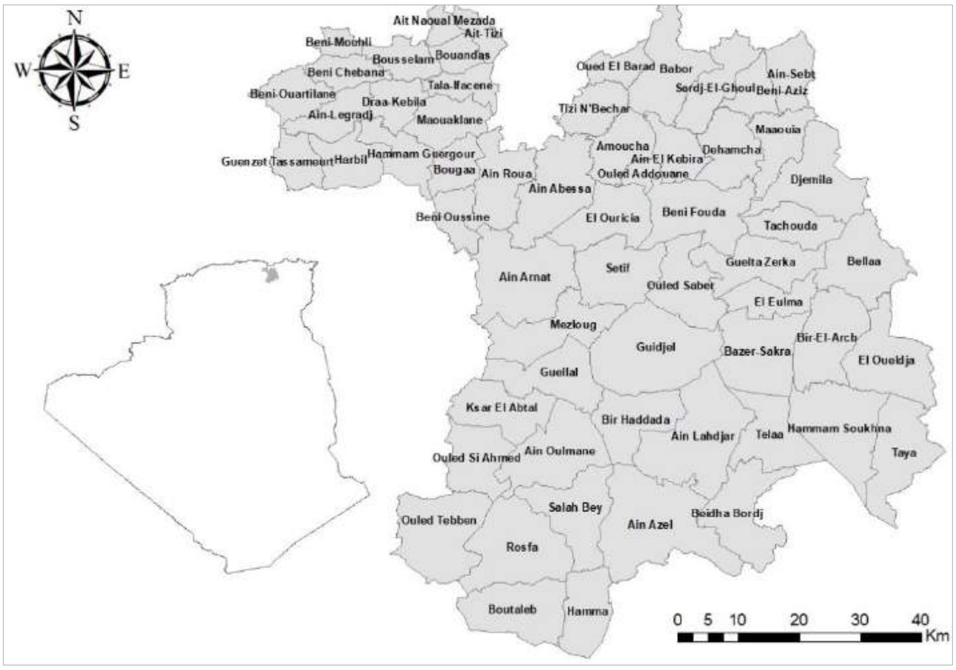

Figure II. 1 : Geographical location of the wilaya of Sétif

II.3. Geographic of the study area

The Ain Azel region is located on a small hill located approximately 50 km south of the capital of the wilaya of Sétif and less than 100 km from the Mediterranean Sea.

This region is found nationally in the north-central part of Algeria. It is part of the southern domain of the Hautes Plaines Sétifiennes and Hodna, located between 35°48' and 35°55' north latitude, 5°27' and 5°33' east longitude and at an altitude of 900 meters.

Two sheets at 1/50,000 are partly covered by this region: n°143 Ain Azel and n° 144 Ain El-Hadjar. It is mainly composed of a plain, oriented NE-SW, which covers an endorheic area of approximately 3000 hectares. Two more or less defined natural and artificial borders surround it, namely the mountainous fault called Kherzet Youcef to the West and Sebkhet El-Hamiet to the North-East. The north, east and south are bordered by main roads and local paths. **[26]**

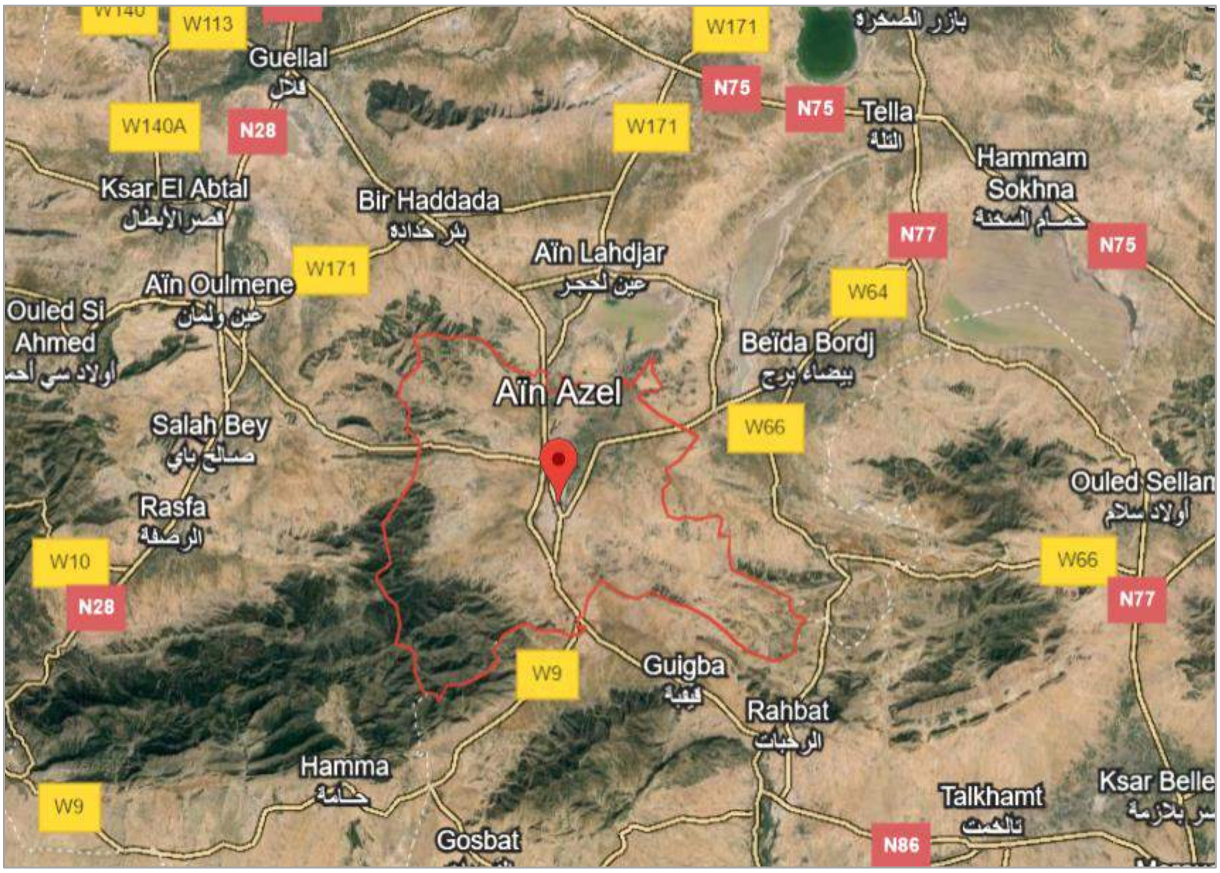

Figure II. 2 : Geographical location of the study area **[32]**

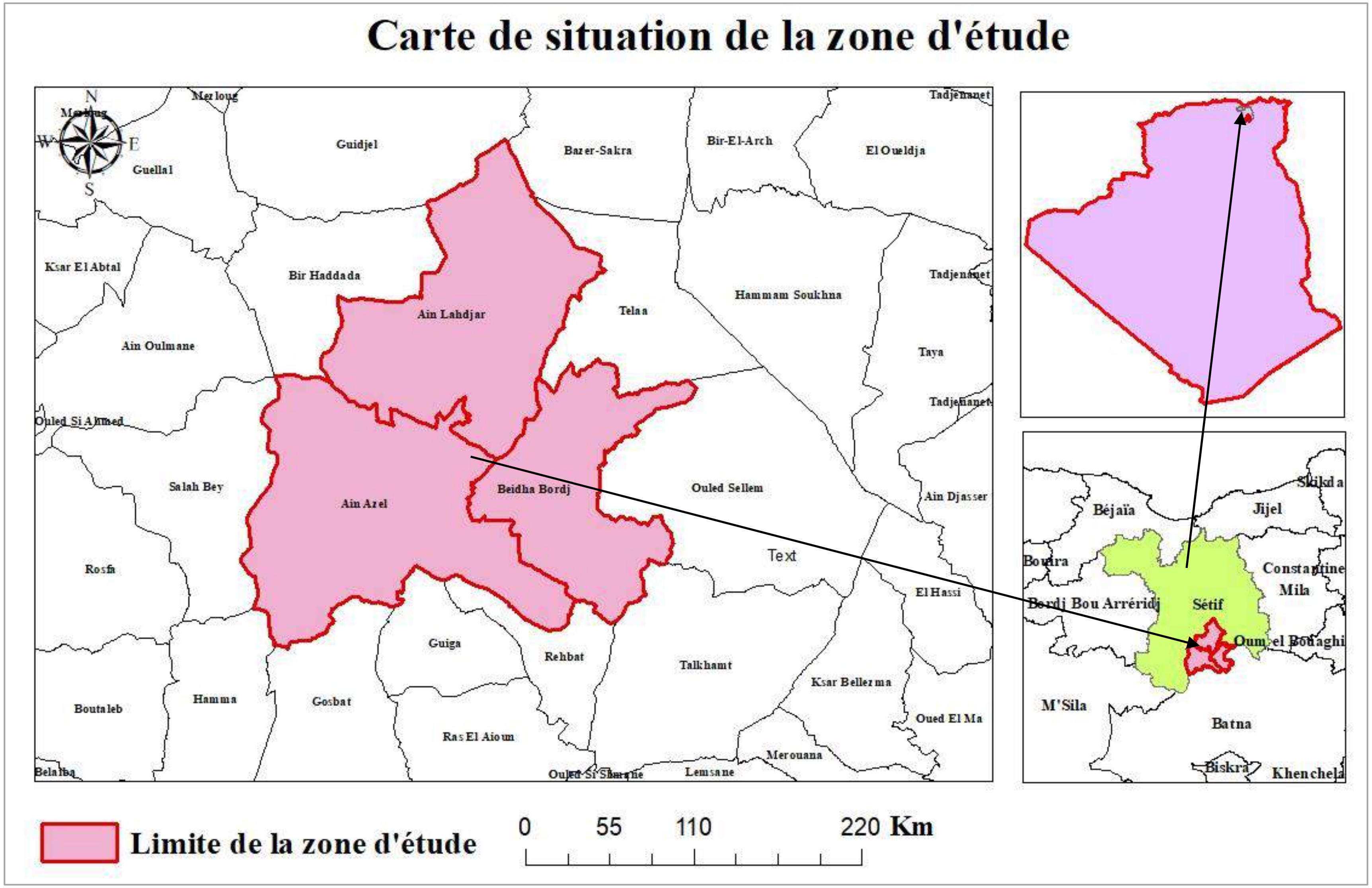

Figure II. 3 : Geographical location of the study region

II.4. Geomorphology

Different chains are present, the most important of which is that of the Hadjar Labiod massif, where the Kherzet Youssef deposit is located. The southern front of Sétif is located to the north of this massif, where Dj. Sekrine and DJ. Youssef are installed. Several mountains (Dj. Boutaleb, Dj. Guétiane, Dj. Debba and Dj. Tzila) and the Fourhal district constitute the northern border of the Hodna Mountains to the south.

Geographically, the study area is made up of the plain which extends between the allochthonous zones of the Djebels Djebbas and Kalaoun in the north and the autochthonous and par autochthonous Hodnean formations on the southern, eastern and western limits, where the Jebels are located. Asmar, Kef Mennchar and Kef Hamara. Several rivers feed this plain. The latter represents the area which seems well watered. **[31]**

II.5. Socio-economic framework of the study area

The Ain Azel region offers a variety of socio-economic activities in a mountainous natural environment favorable to sustainable development and the preservation of forest ecosystems.

II.5.1. Activities and Population

Around 33,000 people live in the Ain Azel region, of whom 3,500 use wooded areas. Agriculture, industry, thermal tourism and the preservation of forest ecosystems and wetlands are part of the region's socio-economic activities. **[33]**

II.5.2. Sustainable development

As part of the sustainable development policy in Sétif, measures are taken to restore steppe zones, preserve biodiversity, enhance forest ecosystems, preserve wetlands, protect historical heritage, manage natural and climatic risks, encourage sustainable economic development, develop the tertiary sector, promote sustainable tourism and revitalize rural areas. **[33]**

II.5.3. Economic Potential

Ain Azel is located in the wilaya of Sétif, which is known for its great economic potential in Algeria. It has strong commercial activity in various sectors and seeks to consolidate its industrial activities while promoting sustainable agricultural and tourism development. **[34]**

II.6. Climate

In a restricted sense, the term "climate" generally refers to the "meteorological average". **[35]**

The climate data comes from the National Meteorological Office, from the Ain Azel station in the wilaya of Sétif in the period 1990-2010.

II.6.1. Precipitation

II.6.1.1. Average monthly precipitation

The monthly average values of precipitation in the Ain Azel region are shown in the following table:

Table II. 1 : Average monthly precipitation at the Ain Azel station (1990-2010 – ONM-Sétif)

Month	Jan	Feb	Mar	Apr	May	June	July	Augst	Sept.	Oct	Nov	Dec
P (mm)	36,2	19,32	27,6	33,13	41,42	13	3,27	6,78	35,71	26,8	21,7	23,4

The table of average monthly precipitation indicates that the Aïn-Azel region experiences a relatively rainy season extending from September to May.

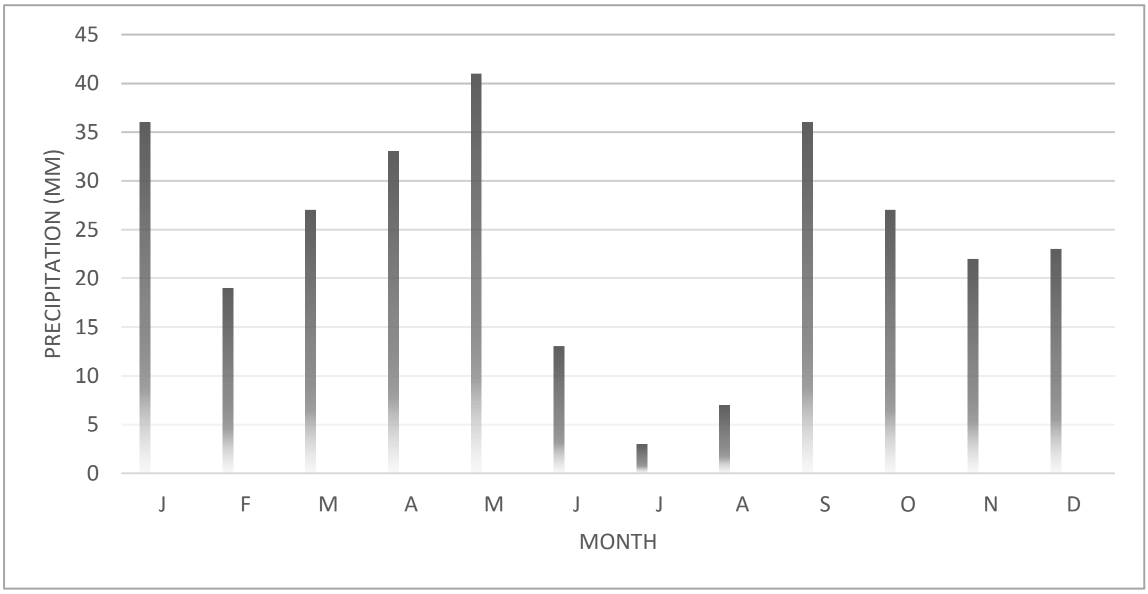

Figure II. 4 : Histogram of average monthly precipitation in Ain Azel (1990-2010)

According to the histogram, the rainiest month for Ain Azel is May. On the other hand, the driest month for the station is July.

II.6.1.2. Average annual precipitation

The annual average values of precipitation in the Ain Azel region are shown in the following table:

Table II. 2 : Annual average precipitation at the Ain Azel station (1990-2010 – ONM-Sétif)

Year	Ain Azel	Year	Ain Azel	Year	Ain Azel
1990	464.39	1997	290.40	2004	403.32
1991	422.13	1998	220.19	2005	227.99
1992	369.75	1999	263.84	2006	355.10
1993	231.08	2000	203.09	2007	354.45
1994	195.34	2001	178.41	2008	185.28
1995	325.47	2002	401.92	2009	60.09
1996	315.27	2003	338.87	2010	220.20

We note that the rainiest year in Ain Azel was 1990 with 464.39 mm, while 2009 recorded only 60.09 mm.

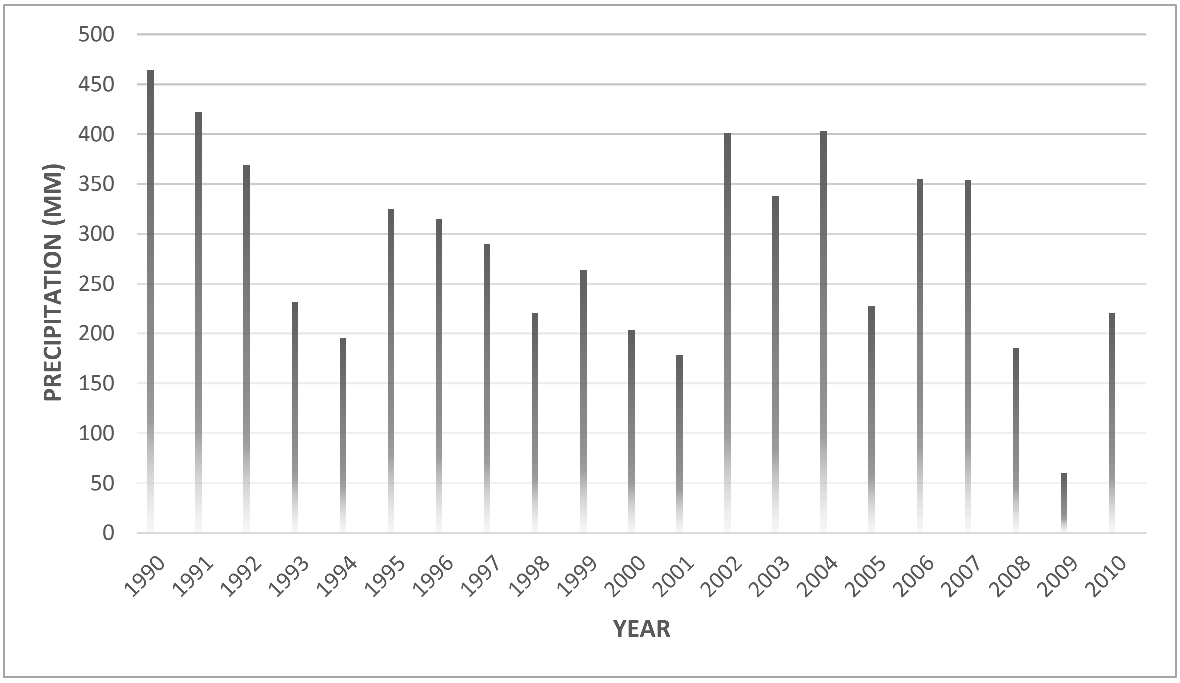

Figure II. 5 : Histogram of average annual precipitation in Ain Azel (1990-2010)

According to this histogram, it is obvious that the rainiest year for the Ain Azel station is 1990.

II.6.1.3. Evaluation of the precipitated water layer

The estimate of the amount of water precipitated on the Ain Azel station in the wilaya of Sétif. By the arithmetic method.

The arithmetic average is a method commonly used to evaluate the volume of precipitated water, particularly in hydrology. Here's how it can be put into practice. The arithmetic measurement allows you to get an idea of the average amount of precipitation during the period studied. This measurement can be beneficial for different analyzes and decisions in hydrology, such as water resources planning, flood risk management, and so on.. **[36]**

$$p_{avr} = \frac{\sum_{i=1}^{N} P_i}{N} \qquad \textbf{II.1}$$

With:

- ✓ P_{avr}: average precipitation in mm;
- ✓ **Pi** : Precipitation recorded in mm;
- ✓ **N**: number of stations.

➢ **Digital Application :**

$$p_{avr} = \frac{\sum_{i=1}^{N} P_i}{N} = \frac{288,33}{1} = 288,33$$

The average precipitation for our region is 288.33 mm

An average precipitation of 288.33 mm provides a general indication of the amount of precipitation the region can expect over a given period, which can have important implications for various aspects of human life and the local ecosystem.

II.6.2. Temperature

Temperature in the context of climate refers to the average of thermal conditions over an extended period of time in a given region. Temperature plays a crucial role in characterizing regional and global climates, and it is influenced by various factors such as latitude, altitude, proximity to water bodies, and the effects of weather phenomena. **[35]**

II.6.2.1. Variations in monthly average temperatures

The following table shows the average monthly temperatures of the study region:

Table II. 3 : Variations in monthly average temperatures in Ain Azel (1990-2010 - ONM Sétif)

Month	Jan	Feb	Mar	Apr	May	June	July	Augst	Sep	Oct	Nov	Dec
T° avr	5.1	6.2	9.6	12.2	16.8	22.6	26.5	25.3	20	16	9.3	5.9

The months of June, July, August and September are the hottest months of the year, with an average annual temperature of 17.93 °C, with an average temperature of 26.9 °C in July and an average temperature of 6.1 °C in January.

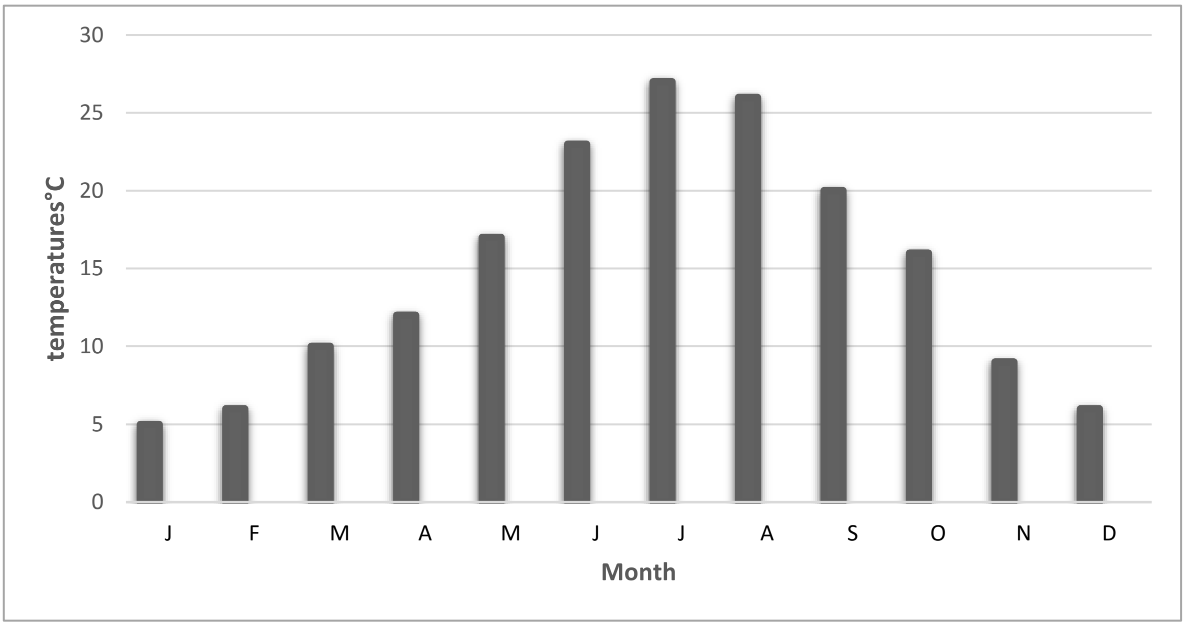

Figure II. 6 : Variation of monthly average temperatures in Ain Azel (1990-2010)

According to the graph, it follows that for both stations, the hottest month is July. However, in both regions, January is the coolest month.

Both stations obtain the same results, with the exception of the Sétif region which is cooler than Ain Azel, but it is a small difference.

II.6.3. Wind

Wind is defined as air in horizontal motion. It is an essential factor in climate and its effects are mainly measured by temperature, evaporation and humidity. Wind direction and speed change in space and time.

The predominant winds during the winter period are those from the West and the North-West. During the summer period, the southerly winds accompany these winds with an annual duration of 25 to 34 days.

The table below shows the average wind speeds recorded at the Aïn-Azel station between 1995 and 2015.

Table II. 4 : Average wind speed at Ain Azel station (1995 - 2015- ONM-Sétif)

Month	Jan	Feb	Mar	Apr	May	June	July	Augst	Sept	Oct	Nov	Déc
Speed (m/s)	4.0	4.2	4.2	5.1	4.8	4.4	4.7	4.5	3.9	3.9	3.9	4.2

April at an average maximum speed of 5.1 m/s, compared to 3.9 m/s for September, October and November.

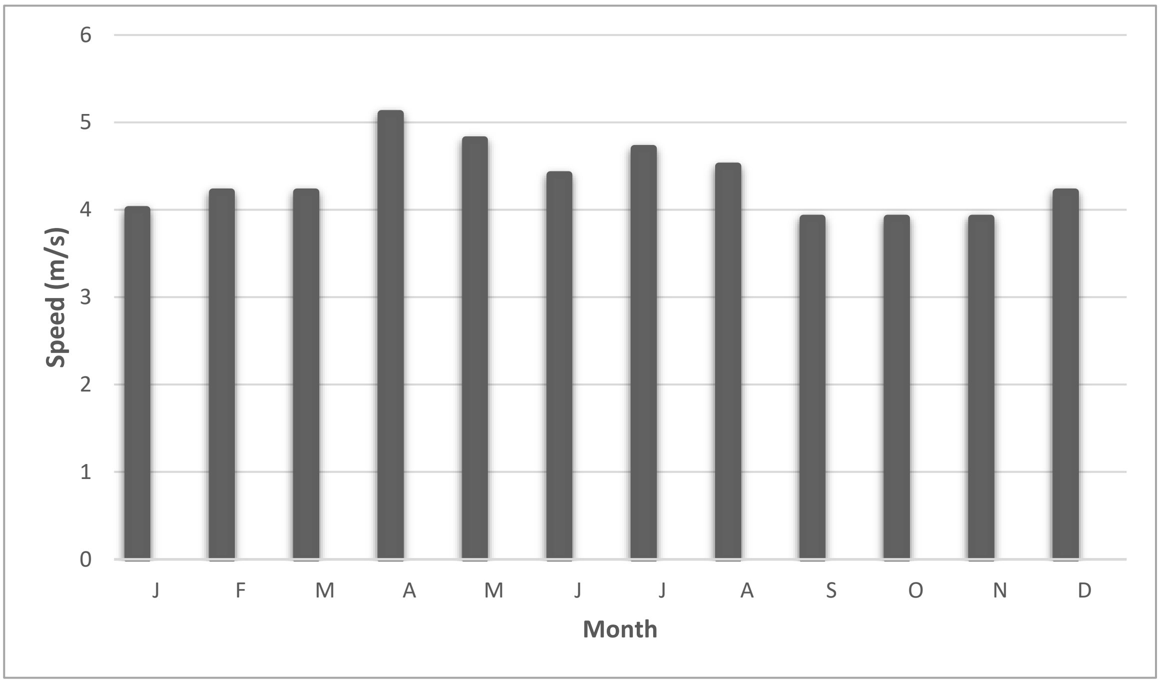

Figure II. 7 : Average wind speed at Ain Azel station (1995 -2015)

According to the graph: September, October and November have respectively 3.9 m/s and 5.1 m/s average maximum speed.

II.6.4. Relative humidity

On average, air humidity in Ain Azel is around 57% this week, with an average of 56% over a fourteen-day period. According to climate data, humidity may vary depending on weather conditions and seasons. It is essential to monitor these humidity levels to assess heat quality and the dangers of significant humidity fluctuations in the area. In Ain Azel, the average humidity rises to around 61% over a 15-day period during the summer. The amount of humidity can fluctuate depending on summer weather conditions. It is crucial to consider this humidity level in order to assess thermal comfort and potential health consequences caused by humidity in this region during the summer months. **[37]**

II.6.5. Evaporation

Insolation in the Ain Azel plain is extremely high, reaching 90% of the theoretical minimum, from 3500 to 4000 hours per year. The climate of the region is very arid, with a very distinct dry season. Climatic instability and aridity can have detrimental consequences on plant resources and lead to soil erosion. In short, the Ain Azel plain is distinguished by high evapotranspiration, which is due to an arid climate, strong insolation and hot winds, making it a particularly dry area. **[38]**

II.7. Geology of the study area

II.7.1. Regional geology

Ain Azel presents a complex regional geology due to its position in the Maghrebid chain and its tectonic history. Since the last century, numerous geological studies have been carried out on the structure, evolution and mineral resources of the Hautes Plaines Sétifiennes.

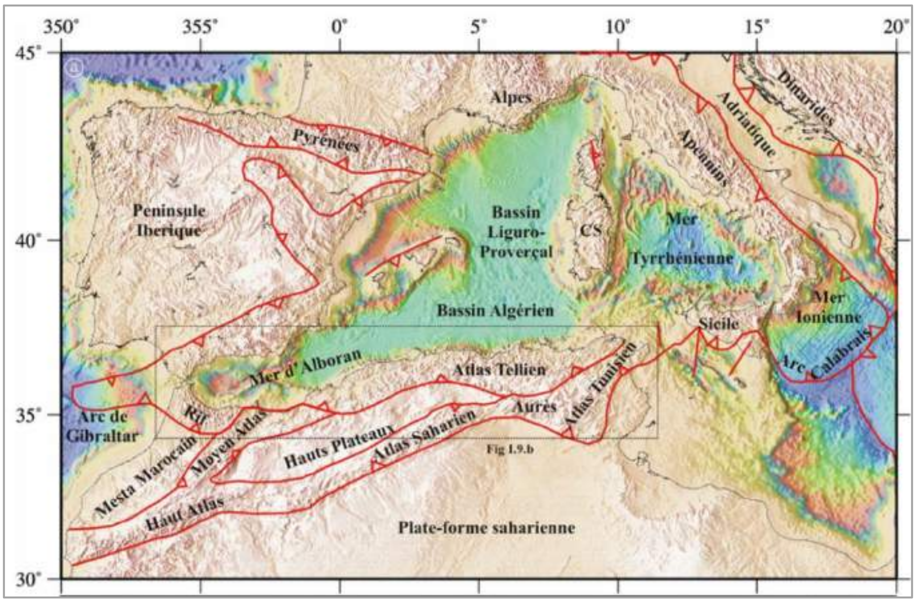

Figure II. 8 : main geological units of the Maghrébides **[39]**

Major mining deposits like that of Chaabet El Hamra have been studied in order to better understand their geology, their structure and the effects that their exploitation has on the environment. Issues such as water pollution caused by mining activity in the region have been highlighted by these studies. **[40]**

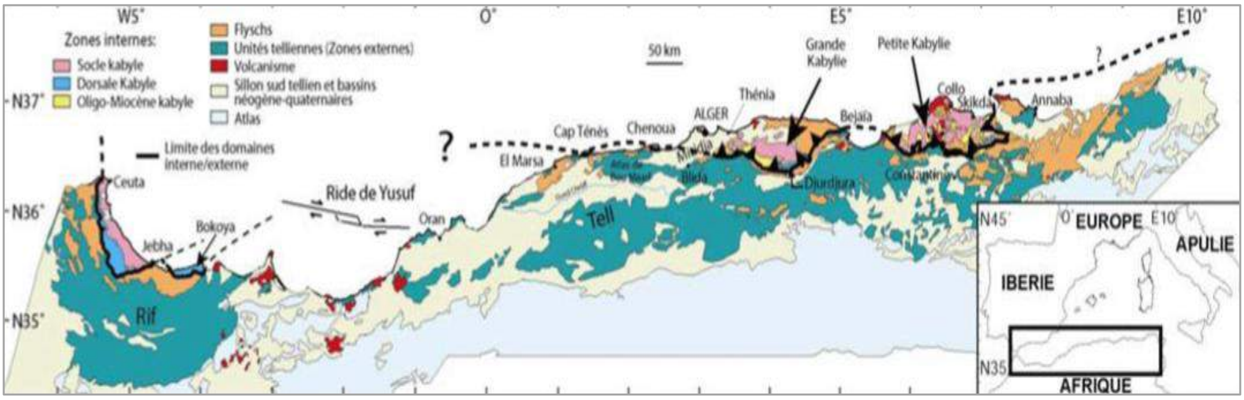

Figure II. 9 : Position of the different geological units of the Maghrébides **[39]**

II.7.1.1. Internal domain

1) Kabyle base

Three distinct lithological sets make up the Kabyle base: a lower crystallophyllian set with gneisses, marbles and amphibolites, an upper crystallophyllian set with satiny schists or phyllades, and a Paleozoic sedimentary set with quartzites, marbles, amphibolites, sericite schists and mica schists. From the Paleozoic to the Upper Oligocene, these geological formations had a complex history. **[41]**

2) Kabyle Dorsal

The Kabyle Dorsal, also called the “limestone chain”, is a key element of the Maghrebid chain in Algeria. It is characterized by sediments dating from the Permian to the Lutetian, including limestones from the Liassic and Eocene, dolomites from the Triassic to the Lower Liassic and sandstones from the Permo-Triassic. The ridge from North to South is divided into three parts: the inner ridge, the middle ridge and the outer ridge. These sections are distinguished by their limestone appearance and density. **[40]**

- **The internal ridge:** The internal ridge is an important part of the region and is part of the Maghrebid chain in Algeria. It is distinguished by a mosaic of sediments from the Permian to the Lutetian, including limestones from the Liassic and Eocene, dolomites from the Triassic to the Lower Liassic and sandstones from the Permo-Triassic. The ridge is divided from north to south into three parts: the inner ridge, the middle ridge and the outer ridge. These segments are distinguished by their appearance and density of limestone. **[42]**

- **The middle dorsal**: which is part of the Maghrebides chain in Algeria, is an important geological element of the area. It is aligned from south to north in the East-West axis ranges, alongside the external and internal ridge. Towards the south, the flysch sheets are overcome by recumbent folds of the middle ridge. Formations ranging from the Rhaetian to the Priabonian, with a crystalline basement flake and Paleozoic terrains at the base of the intermediate ridge units, are part of its series. **[42]**
- **The external backbone:** An important geological part of the region is the outer ridge, which is part of the Maghrebid chain of Algeria. It is characterized by a variety of sedimentary formations ranging from Permian to Lutetian, which include Liassic and Eocene limestones, Triassic to Lower Liassic dolomites, and Permo-Triassic sandstones. Since the Eocene, significant tectonic movements have affected the outer ridge. It is divided into three distinct parts from north to south: the internal dorsal part, the middle part and the external part. These parts differ in their appearance and thickness from the limestones. **[43]**

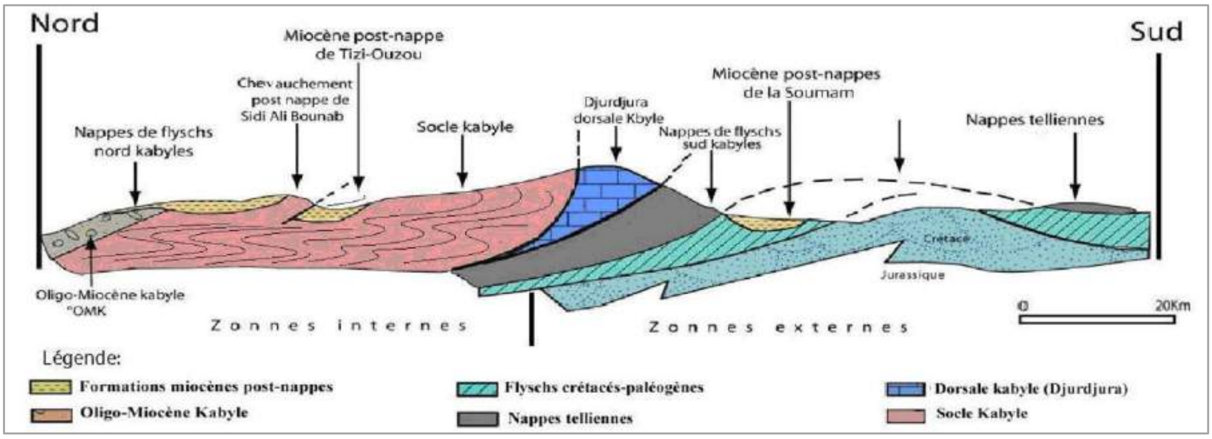

Figure II. 10 : Synthetic section of the central part of the domain telling **[44]**

II.7.1.2. Intermediate domain

The Cretaceous-Paleogene flysch layers crop out over a distance of 800 km between Mostaganem and Bizerte in Tunisia. These are mainly deep sea deposits created by turbidity currents. These flyschs appear in three different ways.

1) Mauritanian Flyschs

Small micrite beds of clayey-sandstone flysch compose the Neocomian flyschoid base complex, with metrical sandstone beds reaching into the Middle Albian. A conglomeratic or micro-conglomeratic limestone of the Vracono-Cenomenanian-Turonian type, with white silicified bands. The Eocene to the Lutetian, bioclastic levels with large foraminifera, with a clay-conglomeratic Senonian and Middle Paleocene. Radiolarites are known locally and reported to Malm. **[45]**

2) Flysch Massylien

A flysch called "Albo – Aptian" is a pelito-quartzitic flysch with a predominantly green color. The summit is composed of fine yellowish Vraconian limestones a few meters thick, black and white phtanites of Cenomanian age and a marl-microbreccia flyschoide ensemble from the Senonian. All sedimentological criteria indicate that the Massylian formations were deposited in a deep zone, probably on an oceanic bedrock. It is common for the Mauritanian flysch to be overcome by the Massylian flysch of more southern origin. **[45]**

3) Numidian Flysch

- ✓ Variously colored clays present in the Tubotomaculum (Late Oligocene) are called sub-Numidian clays;
- ✓ There are also beds of thick sandstone with heterogeneous grains;
- ✓ The clays, marls and flints are known as supra-Numidian. **[45]**

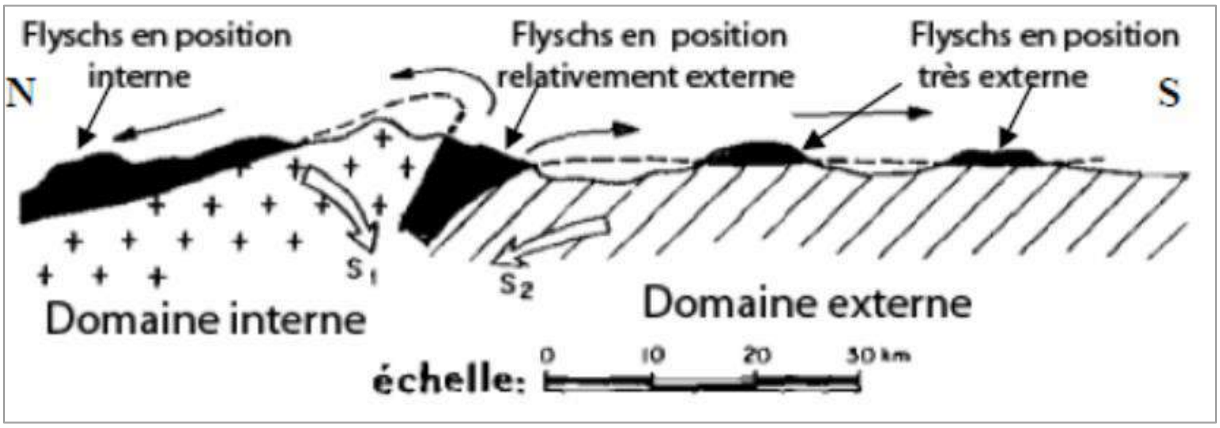

Figure II. 11 : Position of the flyschs in relation to the units of the Maghrébides chain **[46]**

II.7.1.3. External domain

The Tellian domain is made up of a set of allochthonous pellicular layers, mainly composed of marls of Middle Cretaceous to Neogene age, transported towards the South over significant distances. The north is separated from the south.

1) **Ultra-tellian sheets**

The ultra-tellian layers known in eastern Algeria and Tunisia are the bathyal formations from the Cretaceous and Eocene, as well as a more detrital series from the Senonian and Eocene. The characteristics are close to those of Massylian flysch. **[47]**

2) **Tellian sheets sensu-stricto**

The composition of the tellian layers sensu-stricto is composed of platform Lias topped by a marlier Jurassic, then the detrital Cretaceous which becomes marly clay-limestone and finally the Eocene with thick marls. **[47]**

3) **Peni-tellian sheets**

The series of the allochthonous or Tellian foreland, located between the Tellian layers to the North and the autochthonous or para-autochthonous Atlas to the South, are Middle Miocene units that are even more external and of significant, but lesser, allochthony. The series of Djebels Guergour, Anini, Zdimm, Youssef, Braou, Tnoutit, Sékirine, Tafourer, Agmérouel, Zana, Azraouat, Hammam, Ain el Ahdjar, Koudiat Tella and the upper series of Djebel Kalaoun constitute the allochthonous South-Sétifian ensemble, made up of carbonaceous and marly materials dating from the Jurassic to the Miocene. This area is further west. It manifests itself in the form of a large mass of scales restricted by accidents tearing the "Constantin neritic tablecloth". **[47]**

II.7.2. Tectonic phases of the study area

II.7.2.1. Triassic and Lower Jurassic

Tectonic processes had an impact on the Ante-Senonian phase in the Triassic evaporitic formations of the Ain Azel region. It is likely that this phase of compression caused structural deformations which had an impact on the arrangement of the geological layers, which favored the accumulation of salts and gypsum characteristic of Triassic evaporites. The conditions favorable to the precipitation and preservation of these evaporitic minerals in the geological formations of the Ain Azel region could have been created by the tectonic movements associated with this phase. The Lower Jurassic formations present in the Ain Azel region are mainly calcaro-dolomitic facies. **[48]**

II.7.2.2. Upper Jurassic

The calcaro-dolomitic facies and the terrigenous deposits of the Neocomian are Upper Jurassic formations in the Ain Azel region. The geological formations represent the marine and continental environment that prevailed in the region during this period. The Neocomian terrigenous deposits highlight a transition to continental environments with detrital inputs, while the calcareous-dolomitic sediments indicate marine conditions favorable to the precipitation of carbonates. The varied lithologies of the Upper Jurassic show the complex geological evolution of the Ain Azel region during this period. **[49]**

II.7.2.3. Ante-Senonian phase

The Ante-Senonian tectonic period of Ain Azel is characterized by compression which led to East-West oriented folding and strong fracture schistosity. Before the Senonian, a later geological period, this tectonic phase occurred. It caused significant deformations in the local lithosphere and helped shape the geological structure of the region. The Ante-Senonian phase of Ain Azel favored the formation of Triassic evaporitic formations in the region. It is likely that this phase of tectonic compression caused structural deformations which had an impact on the arrangement of the geological layers, which favored the accumulation of salts and gypsum characteristic of Triassic evaporites. **[49]**

II.7.2.4. Tertiary phase

Significant tectonic events marked the Tertiary phase of Ain Azel, which had an impact on the geology of the region. The formation of the different geological units was affected by structural deformations and tectonic movements during this post-Lutetian phase. It probably contributed to the development of complex geological structures and favorable conditions for sedimentation and the evolution of the local geological landscape. Several important geological events had a significant impact on the Ain Azel study area during the Tertiary period. Post-Lutetian tectonic phases, which caused structural deformations and tangential tectonic movements, are part of these events. **[49]**

II.7.2.5. Miopliocène neotectonics phase

Plicatives and brittle deformations were observed in the Miopliocène neotectonics phase of Ain Azel. Folds limiting the Djebel Tella anticline to the south of Sétif, generally aligned in the Atlas direction, present plicative deformations. Regarding fracturing deformations, they are characterized by atlasic direction cracks which reflect the replay of past accidents. Other geological events took place in the region during the Miopliocene neotectonic phase of Ain Azel, in addition to the plicative and brittle deformations mentioned previously. **[50]**

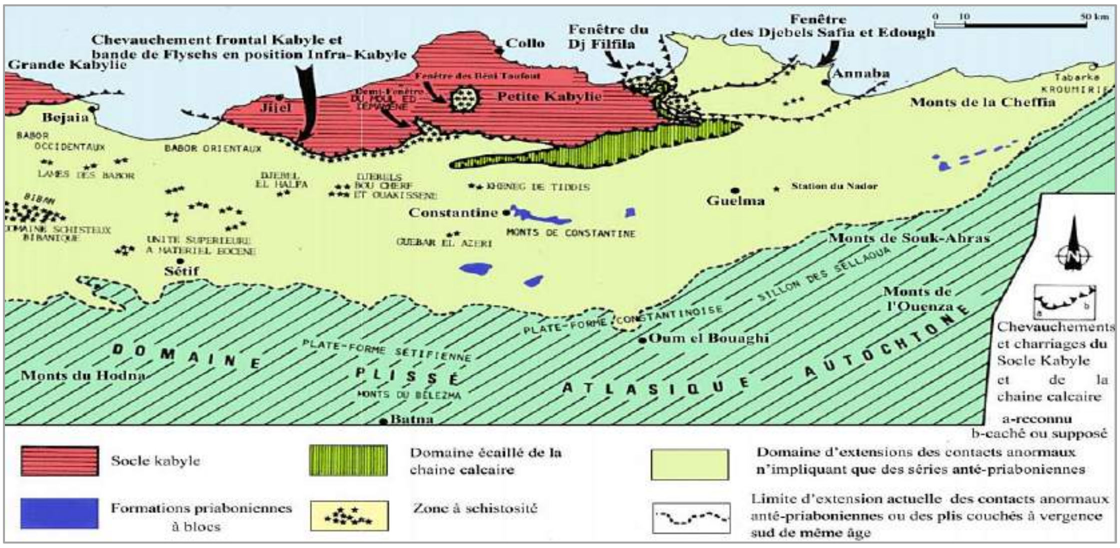

Figure II. 12 : Localisation des structures imputables à la tectonique priabonienne **[51]**

II.8. Local geology

II.8.1. Stratigraphy of the study area

By analyzing the different rock layers, the stratigraphy of Ain Azel allows us to reconstruct the geological history of this region, which helps to understand the past and current geological processes that have influenced the local landscape. The study of the different geological layers that make up the region is called Ain Azel stratigraphy. In geology, stratigraphy is used to reconstruct the geological history of a region by analyzing the sequence of rock layers. It helps determine the age of rocks and fossils, identify environmental changes over time, and correlate rock layers in different regions. **[52]**

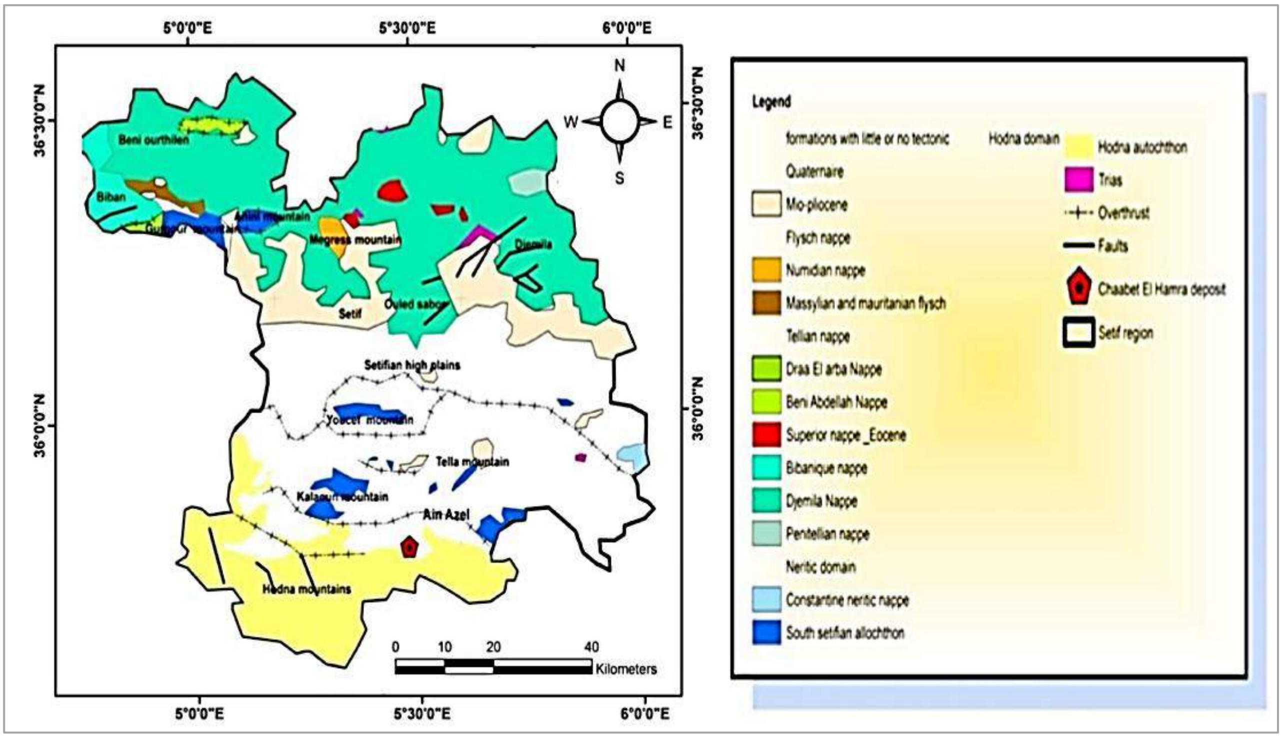

Figure II. 13 : Structural diagram of the regional geology of the study area **[52]**

II.8.2. Lithostratigraphic

The Ain Azel region has a diverse lithostratigraphy that includes several geological formations. Located in the Sétif plain, it is surrounded by the Algerian Atlas Mountains (Tellin and near Saharan) and serves as a natural border between the Hautes Plaines to the north and the Hodna Mountains to the south. Three distinct zones make up its relief: a mountainous zone located to the South and West, a zone of plains located to the North and Center, and a piedmont zone which has a slope ranging from 10% to 20% and a fluctuating altitude. Between 1050 m and 1150 m.

Geological formations such as the Lower-Middle Jurassic (Lias-Dogger) and Upper Jurassic, as well as Barremian carbonate and sandstone formations of the Lower Cretaceous, are linked to the Ain Azel region. **[53]**

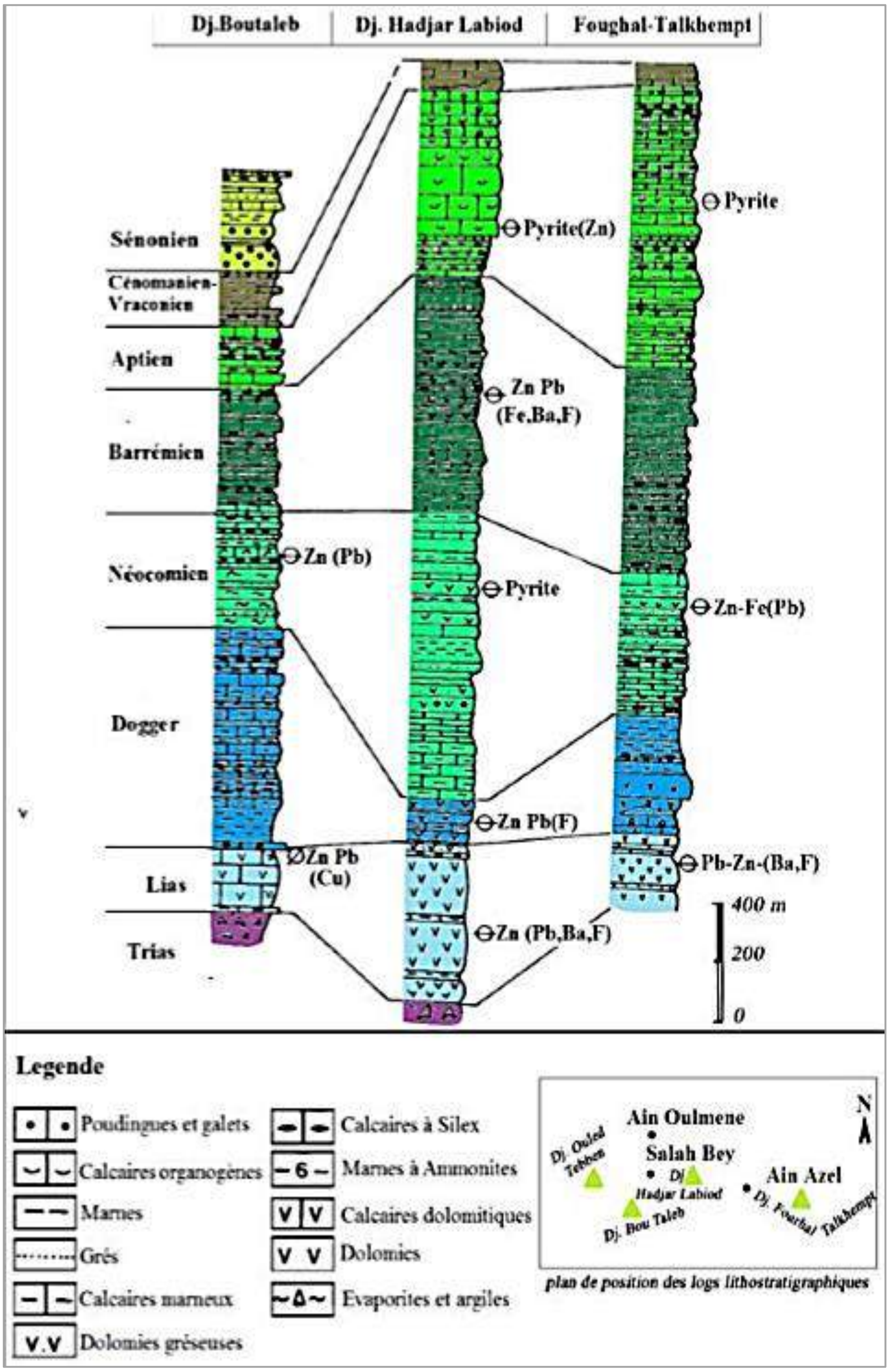

Figure II. 14 : Lithostratigraphic column of the Hodna Mountains massifs. **[49]**

II.9. Hydrogeology of the study area

II.9.1. Hydrogeology of the Sétif region

Due to the drought and scarcity of rainfall, it is crucial in Algeria. The climate of this region is semi-arid and it is part of the high Setifian plains. Because it is part of the large Soummam watershed, its hydro-climatic conditions are particular. In the region, research on hydrogeology has been carried out, in particular concerning thermal mineral springs, the deep aquifers of the Barremian and Hauterivian, as well as the surface water table of the Mio-Plio-Quaternary. Data on the quality of groundwater, their thermal water potential and their pollution levels were provided by these studies. Aquifer recharge and water availability are affected by the region's geological formations, which are mainly composed of limestones, dolomites and sandstones. The Sétif region is also famous for its lead and zinc mines, such as Chaabet El Hamra and Kherzet Youcef, which contain a large amount of groundwater. However, research has found that this groundwater has a level of pollution that makes it unsuitable for human consumption or irrigation. Physicochemical and heavy metal analyzes made it possible to evaluate various groundwater quality indices in the region. **[54]**

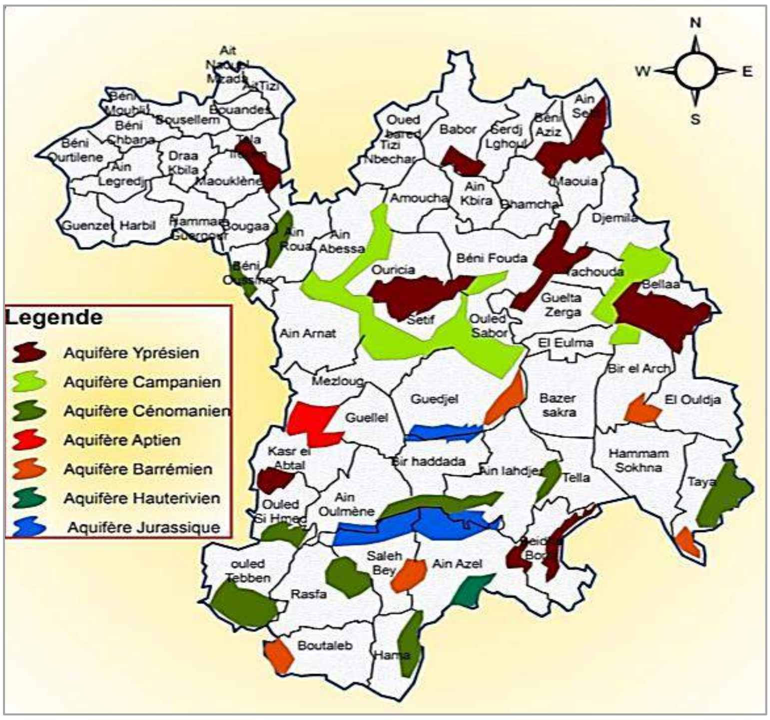

Figure II. 15 : Schematic map of the main aquifers in the wilaya of Sétif **[1]**

II.9.2. Hydrogeology of Ain Azel

It is essential to study the hydrogeology of Ain Azel, located in the Sétif region of Algeria, in order to better manage the water resources of this region. In order to capture the groundwater dynamics, aquifer properties and water quality in this region, studies have been carried out. The importance of Barremian and Hauterivian aquifers, as well as local geological formations such as limestones, dolomites and sandstones, has been highlighted by hydrogeological studies, which have an impact on recharge and water quality. underground.

A thorough analysis of the local geological structure, hydrological characteristics and aquifer dynamics is essential in the field of hydrogeology of Ain Azel in order to ensure efficient and sustainable use of water resources in this particular region. **[55]**

II.9.2.1. Mio-Plio-Quaternary superficial aquifer

The aquifer at Ain Azel is composed of lacustrine limestones, conglomerates and alluvium in the Mio-Plio-Quaternary. It is crucial that these geological formations are present in order to fill this aquifer with water. From the Middle Miocene to the Quaternary, sandy-gravelly deposits are observed in this aquifer, thus creating a "multi-layer aquifer" with fluctuating clay levels. This type of aquifer is designated as "free or semi- captive" and can have a thickness of up to more than 150 meters. It is surrounded by a sandy mantle produced by wind energy, which allows it to have vast water reserves.

The Mio-Plio-Quaternary aquifer in Ain Azel is of great economic importance, since it is used for irrigating crops, growing maritime pine, supporting watercourses, collective or individual watering, to industries and heat pumps. The water table changes each year depending on climatic conditions and agricultural withdrawals, which requires adequate management to ensure its sustainability and availability to meet the diverse water needs of the region. **[55]**

II.9.2.2. Deep aquifer

The hydrological geology of the region is based on the deep Ain Azel aquifer. The geological formations that characterize it include Jurassic dolomites and limestones, as well as Barrémo-Aptian-Cenomanian limestones and dolomites. The depth and composition of this aquifer differs from place to place, with thicknesses of up to 800 meters in some areas.

Water supply to the deep aquifer is provided by direct precipitation due to its vast extent. Recharge is observed when rainwater infiltrates directly, while discharge is manifested by vertical losses towards the underlying formations and horizontal losses towards the aquifer formations of the Mio-Plio-Quaternary. The region's water supply is essential thanks to this deep aquifer, although research has highlighted problems with groundwater quality, such as excessive pollution by zinc, copper and lead. **[55]**

II.10. Conclusion

In summary of this chapter, it is important to highlight a few essential aspects:

- Ain Azel has a semi-arid climate with an annual average precipitation of 365 mm and average temperatures of 14.62°C. Examining the monthly precipitation information highlights a trend where the precipitation curve is always lower than the temperature curve, particularly from June to August.
- To the southwest of the periclinal part of the large anticlinal horst structure of Rahbet, in the district of Fourhal, in the region of Aïn-Azel, south of Sétif, is the deposit of Chaabet el Hamra. It is one of the northeastern outer regions of the Maghreb chain of North Africa. In other words, it belongs to the indigenous and para-indigenous Hodníens region.
- The normal faults which disrupt the lithology of the sector are characteristic of brittle tectonics. Thanks to this geological study, it was possible to determine the lithological composition of the land which favors the formation of possible aquifers. According to the geological description, the Barremian and Hauterivian formations could be aquifers.
- The studied area is mainly concerned by two major aquifer systems: a superficial aquifer which corresponds to the Mio-Plio-Quaternary formations and a complex of deep aquifers from the Lower Cretaceous, more precisely the Hauterivian and the Barremian, which play a crucial role in the water supply of the region.

Chapiter III :

Water suitability for consumption and irrigation

III.1. Introduction

In this chapter, we will focus on the water supply, we have done a physic-chemical study on the various parameters that affects the quality of the drinking water of the study region. We studied 50 drill holes in 2018 using drinking water diagram software (Piper, Schoeler-Berkaloff, Stabler-Collins and Stiff) and water irrigation diagram software (Riverside, Wilcox or Wilcox log). In addition, we calculated the quality indices (SAR, SSP, PI, KR, MR and RSBC) to assess the capacity of water to be used for agricultural irrigation.

III.2. Presentation of the Avignon Hydrochemistry software (diagrams)

The Hydrochimie software suite from the University of Avignon (LHA) offers a range of specialized tools. This program is specifically designed to process hydrochemical and isotopic data, generate graphical representations and perform statistical analyses. It offers the possibility of creating hydrochemical schemes such as those of Piper, Stiff, Schoeller-Berkalov, Korjinski, Riverside, Wilcox, Stabler and ternary. The aim of these diagrams is to simplify communication between researchers, to provide teachers with an educational tool, and to support research in hydrochemical and isotopic analysis. **[56]**

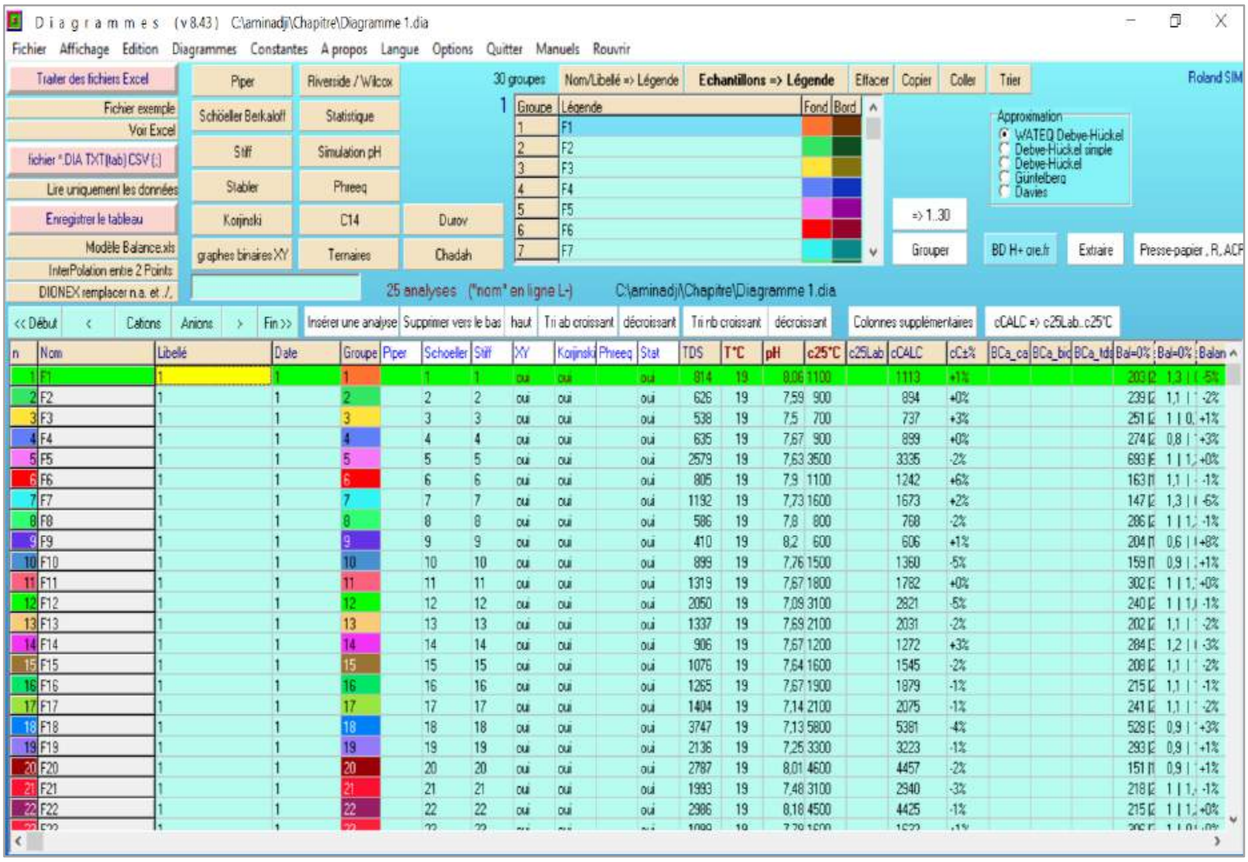

Figure III. 1 : Representation of the interface of the Avignon hadrochemical software

III.2.1. Richards or Riverside or Wilcox diagram

The Wilcox diagram is an important diagram that provides very useful information on the risk of soil salinization. Using data from the sodium adsorption ratio (SAR), this diagram presents a precise visual representation of the hadrochemical characteristics of the water, which facilitates its classifications and uses. **[57]**

III.2.2. Piper diagram

The Piper diagram shows the chemical facies of a set of water samples. This type of diagram is particularly suitable for studying the evolution of water facies when mineralization increases or to indicate the types of dominant cations and anions and to distinguish groups of samples **[58]**

III.2.3. Schoeller-Berkaloff diagram

The Schoeller-Berkaloff diagram is a semi-logarithmic graphic representation: on the axes of the abscissa are represented the different ions. For each of the major ions, the real content of mg/l is plotted on the ordinate axis, the points obtained are connected by straight line segments. This diagram is widely used in the field of water hydrochemistry, with very good results.[59]

III.2.4. Stiff diagram

This diagram is a method used in hydrochemistry to graphically visualize the results based on the concentrations of the main ions present. The different zones of this diagram correspond to specific ion combinations, which makes it possible to obtain a visual representation of the water quality. [60]

III.2.5. Stabler-Collins diagram

This diagram shows the different steps in the groundwater treatment process and the interactions between the various elements of the system. Each step in the groundwater treatment process is illustrated by each level of the diagram. [61]

III.3. Presentation of physic-chemical parameters

The results of the physical and chemical analysis of water from the Mio-Plio-Quaternary aquifer for the boreholes in our studied area are presented in (Table A.1):

III.4. Verification of the ion balance

The physic-chemical parameters of groundwater in the study area are presented in (**Table A.1).**

The ion balance is the first step in validating the physicochemical parameters of groundwater before starting water quality for supply or irrigation. It is given by formula III.1.

$$IB\ (\%) = \frac{|\sum cation - \sum anion|}{\sum cation + \sum anion} \times 100 \ldots\ldots\ldots\ldots \textbf{III.1}$$

- ✓ BI = 0%: ideal ion balance;
- ✓ BI < 5%: good analyses;
- ✓ 5% < BI < 10%: exploitable analyses;
- ✓ BI > 10%: analyses to be repeated. **[62]**

➢ **<u>Interpretation:</u>**

The results of the ion balance are presented in **(Table III.1)**. According to the table, all boreholes have ion balance values between 0 and 10 which allows us to consider these analyses as reliable, except for borehole 33 which gave a value of 11.59%. This value exceeds 10%. So, this drilling, is not considered in our study.

Table III. 1 : Ionic balance of physic-chemical analyses

Water points	IB (%)	Classification	Water points	IB (%)	Classification
D1	5,485	Actionable Analytics	**D26**	1,497	Good analyzes
D2	2,040	Good analyzes	**D27**	1,116	Good analyzes
D3	0,788	Good analyzes	**D28**	2,296	Good analyzes
D4	3,498	Good analyzes	**D29**	1,028	Good analyzes
D5	0,477	Good analyzes	**D30**	3,283	Good analyzes
D6	0,916	Good analyzes	**D31**	1,612	Good analyzes
D7	6,221	Actionable Analytics	**D32**	0,834	Good analyzes
D8	0,732	Good analyzes	**D33**	11,598	Analyzes to be redone
D9	7,689	Actionable Analytics	**D34**	0,799	Good analyzes
D10	1,087	Good analyzes	**D35**	2,717	Good analyzes
D11	0,103	Good analyzes	**D36**	3,300	Good analyzes
D12	0,877	Good analyzes	**D37**	3,766	Good analyzes
D13	2,166	Good analyzes	**D38**	1,720	Good analyzes
D14	3,172	Good analyzes	**D39**	0,301	Good analyzes
D15	1,819	Good analyzes	**D40**	3,258	Good analyzes
D16	1,223	Good analyzes	**D41**	5,785	Actionable Analytics
D17	1,760	Good analyzes	**D42**	3,209	Good analyzes
D18	2,728	Good analyzes	**D43**	4,098	Good analyzes
D19	1,207	Good analyzes	**D44**	0,820	Good analyzes
D20	0,699	Good analyzes	**D45**	1,990	Good analyzes
D21	0,685	Good analyzes	**D46**	4,143	Good analyzes
D22	0,143	Good analyzes	**D47**	0,769	Good analyzes
D23	0,318	Good analyzes	**D48**	0,994	Good analyzes
D24	0,448	Good analyzes	**D49**	0,020	Good analyzes
D25	0,932	Good analyzes	**D50**	1,927	Good analyzes

III.5. Calculation of Alkalinity and Total Solids Below

III.5.1. Completed alkalinity (TAC)

This measurement represents the amount of free alkaline such as carbonates and hydrogen carbonates present in water. The TAC plays a key role in maintaining water balance, which has a direct impact on pH stability. An appropriate TAC ensures pH stability by acting as a buffer, thus reducing acid or base variations **[63]**

TAC = [OH-] + [Co^{3}-] + [HCO^{3}-] (Meq/L) **III.2**

- Low TAC: less than 1 meq/L;
- Moderate TAC: 1-2 meq/L;
- High TAC: more than 2 meq/L. [64]

➢ **Interpretation:**

The calculation results are presented in **(Table III.2. A)** variety of TAC values are observed, ranging from about 1.826 to 11.006 meq/L. This means that the water in our region has an important buffer capacity to withstand changes in pH. However, we have also identified some extremely high values. Our results indicate that drilling water in our study area generally has a high buffer capacity, which is positive for maintaining a stable and safe pH for human consumption.

Note: We obtained the OH- values from Avignon Hydrochemistry (LHA) software.

III.5.2. Total solids below (TDS)

Total bottom solids represent dissolved matter in water. They are expressed in milligrams per litre (mg/L) and play an essential role in measuring the purity of the water. **[65]**

TDS min=∑ions (mg/l) + [SiO_2] (mg/l) - 31*[HCO3-] (mg/l) …… **III.3**

TDS max=∑ions (mg/l) + [SiO_2] (mg/l) (mg/l) …………… **III.4**

In Algeria, TDS (Salinity Rate) levels for drinking water usually vary between 500 and 1500 mg/l. **[27]**

➢ **Interpretation:**

According to Table III.2, and comparing with Algerian standards, values of TDS vary between 500 and 2800 mg/L **[54]**. All boreholes presented values of TDS in the range of

Algerian standards, except for borehole 18, it presented a value of TDS that exceeded these standards.

After calculating the results (TAC and TDS), we will display them in the following table:

Table III. 2 : Alkalinity and Solids under total drilling in the study area

Wp	TAC méq/l	TDS (mg/l)	Wp	TAC méq/l	TDS (mg/l)
D1	4,628	740,000	**D26**	3,843	830,909
D2	4,301	569,091	**D27**	3,397	730,909
D3	4,005	489,091	**D28**	3,510	928,182
D4	3,844	577,273	**D29**	4,399	987,273
D5	11,006	2344,545	**D30**	4,511	770,909
D6	2,916	731,818	**D31**	3,001	1106,364
D7	4,616	1083,636	**D32**	3,804	730,000
D8	4,814	532,727	**D33**	/	/
D9	2,423	372,727	**D34**	3,526	1140,909
D10	2,306	817,273	**D35**	4,711	636,364
D11	5,008	1199,091	**D36**	3,307	595,455
D12	4,493	1863,636	**D37**	3,401	646,364
D13	4,205	1215,455	**D38**	4,321	1240,909
D14	5,516	823,636	**D39**	4,716	751,818
D15	4,008	978,182	**D40**	4,004	560,909
D16	4,008	1150,000	**D41**	3,620	579,091
D17	4,706	1276,364	**D42**	4,000	470,909
D18	5,395	3406,364	**D43**	5,301	801,818
D19	4,003	1941,818	**D44**	4,910	697,273
D20	1,826	2533,636	**D45**	3,907	498,182
D21	4,005	1811,818	**D46**	2,915	1092,727
D22	3,427	2714,545	**D47**	3,108	1343,636
D23	4,913	999,091	**D48**	3,402	1680,909
D24	3,839	1333,636	**D49**	2,818	758,182
D25	4,611	1024,545	**D50**	4,008	540,909

III.6. Study of the calcium-carbon balance of water (saturation indices)

III.6.1. Langelier index

Indeed, we use the Langelier method to evaluate the aggressiveness of the water. The calculation of the saturation index, also called Langelier index (IL), constitutes the basis of this method. The Langelier index designates the disparity between the actual pH of water and its calculated pH. The pH represents the theoretical saturation pH. **[66]**

$$IL = PH - PHs \ldots\ldots\ldots\ldots \quad \textbf{III.5}$$

PHs represents the balance between calcium, carbonate and bicarbonate ions in water. When the pH of the water is equal to the saturation pH (PHs), the water is in calcium-carbonic balance and tends neither to dissolve nor to precipitate calcium carbonate. **[67]**

Table III. 3 : The water classification scale according to Langelier

IL < 0	aggressive
IL = 0	balance
IL ≥ 0	encrusting

- **Interpretation :**

The Langelier oscillates between -0.44 and 1.38. The values of the water indices of all the boreholes of the Mio-Plio-Quaternary aquifer present in (**Table A.1**) exceed zero, which means that the water of these boreholes is encrusting, with the exception of the aggressive drilling (D28, D31, D32, D41). According to Langelier, the overall appearance of these waters is encrusting.

Note: We obtained the PH values from Avignon Hydrochemistry (LHA) software.

III.6.2. Larson saturation index IC (corrosiveness index)

The propensity of water to corrode can be assessed using the Larson index, which is calculated using this formula:

$$IC = \frac{2\times[SO4\ 2-\ ]+|Cl-\ ]}{(TAC)} = \frac{2.[SO4\ 2-\ ]+|Cl-\ ]}{2[HCO3\ -\ ]} \ldots\ldots\ldots \quad \textbf{III.6}$$

Table III. 4 : Interprétation of the Larson Index classification

IC <0,2	It is not likely to corrode
0,2 ≤ IC < 0,4	Corrosion is rare
0,4 ≤ IC < 0,5	Susceptible to corrosion
0,5 ≤ IC < 1	Medium corrosion
IC ≥ 1	Very resistant to corrosion

- **Interpretation :**

The calculated values of the LARSONR index vary between 0.46 and 15.86. According to the LARSON index, the majority of waters from the Mio-Plio-Quaternary aquifer in the Ain Azel area were found to be very resistant to corrosion. The exception of these Drills (D2. D3.D4. D8. D7.D14.D35. D39. D40. D42. D45. D50,) which have average Corrosion.

III.6.3. Ryznar saturation index (stability index)

It is also called the stability index, it makes it possible to determine whether water has an aggressive or scaling tendency. This index is calculated according to the following formula:

$$IR = 2pHs - pH \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{III.7}$$

Table III. 5 : The water classification scale according to Ryznar

IR < 6	Corrosive water
6 ≤IR ≤7	Slightly corrosive water
IR> 7	Encrusting water

- **Interpretation:**

According to the Ryznar index, the majority of the waters of the Mio-Plio-Quaternary aquifer were found Slightly corrosive with the exception of these Drills (D5. D18. D21. D22. D24. D48) Are Corrosive and these Drills (D2. D27. D32).

After calculating the results (IL, IC and IR) of the drillings in the Ain azel region, we will display them in (Table A.1)

III.7. Assessment of the water quality of the study area for drinking water

III.7.1. Physical water parameters

III.7.1.1. Temperature (T °C)

The water must be at a temperature between cool and temperate in order to be pleasant. As a general rule, the acceptable temperature is between 10- 25 ° C **[68]**.

The water temperature in our study area is 19 ° C so this parameter is ideal for human consumption in terms of comfort, perceived quality.

At this temperature, it is possible that the water is considered fresh and pleasant to drink. Its taste or smell should not be unusual, which could suggest water quality problems.

III.7.1.2. Potential dihydrogen (pH)

The most significant indirect impact on health is pH, which is associated with exposure to metals. **[69]**

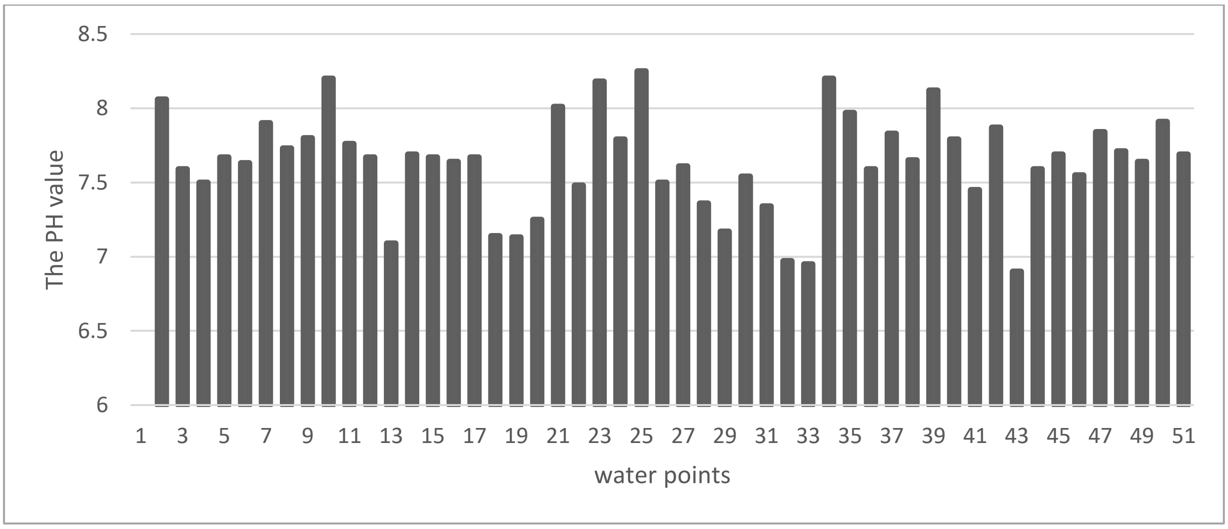

Figure III. 2 : pH of boreholes in the study area.

(Figure III.2) shows the pH variation as a function of drilling, which varies between 6.9 and 8.25. According to Algerian standards, these values comply with the standards, which stipulate that the pH must be between 6.5 and 9.

The pH of water from boreholes in our region complies with the Algerian drinking water standard which stipulates that the pH must be between 6.5 and 9. Thus, this water meets the standards for the quality of drinking water in Algeria.

III.7.1.3. Electrical conductivity (EC)

The electrical conductivity of water is defined as its ability to allow an electric current to pass through it at a variable speed. There is a direct correlation between the quantity of salts dissolved in this water and this one, and the representative values are calculated at temperatures close to 20°C and expressed in µs/cm. **[70]**

In water intended for human consumption, it is recommended to achieve a maximum electrical conductivity of 2800 µs/cm, in accordance with the rules in Algeria.

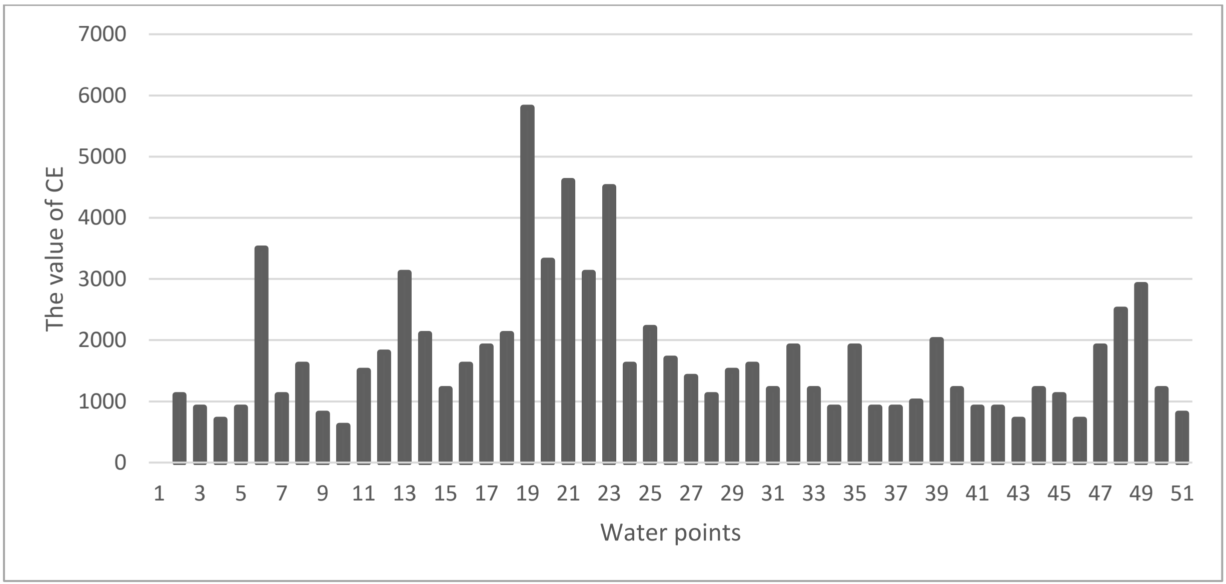

Figure III. 3 : Change in drilling conductivity in the Ain Azel area

The CE values are 600 to 5800 µ s/cm, with an average of 1736 µ s/cm so there are 8 boreholes that have exceeded the maximum electrical conductivity (2800 µ s/cm). The 50 boreholes were classified according to their degree of mineralization, ranging from "Important" to "Excessive." In water intended for human consumption, it is recommended to achieve a maximum electrical conductivity of 2800 µ s/cm, in accordance with the rules in Algeria.

III.7.1.4. Hardness (TH)

Sedimentary rocks, along with soil infiltration and runoff, are the primary natural sources of water hardness. Hard water generally comes from regions where the topsoil is thick and the rocks are limestone. In general, groundwater has a higher hardness than surface water. **[71]**

Algerian standards stipulate that the maximum concentration authorized for drinking water is 500 mg/l.

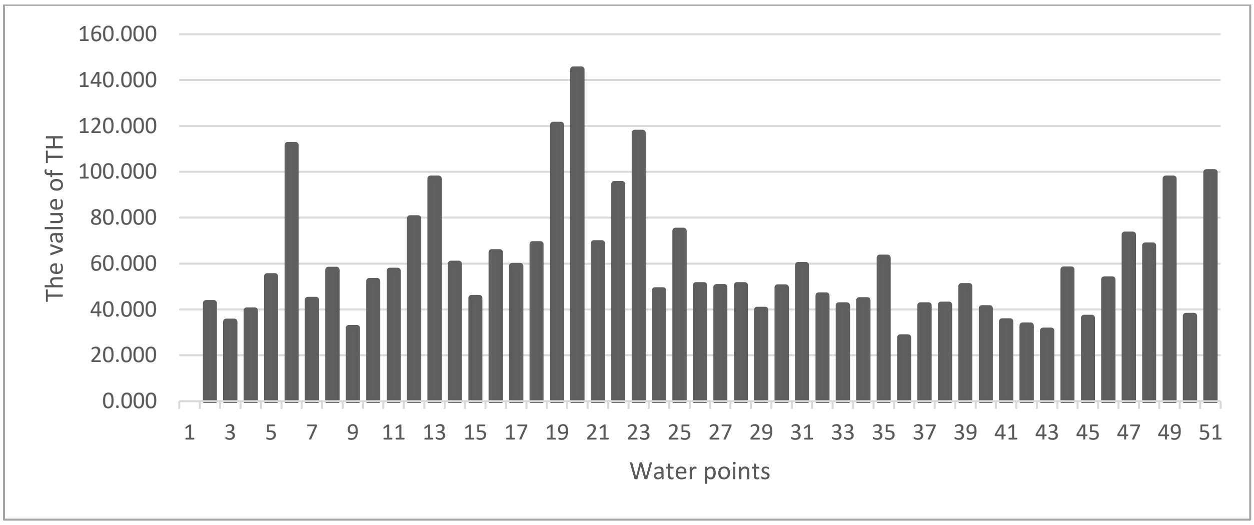

Figure III. 4 : TH of the boreholes of the study area.

TH values range from 28 to 145 mg/L. The Algerian standards stipulate that the maximum allowable concentration is 500 mg/L **[57]**, so it can be concluded that the waters in our region are fresh and moderately mild. The quality of these waters is illustrated in (**Table III.6)**.

Table III. 6 : Water quality from boreholes in the Ain Azel area according to the TH

TH (°F)	**0 – 7**	**7 – 22**	**2 – 32**	**32 – 54**	**> 54**
Water quality	Gentle	Moderately sweet	Quite gentle	Hard	Very hard
	All drilling except (D5-D11-D12-D18-D19-D24-D46-D48-D50)	D5-D11-D12-D18-D19-D24-D46-D48-D50	/	/	/

III.7.1. Chemical water parameters

III.7.1.1. Cation

- **Calcium (Ca^{2+}) :**

Nature contains a large amount of calcium, an alkaline earth metal, mainly in limestone rocks. There are two natural ways to find Ca2+ ions in water: the dissolution of carbonate formations (CaCO3) or gypsum formations (CaSO4).

Waters containing more than 200 mg/L of calcium cause disadvantages for both domestic and food use. **[72]**

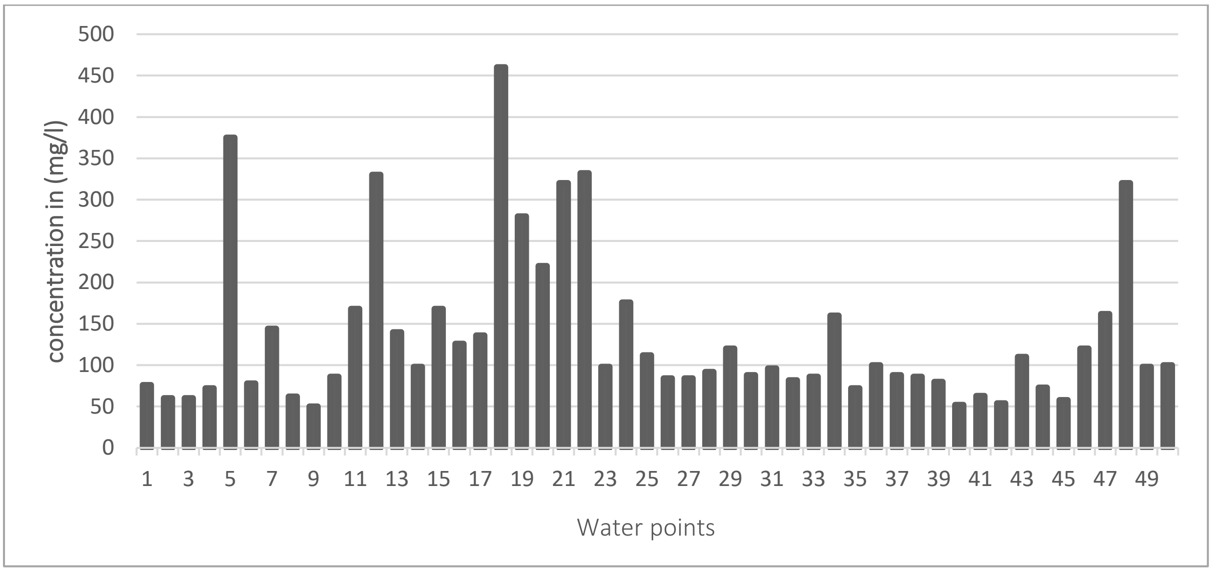

Figure III. 5 : Ca^{2+} in the boreholes of the study area.

Ca^{2+} values range from 50 to 460 mg/L. The Algerian standards stipulate that the maximum permitted concentration is 200 mg/L. The drilling classification according to Ca^{2+} is given in Table III.7.

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

Magnesium is one of the most widespread elements in nature. It constitutes approximately 2.1% of the earth's totality. According to drinking regulations in Algeria. Waters containing more than 150 mg/L of Magnesium are disadvantageous for both domestic and food use.. **[73]**

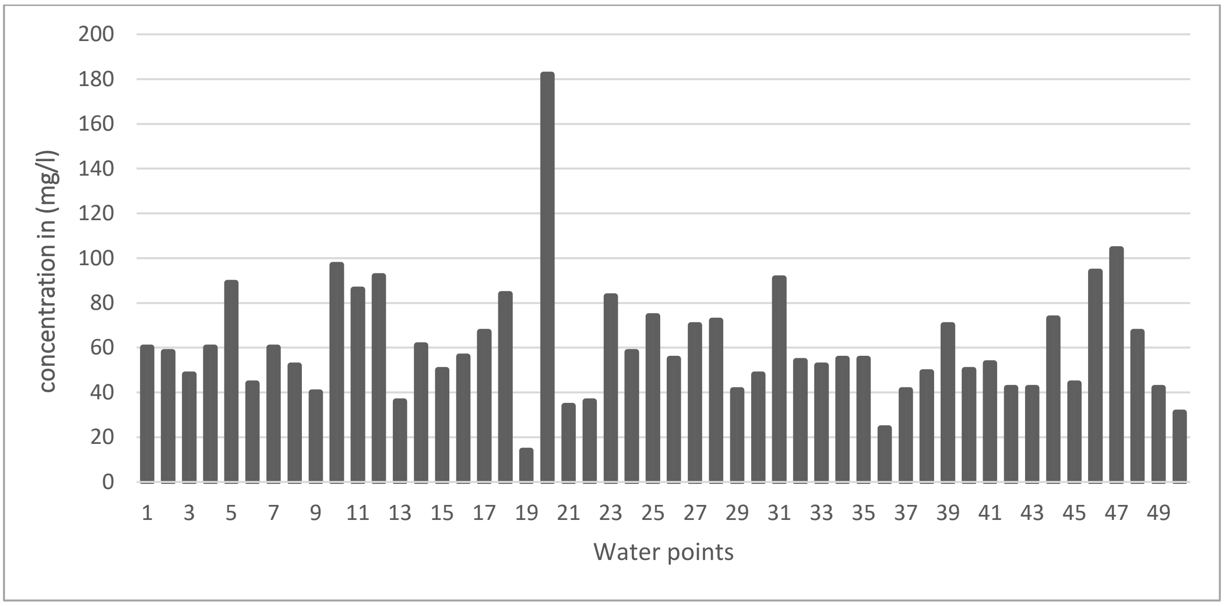

Figure III. 6 : Mg^{2+} in the boreholes of the study area.

Magnesium (Mg^{2+}) in groundwater samples ranged from 14 to 182 mg/L. According to Algerian standards. Waters containing more than 150 mg/L Magnesium result in disadvantages for both domestic and food use

- **Sodium (Na^+) :**

Sodium is a constant substance found in water, however levels can fluctuate widely. In any case, leaching from geological formations containing sodium chloride can be caused by the decomposition of mineral salts such as sodium and aluminum silicates, salt waters entering aquifers, and by many uses industrial. **[74]**

In fact, sodium is often associated with chloride pollution. According to drinking regulations in Algeria, it is necessary to respect a sodium concentration equal to or less than 200 mg/l. **[73]**

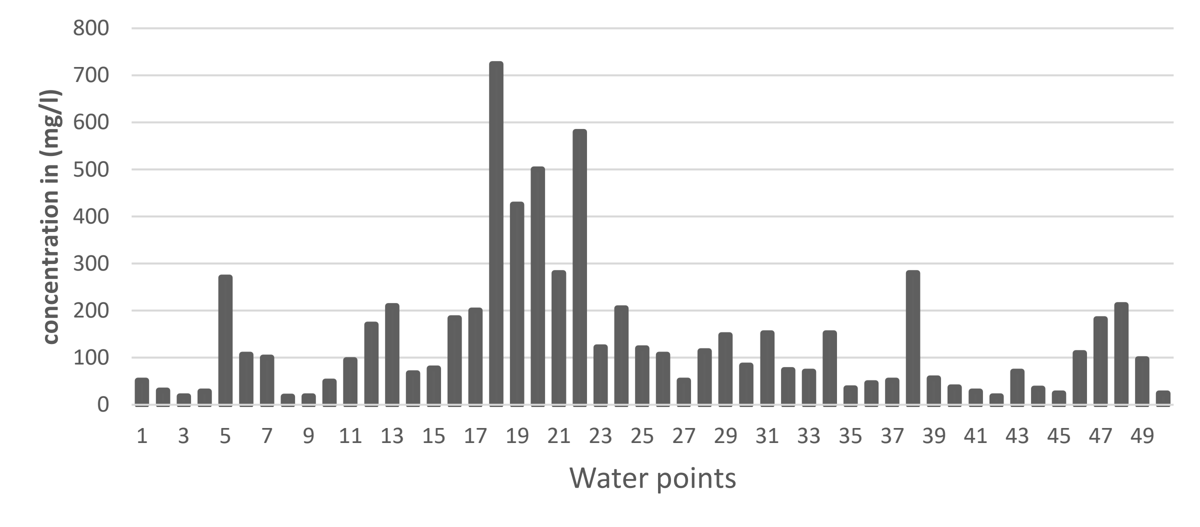

Figure III. 7 : Variation de la teneur en sodium dans les forages de la zone d'Ain Azel

Na^+ values range from 17 to 724 mg/L. In fact, sodium is often associated with chloride pollution. According to the regulations on portability in Algeria, it is necessary to respect a sodium concentration of 200 mg/L.

In our study there are several analyses greater than 200 mg/L therefore eliminate (10 drills) present in the **(Table III.7)**

- **Potassium (K^+) :**

In general, potassium is the least present main element in waters. It plays an essential role in life. Current regulations in Algeria stipulate that the amount of potassium in water should not exceed 12 mg/l study results.

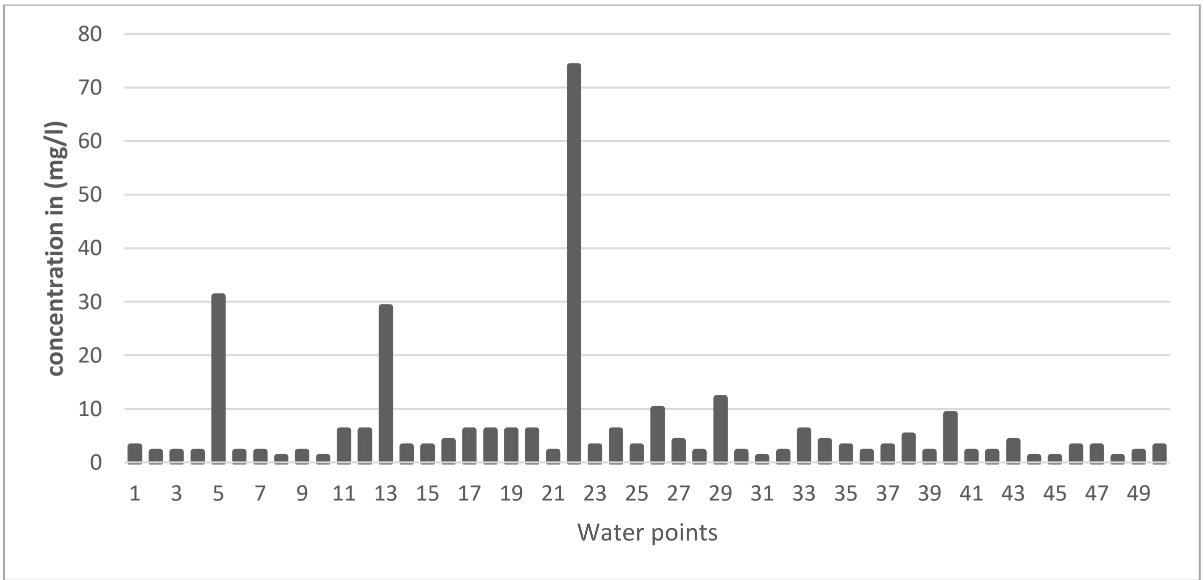

Figure III. 8 : K^+ in the boreholes of the study area.

K^+ values range from 1 to 74 mg/L. The Algerian standards stipulate that the amount of potassium in water must not exceed 12 mg/l the results of the study. In our study, we have 3 boreholes in which the value of potassium was exceeded the Algerian standards, shown in the **(Table III.7)**

III.7.1.2. Anion

- **Bicarbonate (HCO_3^-) :**

Bicarbonates come from different origins and have no direct impact on health. However, they play a role thanks to the cations with which they are associated (sodium, calcium) and which often give them a salty taste. Bicarbonates are generally produced by the dissolution of carbonate minerals and the influence of CO2 present in meteoric waters and soil. The maximum concentration threshold is 600 mg/l. **[74]**

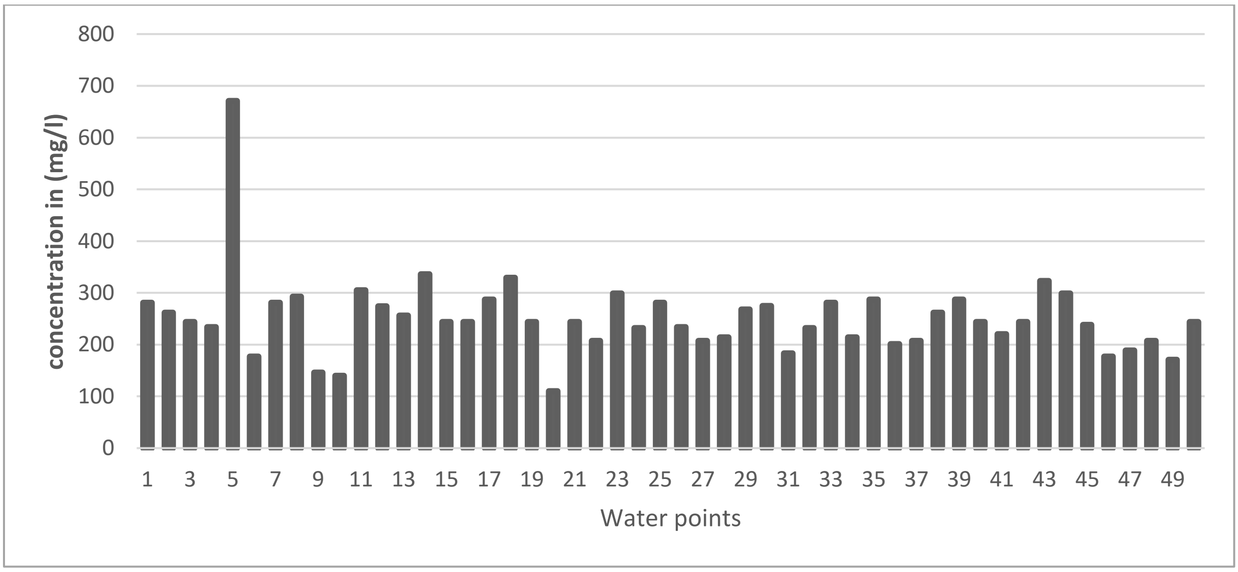

Figure III. 9 : HCO_3^- in the boreholes of the study area.

HCO_3^- variant values between 110 and 671 mg/L. Algerian standards should not exceed 600 mg/L. All the boreholes meet the Algerian standard, except one borehole, shown in **(Table III. 7).**

- **Chloride (Cl^-) :**

Chloride ion (Cl^-) is a predominant natural form of chlorine and is extremely soluble in water. The main source of chloride in natural water is particularly sedimentary evaporation rocks. **[73]**

In accordance with Algerian drinking water standards, the chloride content of drinking water shall not exceed 500 mg/l.

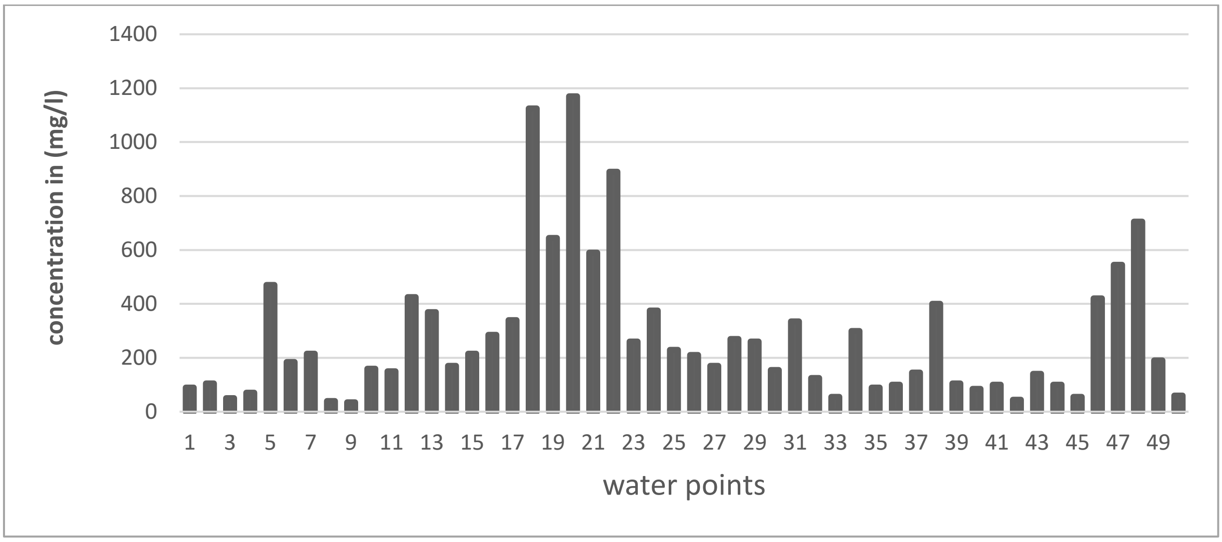

Figure III. 10 : **11**the Ain Azel zone

In the study area, the chloride ion content in all groundwater samples ranged from 35 to 1170 mg/l with an average value of 281.02 mg/l. Water from drilling is considered to be non-chlorinated (Cl less than 500 mg/l) **[74]**

They may be considered as chlorides with the exception of the Drills present in **(Table III.7).**

- **Sulphate (SO_4^-) :**

The presence of sulphate ions in water is caused by the dissolution of geological formations containing gypsum. **[75]** Current regulations in Algeria were recommended to have a sulphate concentration of 500 mg/l in water. Since 1998, the EU has proposed a maximum limit of 250 mg/l for high sulphate concentrations (above 400 mg/l).

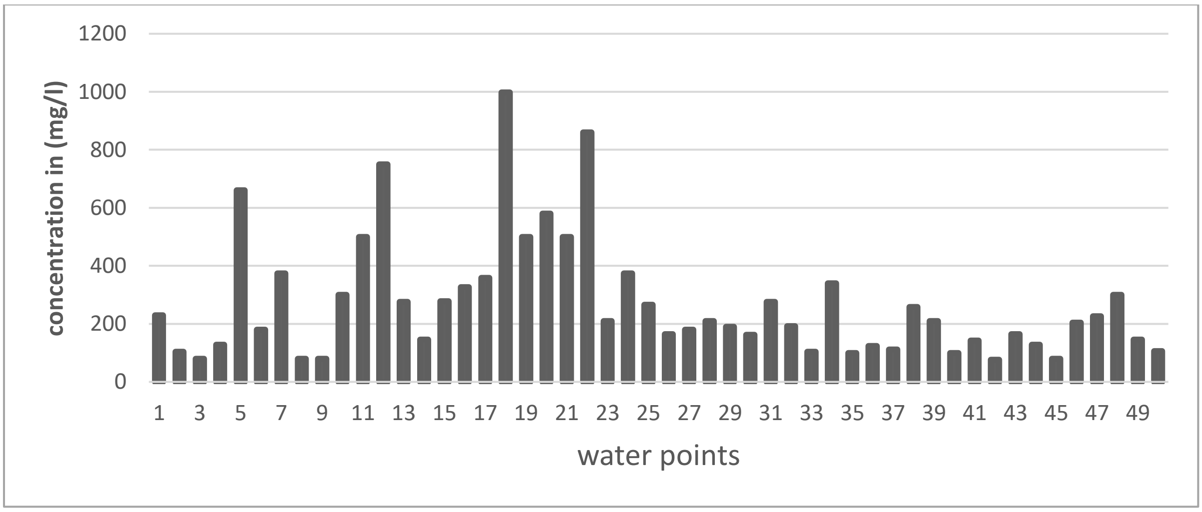

Figure III. 12 : 13the Ain Azel area

Sulphate concentrations found in groundwater samples in the study area ranged from 76 to 998 mg/l with an average of 272 mg/l. They meet the standard of power in Algeria. Except for Drilling in **(Table III. 7)**.

- **Nitrate (NO_3^-) :**

Nitrates, the most oxidized nitrogen, have a high solubility in water. Chemical fertilizers used in agriculture and wastewater discharges are mainly responsible for their presence in groundwater. **[75]** Algerian regulations, the maximum recommended value for nitrates in drinking water is 50 mg/l.

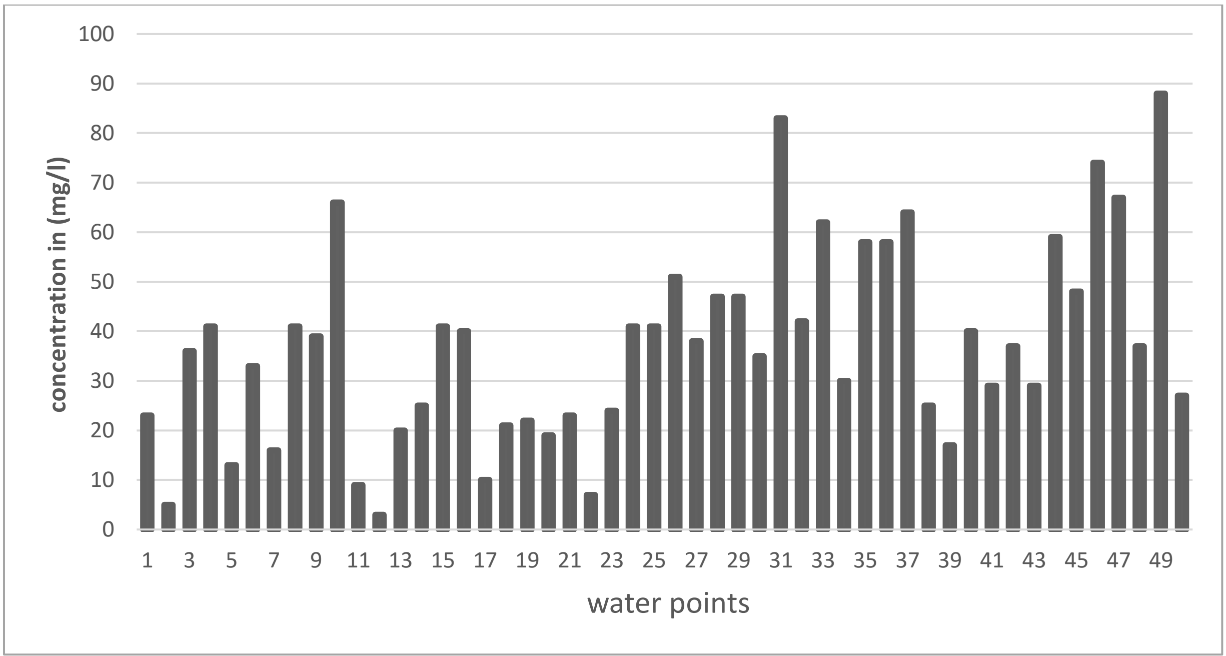

Figure III. 14 : **15**the Ain Azel area

Normal nitrate levels were observed in the water samples taken ranged from 3 to 88 mg/l, with an average of 36.51 mg/l, which is consistent with the required standards. Water samples therefore comply with water quality standards in Algeria. **[76]** Drilling has a high concentration of nitrates, thus exceeding the maximum permitted limit, as shown in **(Table III. 7)**. For other boreholes, there is a limited amount of nitrates (below the permitted limit).

Table III. 7 : The Chemical Parameters of Drilling in the Ain Azel Zone

Chemical Parameters	The Algerian standard	Drilling
Calcium	Drilling >200 mg/l	D5-D12-D18-D19-D20-D21-D22-D48
Magnesium	Drilling >150 mg/l	D20
Sodium	Drilling >200 mg/l	D5-D13-D18-D19-D20-D21-D22-D24-D38-D48
Potassium	Drilling >12 mg/l	D5-D13-D22
Bicarbonate	Drilling >600 mg/l	D5
Chloride	Drilling >500 mg/l	D18-D19-D20-D21-D22-D47-D48
Sulphate	Drilling >400 mg/l	D5-D11-D12-D18-D19-D20-D21-D22
Nitrate	Drilling >50 mg/l	D10-D26-D31-D35-D36-D37-D44-D46-D47-D49

III.8. Classification by Water Chemical Facial Diagrams

Water chemical facies diagrams play a crucial role in categorizing, interpreting and evaluating the chemical composition of groundwater. In our studies, we use diagram software such as Piper, Schoeler-Berkaloff, Stabler-Collins and Stiff to analyze these parameters. The values are given in milliequivalents per liter (meq/L).

III.8.1. Classification according to diagram of PIPER

The analysis and interpretation of hadrochemical data is facilitated by the Piper diagram, which provides essential information on groundwater-related chemical composition, quality and hydrogeological processes.

➢ **Interpretation :**

The major ion data reported on this diagram identified the chemical characteristics of the groundwater in the study area, the spatial distribution of which is illustrated in (**Figure III.13**).

✓ Calcium and magnesium bicarbonate (D3.D8.D42): Distinguishes itself by a high presence of bicarbonate ions as well as high calcium and magnesium concentrations. It is frequently linked to groundwater that has been in contact with carbonate rocks (such as limestone), resulting in the dissolution of these respective minerals.

- ✓ Sodium and potassium chloride or sodium sulphate (D18.D19.D38): This type of facies is distinguished by high levels of chloride or sulphate ions, as well as sodium and potassium. It is frequently associated with water that has evaporated in arid environments, resulting in high concentrations of dissolved salts.
- ✓ Chloride and calcium and magnesium sulphate (D1 to D50 except for the drills already mentioned): This type of facies is distinguished by high levels of chloride and sulphate ions, as well as high levels of calcium and magnesium. It frequently associates with waters that have passed through rocks containing sulphate and chloride minerals.

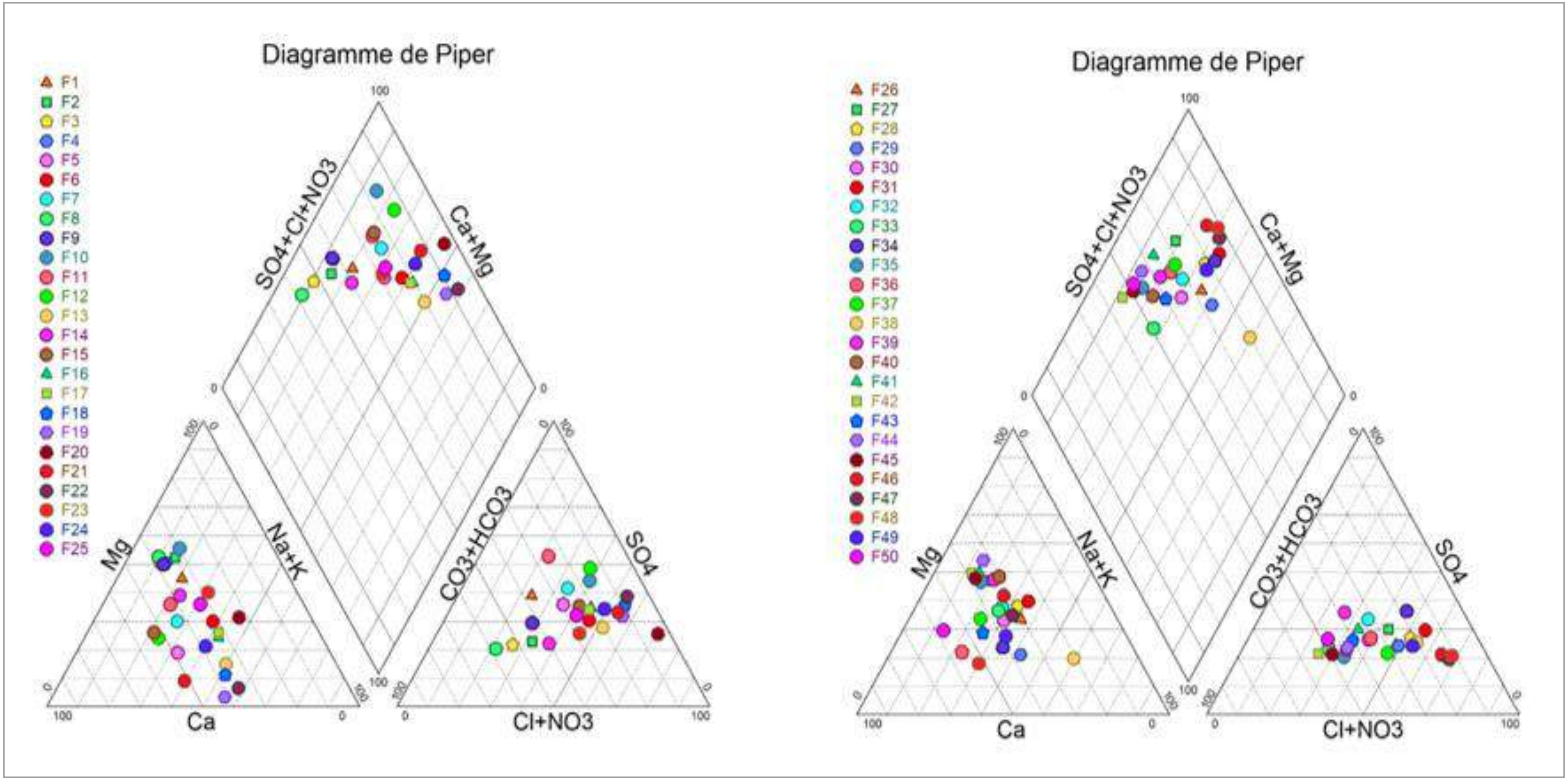

Figure III. 16 : Water classification of Ain Azel wells on diagram of PIPER

III.8.2. Classification according to Schoeller-Berkaloff diagram

The analysis and interpretation of the chemical composition of groundwater is facilitated by Schoeller-Berkaloff's diagram, which provides essential information on water quality.

- **Interpretation :**

According to Algerian standards, the evaluation of the concentrations of key ions in the water samples of the Mio-Plio-Quaternary aquifer in the region studied reveals a great diversity of chemical compositions. The classification of the samples according to the Schoeller-Berkaloff diagram shows that most of them are chlorinated, followed by sulphates and bicarbonates. However, no samples meet the recommended drinking standards due to high concentrations of chlorides, sulphates and other ions. There is an urgent need to treat water to reduce these concentrations to safe levels for human consumption, using techniques such as filtration and disinfection to ensure the safety and quality of drinking water.

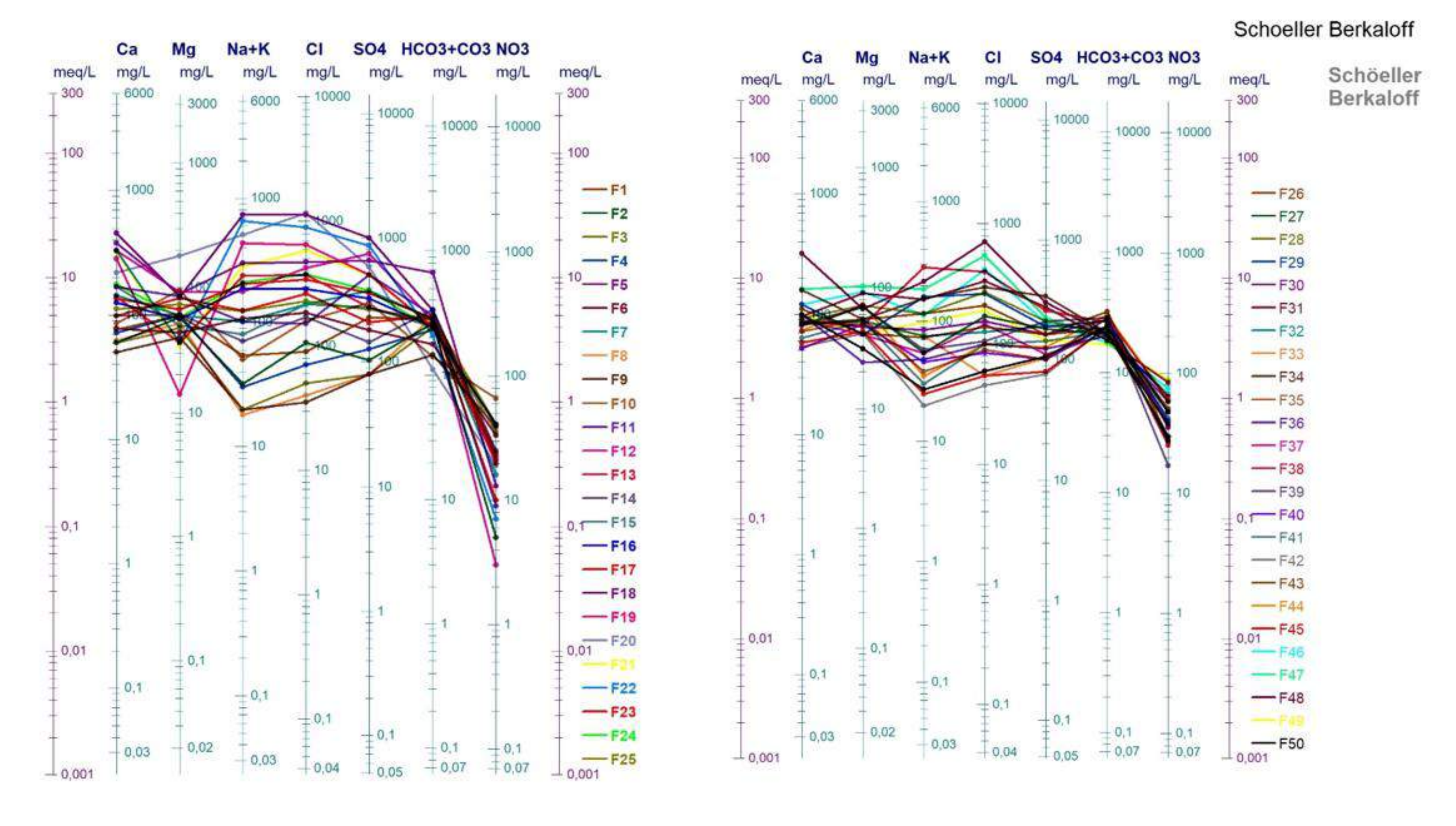

Figure III. 17 : Ain Azel water classification on Schoeller-Berkaloff diagram

III.8.3. Classification according to Stiff diagram

Stiff's diagram is a versatile and effective instrument for analyzing and interpreting the chemical composition of groundwater, providing essential information on water quality.

- **Interpretation :**

Thanks to this diagram, it is possible to observe the interactions between these ions in order to measure the quality of the water and its potential for use. Thus facilitating the assessment of water quality. The elements present in (**Table III.8)** and **(Figure III.15**) are distinct due to the results obtained.

Table III. 8 : Classification of Ain Azel bore water according to Stiff diagram

Chemical facies	Water points	Interpretation
Sulfated Magnesian	D1. D4. D9. D10. D25. D32. D39.	Generally, they are considered drinkable at normal concentrations.,
Magnesian Bicarbonate	D2. D3. D8. D14. D35. D40. D41. D42. D44. D45.	These waters are considered safe to drink, although high concentrations of magnesium may cause a feeling of laxity.
Calcium sulfate	D5. D7. D11. D12. D15. D36.	These waters generally pose no danger to human health, and they are considered drinkable.
Calcium Bicarbonate	D14. D30. D43. D50.	These waters are generally considered drinkable and may have health benefits due to their high calcium levels.
Calcium Chloride	D21. D24. D30. D34. D37. D48. D49.	The water present is drinkable, however a high chloride concentration can give a salty flavor to the water.
Magnesian Chloride	D23. D25. D26. D27. D28. D31. D46. D49.	These waters are possible to consume, but high concentrations of chloride and magnesium can influence the flavor of the water.
Sodium chloride	D6. D13. D16. D17. D18. D19. D20. D22. D24. D26. D29. D38.	These waters are drinkable, however a high chloride concentration can give a salty flavor to the water.

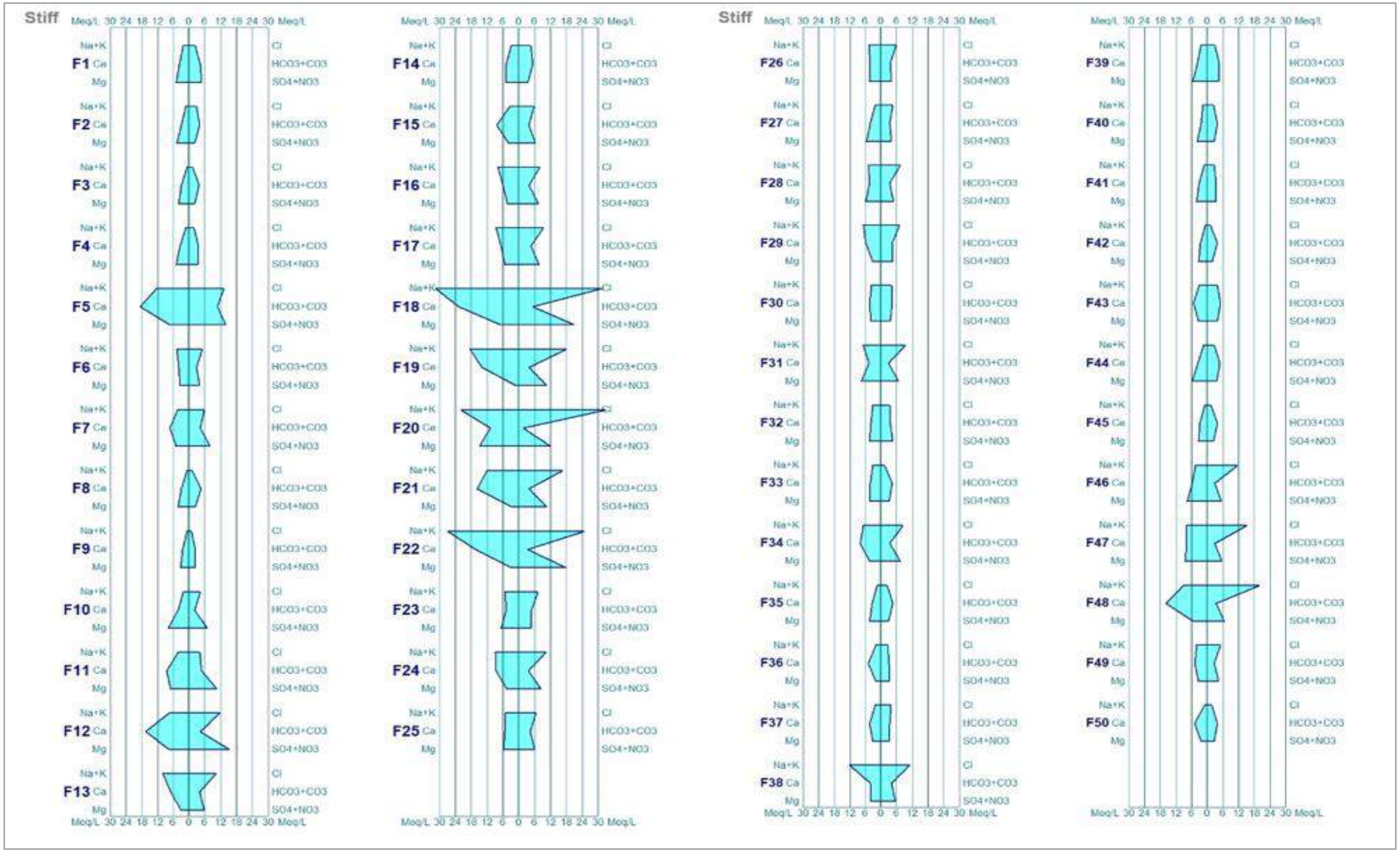

Figure III. 18 : Ain Azel Well Water Classification on Stiff Chart

III.8.4. Classification according to Stabler diagram

The Stabler diagram is used to classify water by chemical composition. This makes it possible to identify the various chemical characteristics of groundwater in our region.

- **Interpretation :**

The proportion of each ionic species in the cationic or anionic sum of a solution can be evaluated using the Stabler diagram. The anions and the cations are classified individually according to their decreasing order, the results obtained make it possible to differentiate the elements present in (**Table III. 9)** and **(Figure III. 16**).

Table III. 9 : Chemical facies of the drilling waters of the study area According STABLER

Chemical facies	Water points	Interpretation
Sulfated Magnesian	D1. D10. D32. D39	Sulfate (SO4-) and magnesium (Mg2+) are abundant in these waters. Generally, they are considered drinkable at normal concentrations, however a high sulfate concentration can cause a feeling of laxation. It is also possible that high levels of magnesium cause laxative effects.
Magnesian Bicarbonate	D2. D3. D4. D8. D9. D35. D40. D41. D42. D44. D45	Bicarbonate (HCO3-) and magnesium (Mg2+) are present in these waters. Generally, they are considered drinkable, although high levels of magnesium can cause a feeling of laxity.
Calcium sulfate	D7. D11. D12. D15.	This is water containing a high content of sulfate (SO4-) and calcium (Ca2+). At normal concentrations, these waters generally pose no danger to human health, and they are considered drinkable..
Calcium Bicarbonate	D14. D34. D50	Waters containing bicarbonate (HCO3-) and calcium (Ca2+) are present in this box. These waters are generally considered drinkable and may have health benefits due to their high calcium levels..
Calcium Chloride	D5. D21. D22. D24. D25. D30. D34. D36. D37. D47. D48. D49	The waters present in this box are abundant in chloride (Cl-) and calcium (Ca2+). They may be drinkable, however a high chloride concentration can give a salty flavor to the water..
Magnesian Chloride	D23. D27.D28. D31. D46	These waters contain a large quantity of chloride (Cl-) and magnesium (Mg2+). It is possible to consume them, but high concentrations of chloride and magnesium can influence the flavor of the water.
Sodium chloride	D6. D13. D16. D17. D18. D19. D20. D26. D29. D38	This box indicates waters containing a high content of chloride (Cl-) and sodium (Na+). These waters may be drinkable, however a high chloride concentration can give a salty flavor to the water.

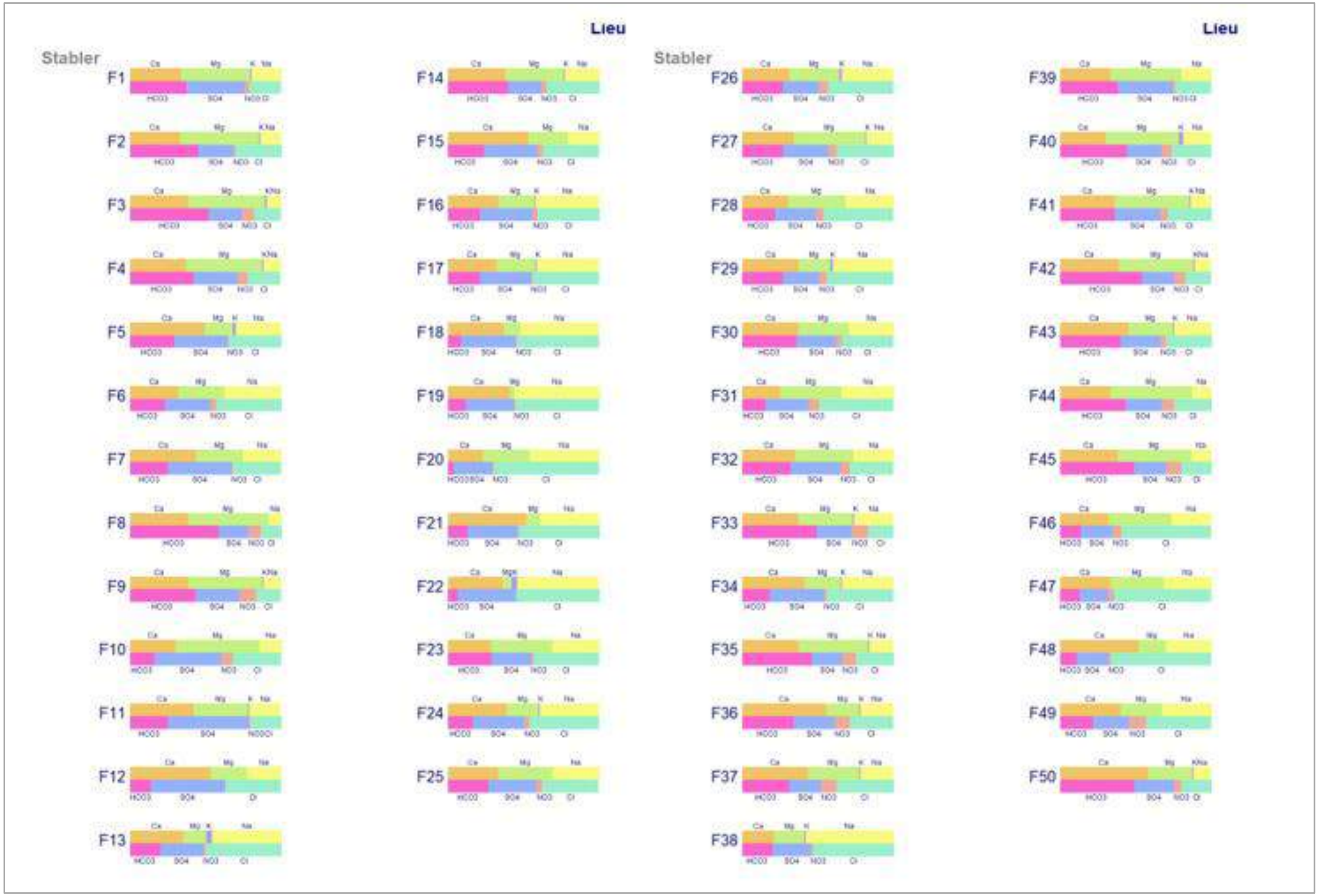

Figure III. 19 : Water classification of Ain Azel boreholes on Stabler diagram

III.9. Irrigation suitability of water

III.9.1. Electrical conductivity

It is crucial to take into account the correlation between water conductivity and irrigation in order to assess the quality of the water used in this situation. The electrical conductivity of the water used for irrigation makes it possible to directly evaluate its salt concentration. Controlling water salinity is of paramount importance in order to avoid adverse effects on plant growth and irrigation efficiency.

Table III. 10 : Water classification by electrical conductivity [77]

Class	**Electrical conductivity in (µS)**	**Classification**
C1	EC< 250	Low salinity water
C2	250< EC< 270	Medium salinity water
C3	270< EC< 2250	High salinity water
C4	2250 < EC< 5000	Very high salinity water

- **<u>InterprEtation :</u>**

Conductivity measurements were made of the Ain Azel boreholes on the samples at 19 ° C. Despite the high electrical conductivity in the study region, the measured electrical conductivity has an amplitude of variation of 600≤ CE ≤5800µS/cm. It is crucial to maintain an adequate electrical conductivity of the irrigation water, usually between 600 and 1700 µ S/cm, in order to guarantee optimum growing conditions of the crops and to avoid salinity problems. The measured majority of our groundwater conductivity (50 Drilling) in our Azel Ain regions belongs to Class C3, except drilling (5.12.18.19.20.21.22.23.47.48) belongs to Class C4 which translates as suitable for irrigation**. (Table A.3)**

III.9.2. Sodium absorption ratio (SAR)

The assessment of groundwater quality for irrigation is influenced by sodium concentration, as it reduces soil permeability. The risk of sodium in irrigation water can be fully captured by SAR, which establishes the criteria for its contribution to agriculture.

The following equation defines the sodium absorption ratio (SAR):

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \qquad \textbf{III.8}$$

Table III. 11 : SAR classification [78]

SAR	Classification
SAR <10	Alkalinity risk is low.
10 <SAR <18	Alkalinity risk is medium.
18 <SAR <26	Alkalinity risk is high.
SAR > 26	Risk of alkalinity is very high.

The RAS values calculated and the interpretation shown in **(Table A.4)** and **(Figure III.17**):

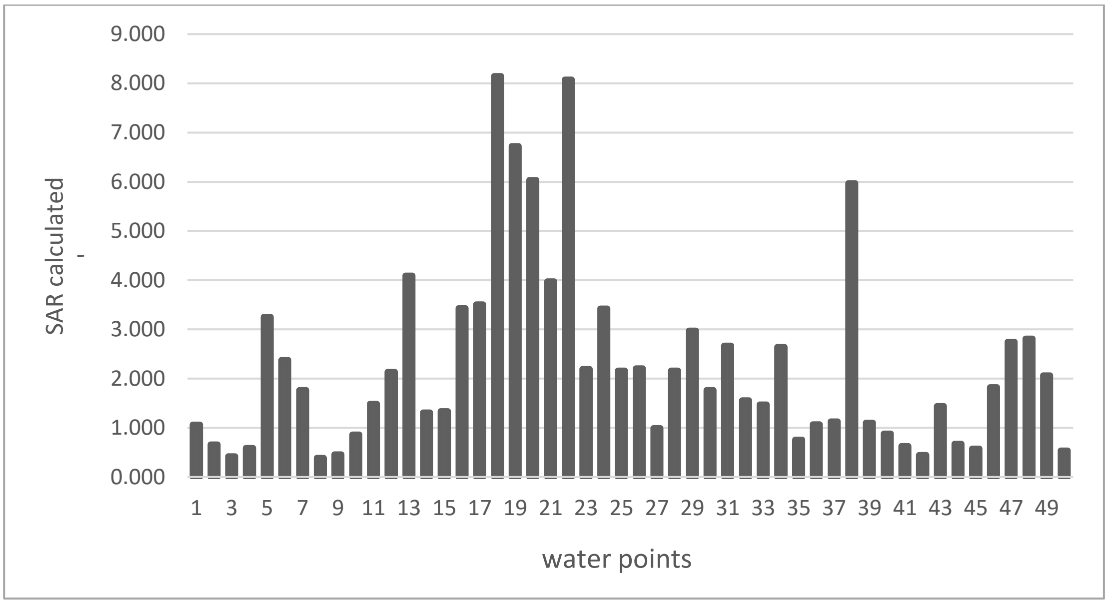

Figure III. 20 : Histogram of the SAR values of the different water points

- **<u>Interpretation :</u>**

All results from the analysis of the Ain Azel boreholes with SAR values between 0.39 and 8.15 and all results below 10 meq, suggesting a low risk of alkalinity. Therefore, all water samples are excellent for irrigation.

III.9.3. Wilcox diagram (Sodium percentage Na%)

According to Wilcox, the classification is based on electrical conductivity and the amount of sodium in water, expressed as a percentage. The representation of the various samples in this scheme makes it possible to characterise the waters according to their capacity to be used for irrigation using the following equation:

$$\%Na = \frac{Na^{+}}{Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}} \times 100 \qquad \textbf{III.9}$$

- **<u>Interprétation :</u>**

According to the Wilcox diagram **(Figure III.18)**, it can be observed that the representation of the percentage of sodium in relation to the conductivity of the water points of the Mio-Plio-Quaternary aquifer reveals that:

- ✓ Class C1 is assigned to 12% of water points, indicating that they offer exceptional quality for irrigation. This suggests that these waters have low exchangeable sodium and low electrical conductivity, making them perfect for irrigation without the risk of salt accumulation in the soil.
- ✓ Class C2 is assigned to 62% of water points, indicating that they offer adequate quality for irrigation. Despite a slight decrease in quality compared to class C1, these waters remain suitable for irrigation.
- ✓ Class C4 is assigned to 12% of water points, indicating poor irrigation quality. These waters have an increased concentration of exchangeable sodium and increased electrical conductivity, which can lead to risks of salt accumulation in the soil.
- ✓ Class C5 is assigned to 14% of water points, indicating poor irrigation quality. Exchangeable sodium and the high electrical conductivity of these waters make them unsuitable for irrigation due to the high risk of accumulation of salts in the soil and damage to crops.

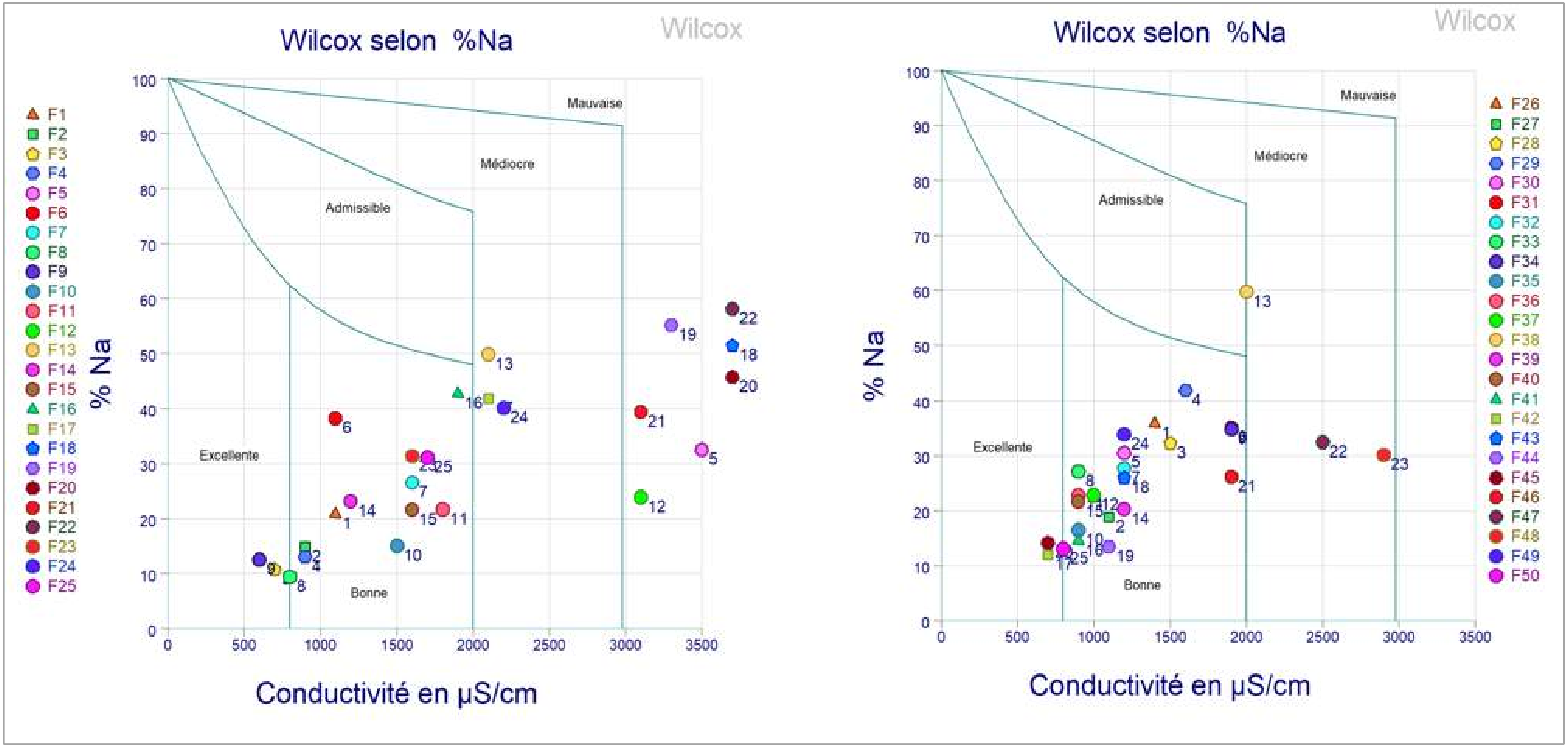

Figure III. 21 : Ain Azel Water Classification on Wilcox Diagram

III.9.4. Wilcox log diagram (Sodium absorption ratio (SAR))

The electrical conductivity of water and the adsorption index of SAR sodium, which is calculated using three elements: sodium, magnesium and calcium, are necessary for use.

- **<u>Interpretation :</u>**

According to the Wilcox log diagram of the SAR method (**Figure III.19**), it can be observed that the SAR values in relation to the electrical conductivity of the water points of the Mio-Plio-Quaternary aquifer reveal that:

- ✓ 76% of water points are classified in class (C3 S1) and (C2 S1): This category includes high salinity waters with a low risk of alkalination, which means that they are suitable for irrigation.
- ✓ 24% of water points are classified in class (C4 S1), (C4 S2) and (C3 S2), suggesting poor irrigation quality. Generally, water in this category is perceived to be slightly unsuitable for irrigation.

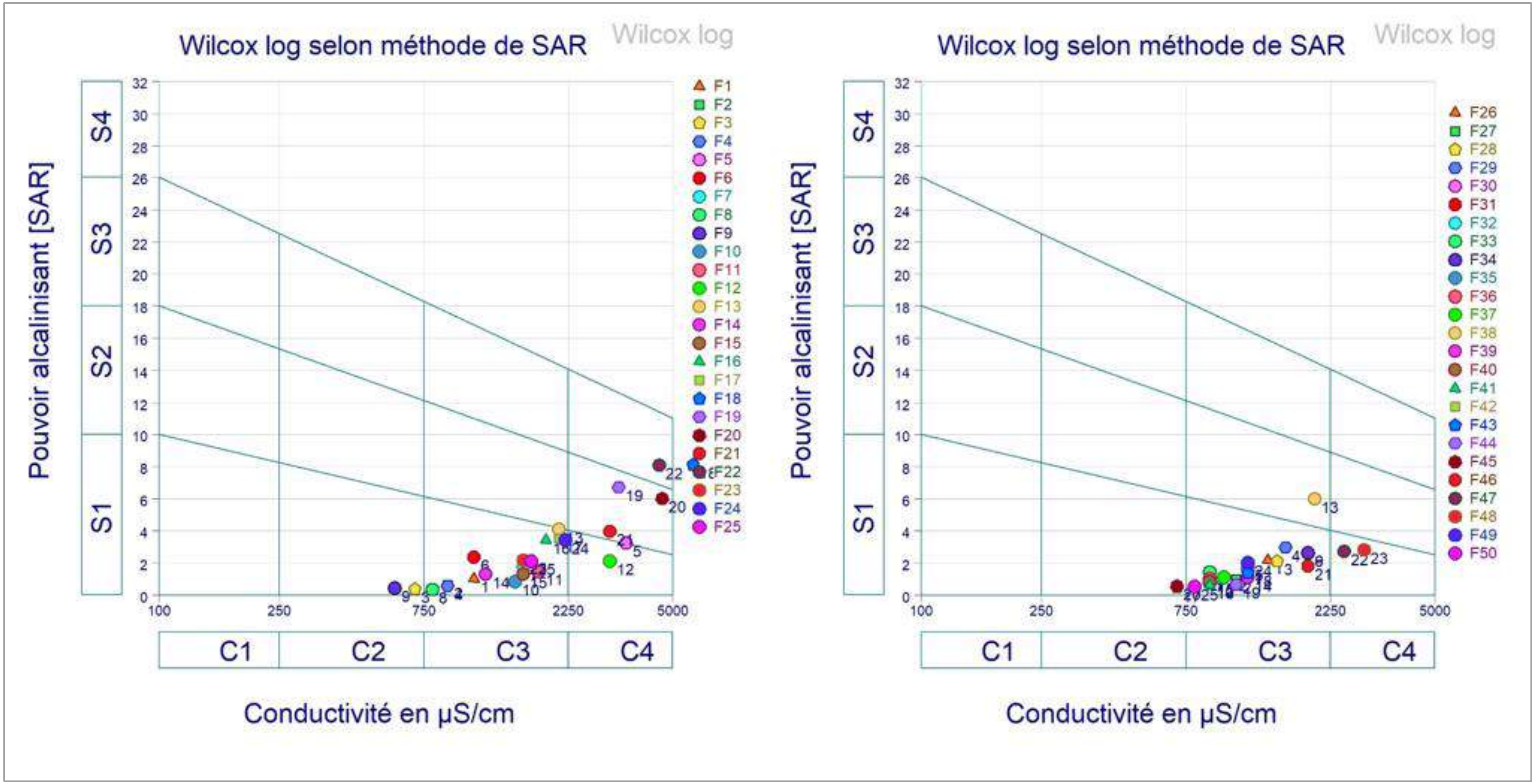

Figure III. 22 : Ain Azel bore water classification on Wilcox log diagram

III.9.5. Riverside diagram

The Riverside diagrams, in conjunction with the determination of alkalination risk, allow the classification of irrigation water according to the measured CEET parameters of the SAR.

- **Interpretation :**

According to the Riverside SAR method diagram (**Figure III.20**), it can be observed that the representation of the sodium absorption ratio in relation to the conductivity of the water points of the Mio-Plio-Quaternary aquifer reveals that:

- ✓ Class (C3-S1) and (C2-S1): Includes waters with high salinity and low risk of alkalination. These are only four wells, representing 78% of the wells. Water in this category has an increased risk of sodium accumulation in the soil and generally requires specific management methods, such as drainage, in order to be used for proper irrigation.
- ✓ Class (C4-S1) and (C3-S2): Includes waters with very high salinity and low risk of alkalination, representing 10% of the water points analysed. Water in this category has a high risk of sodium accumulation in the soil and is generally unsuitable for irrigation.
- ✓ Class (C4-S2), (C4-S2), (C5-S3) and (C4-S3): It corresponds to waters with extremely high salinity and medium risk of alkalination. The water points of the Mio-Plio-Quaternary aquifer account for 12 per cent of this amount. In general, water in this category is considered to be totally unsuitable for irrigation.

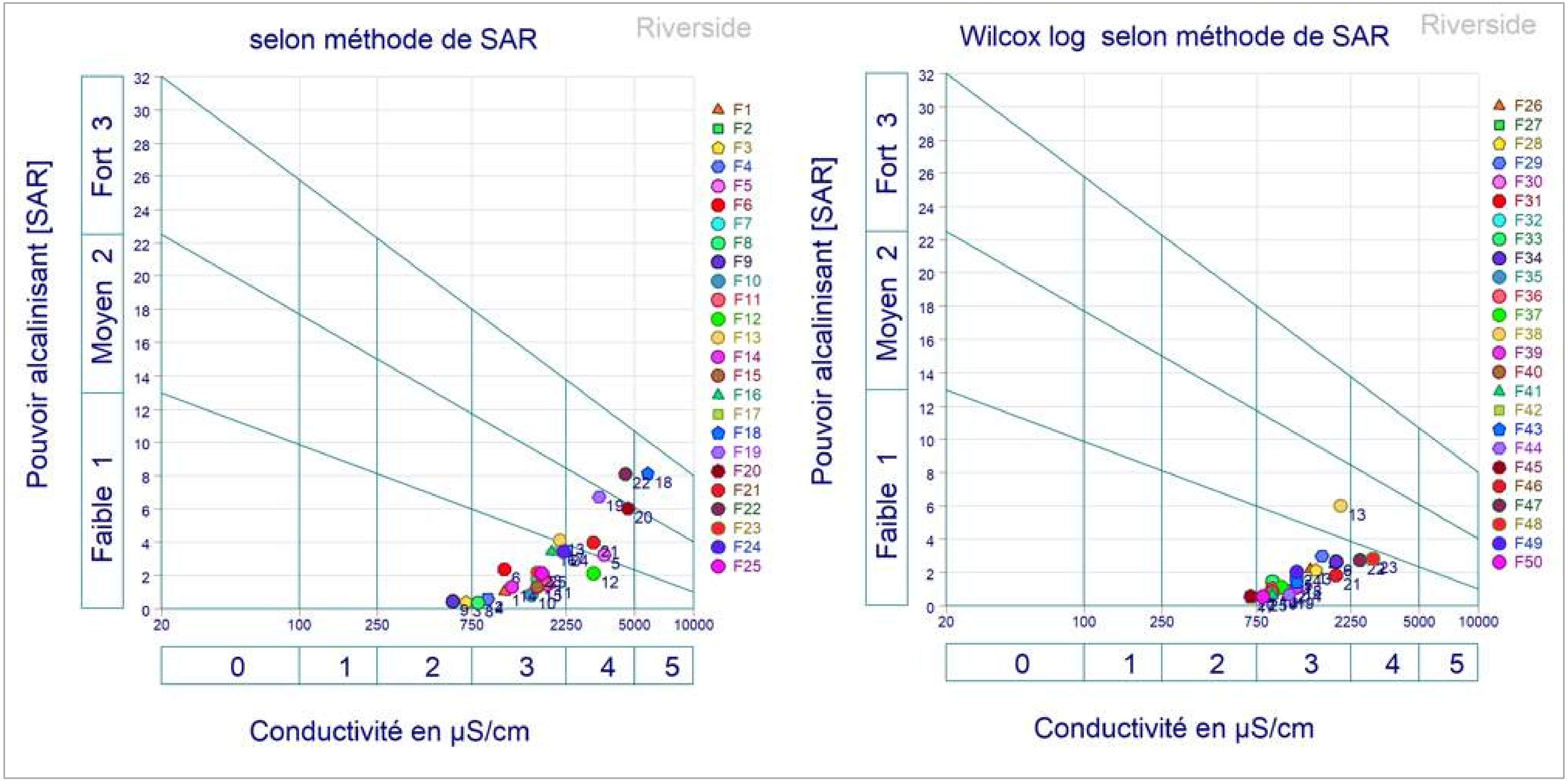

Figure III. 23 : Water classification of the Ain Azel boreholes on the Riverside diagram

III.9.6. Percentage of soluble sodium (SSP)

Percentage soluble sodium (SSP) is also used to assess the risk associated with sodium **[65]**. In addition, the SSP called% Na is calculated using the following equation:

$$SSP = \frac{Na^{+}+K^{+}}{Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}} \times 100 \quad \textbf{III.10}$$

Table III. 12 : Classification of Na (%) **[78]**

SSP (%)	Category
SSP < 20	Excellent
20 <SSP < 40	Good
40 <SSP < 60	Eligible
60 <SSP < 80	Poor
SSP > 80	Bad

The calculated SSP values and the interpretation shown in **(Table A.5)** and **(Figure III.21**):

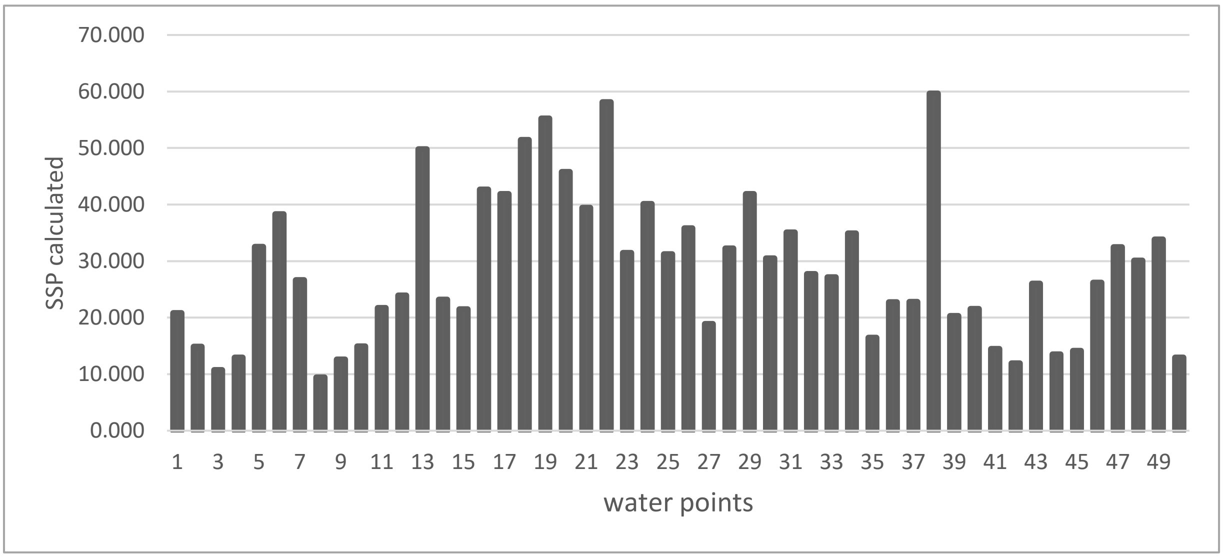

Figure III. 24 : Histogram of the SSP values of the different water points

- **<u>Interpretation :</u>**

The estimated SSP values ranged from 9.40% to 59.66%. With an average of 28.72%. These results indicate that the majority of the boreholes studied are good for irrigation.

III.9.7. Residual sodium bicarbonate (RSBC)

The concentration of bicarbonate and carbonate affects the irrigation capacity of the water. High RSBC water (resudial sodium bicarbonate) has a high pH. The soil irrigated with such water becomes infertile and leads to the deposition of sodium carbonate. **[66]** The RSBC is calculated by the following equation:

$$RSBC = [HCO_3^-] - [Ca^{2+}] \quad \text{...} \quad \textbf{III.11}$$

Table III. 13 : Water classification by RSBC **[80]**

Water class	RSBC value (meq/l)	Water quality
1	RSBC < 5	Satisfying
2	5 <RSBC< 10	Marginal
3	RSBC>10	Unsatisfactory

The RSBC values calculated and the interpretation shown in **(Table A.6)** and **(Figure III.22)**:

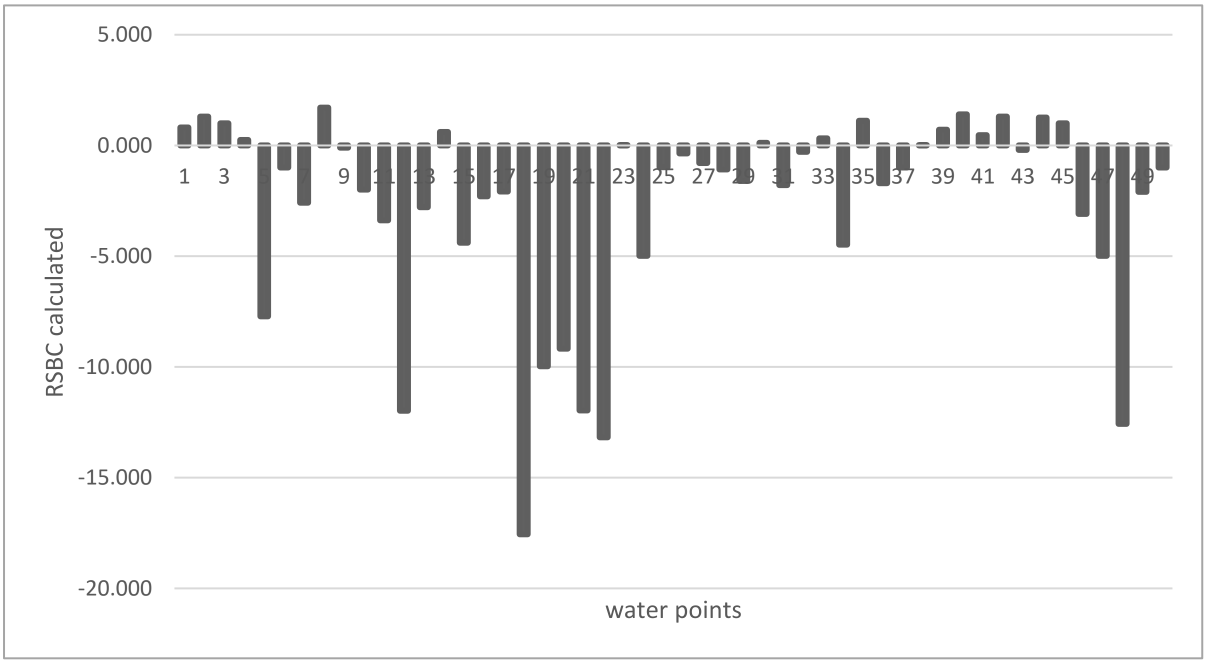

Figure III. 25 : Histogram of the RSBC values of the study area

➢ **<u>Interpretation :</u>**

The calculated RSBC values range from -17.56 to 1.708, indicating that most groundwater samples have a RSCB below 0. It is reported that if the value of RSBC is less than 5, the water is satisfactory for irrigation. Thus, all water samples have excellent quality for irrigation proposals.

III.9.8. Permeability index (IP)

The permeability index (PI) was also used to assess sodium risk and water suitability for agricultural use. This index is calculated by the method suggested by Doneen. **[81]** in the following equation:

$$IP= \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+}+Mg^{2+}.+Na^{+}.} \times 100 \ldots\ldots\ldots\ldots\ldots \textbf{III.12}$$

- ✓ IP greater than 75%: water is suitable for irrigation.
- ✓ 25% to 75%: water can be used under certain conditions.
- ✓ IP less than 25%: water is no longer usable. **[80]**

The calculated permeability index (PI) values and the interpretation shown in **(Table A.7)** and **(Figure III.23)**:

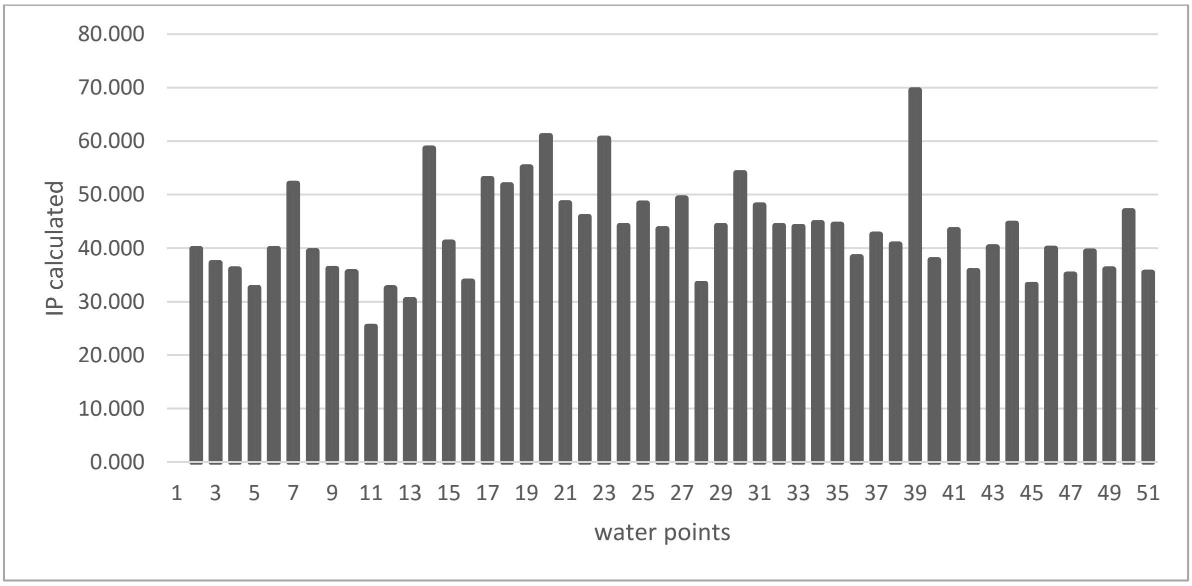

Figure III. 26 : Histogram of IP values of different water points

➢ **<u>Interpretation:</u>**

The permeability index results show a variation from 25.31% to 69.51% with an average of 42.89%. These results indicate that the majority of the boreholes studied are eligible for irrigation.

III.9.9. Magnesium risk (VAS)

Water has a balance between calcium and magnesium. However, a high magnesium content in water can jeopardize soil quality and reduce agricultural yields. Soil pH can be altered by the alkaline nature of magnesium, which can affect the availability of nutrients to plants. Thus, in order to avoid adverse effects on agricultural productivity, it is essential to carefully monitor the concentration of magnesium in the water used for irrigation. **[82]**

As indicated in the following formula:

$$VAS = \frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}} \times 100 \ldots\ldots\ldots\ldots \textbf{III.13}$$

- ✓ If the VAS water is greater than 50%, it is unsuitable for irrigation;
- ✓ If VAS is less than 50%, this is appropriate. Very useful for irrigation. **[80]**

The calculated Magnesium Risk (VAS) values and the interpretation shown in **(Table A.8)** and **(Figure III.24**):

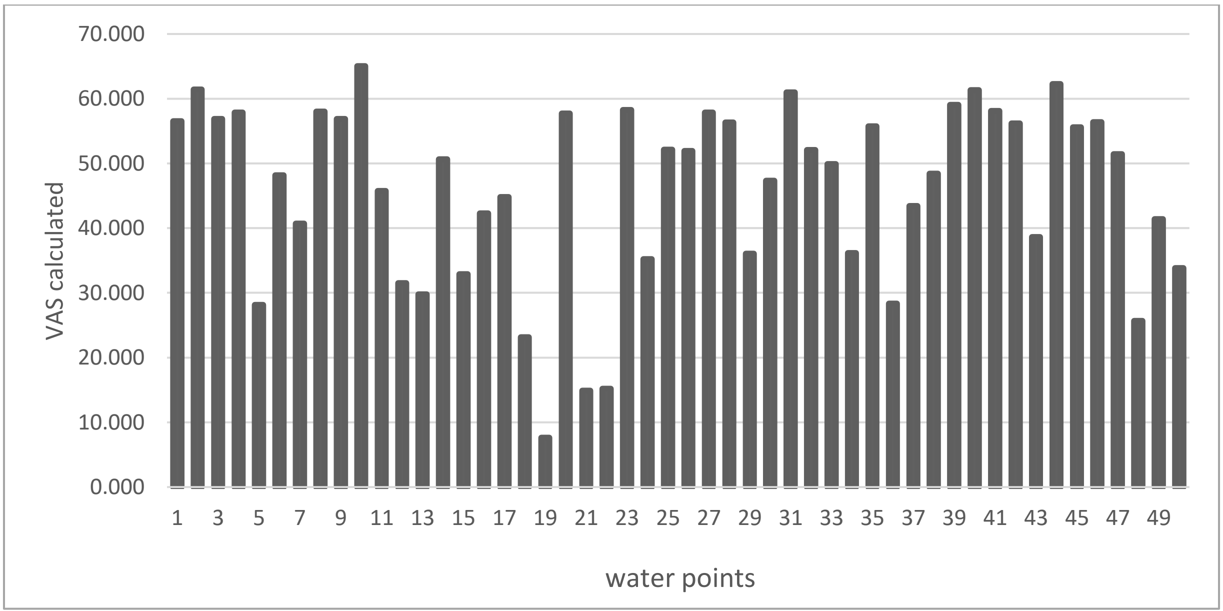

Figure III. 27 : Histogram of the VAS values of the different water points

- **<u>Interpretation :</u>**

The variation in VRE values is between 7.62% and 65.03%, with an average of 45.83%. These results indicate that 50% of the boreholes have suitable water in terms of Magnesium Hazard (VAS), and 50% of the boreholes have inadequate water according to this criterion.

III.9.10. Report by Kelly (KR)

Kelly's report, which examines sodium, calcium and magnesium levels, can also be used to assess the ability of water to be used for irrigation.

The Kelly report is used to compare sodium, calcium and magnesium. **[83]**

As indicated in the following formula:

$$KR = \frac{Na^{+}}{Ca^{2+}+Mg^{2+}} \quad \textbf{III.14}$$

- ✓ If KR > 1 water is not suitable for irrigation;
- ✓ If KR < 1, water it is suitable for irrigation **[80]**

The calculated Kelly Report (KR) values and interpretation shown in **(Table A.9)** and **(Figure III.25)**:

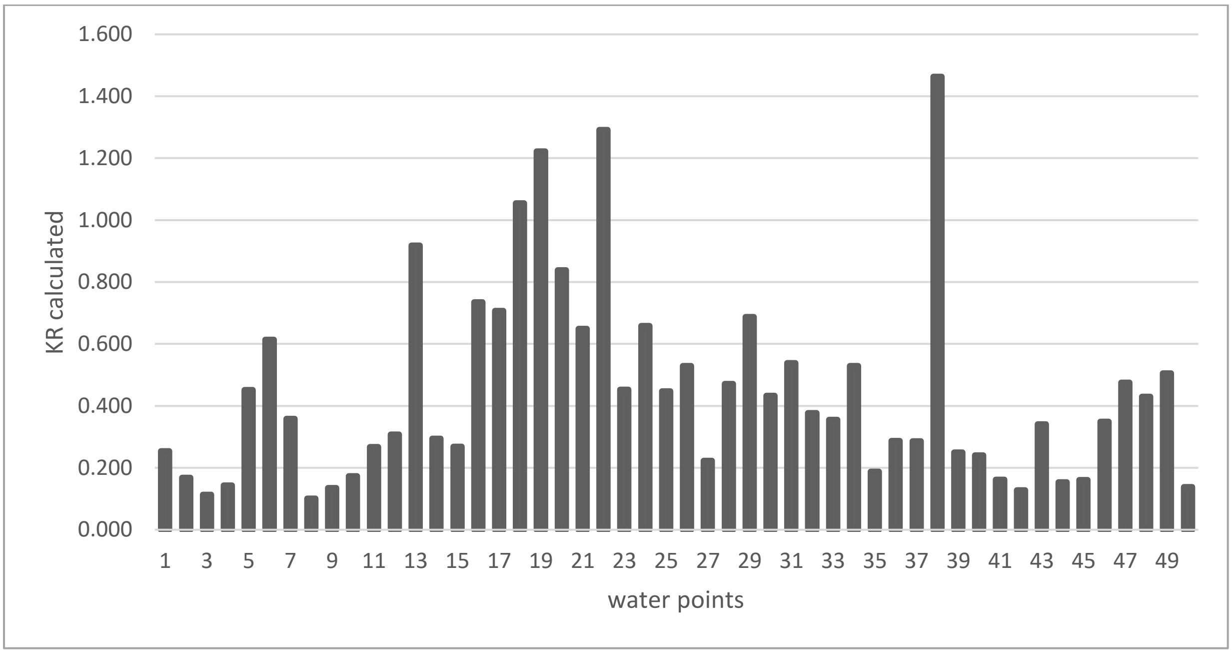

Figure III. 28 : Histogram of the KR values of the different water points

➢ **<u>Interpretation :</u>**

Based on the Kelly ratio (KR) classification, the measurements obtained for the water points analyzed fluctuate between 0.1 meq/l and 1.463 meq/l, with an average of 0.446 meq/l. These values indicate that all water points analyzed are considered suitable for irrigation, except: D18, D19 and D38.

The results of the water indices for agricultural use for the (50) boreholes in our study area are presented in the table below:

Table III. 14 : Calculated irrigation indices of the study area

Wp	SAR	SSP	RSBC	IP	VAS	KR	Na%	Wp	SAR	SSP	RSBC	IP	VAS	KR	Na%
D1	1,062	20,821	0,813	39,867	56,552	0,254	20,123	**D26**	2,209	35,828	-0,357	49,290	51,912	0,529	33,945
D2	0,662	14,865	1,300	37,230	61,446	0,168	14,306	**D27**	0,995	18,911	-0,799	33,365	57,876	0,223	18,078
D3	0,420	10,723	1,005	36,017	56,877	0,113	10,068	**D28**	2,163	32,271	-1,084	44,150	56,337	0,472	31,942
D4	0,590	12,951	0,242	32,586	57,876	0,143	12,430	**D29**	2,976	41,877	-1,596	54,013	36,033	0,688	39,971
D5	3,255	32,503	-7,716	39,864	28,124	0,451	30,448	**D30**	1,768	30,508	0,116	47,974	47,349	0,433	30,081
D6	2,379	38,294	-0,992	52,082	48,188	0,614	37,873	**D31**	2,669	35,091	-1,791	44,171	60,981	0,539	34,956
D7	1,767	26,635	-2,581	39,436	40,722	0,359	26,326	**D32**	1,558	27,701	-0,290	43,977	52,055	0,377	27,268
D8	0,385	9,402	1,708	36,131	58,032	0,100	9,088	**D33**	/	/	/	/	/	/	/
D9	0,460	12,600	-0,102	35,467	56,877	0,135	11,827	**D34**	2,644	34,927	-4,477	44,373	36,173	0,529	34,394
D10	0,860	14,949	-1,997	25,315	65,030	0,174	14,772	**D35**	0,756	16,457	1,111	38,289	55,741	0,188	15,668
D11	1,486	21,706	-3,385	32,505	45,769	0,267	20,929	**D36**	1,072	22,758	-1,696	42,562	28,351	0,287	22,191
D12	2,133	23,898	-11,977	30,269	31,490	0,308	23,412	**D37**	1,126	22,815	-0,999	40,672	43,444	0,286	22,053
D13	4,096	49,819	-2,791	58,603	29,773	0,918	46,078	**D38**	5,970	59,657	0,002	69,512	48,437	1,463	59,037
D14	1,309	23,187	0,616	41,027	50,647	0,294	22,592	**D39**	1,103	20,322	0,711	37,783	59,060	0,250	19,904
D15	1,340	21,516	-4,385	33,756	32,917	0,268	21,035	**D40**	0,879	21,521	1,404	43,390	61,320	0,240	18,828
D16	3,429	42,661	-2,289	52,932	42,289	0,735	42,123	**D41**	0,629	14,465	0,462	35,734	58,107	0,162	13,882
D17	3,508	41,855	-2,083	51,758	44,819	0,707	41,129	**D42**	0,446	11,943	1,304	40,136	56,185	0,127	11,210
D18	8,150	51,447	-17,562	55,110	23,140	1,054	51,198	**D43**	1,440	26,027	-0,196	44,586	38,632	0,340	25,181
D19	6,723	55,207	-9,973	60,952	7,616	1,222	54,752	**D44**	0,673	13,490	1,257	33,184	62,246	0,153	13,260
D20	6,038	45,769	-9,175	48,409	57,698	0,838	45,448	**D45**	0,578	14,103	1,006	39,942	55,570	0,160	13,766
D21	3,976	39,458	-11,969	45,820	14,906	0,649	39,293	**D46**	1,827	26,161	-3,087	35,058	56,360	0,349	25,748
D22	8,074	58,138	-13,175	60,483	15,166	1,292	54,081	**D47**	2,745	32,449	-4,986	39,405	51,419	0,476	32,137
D23	2,192	31,478	0,010	44,171	58,270	0,453	31,029	**D48**	2,814	30,094	-12,576	36,035	25,661	0,429	30,011
D24	3,425	40,091	-4,980	48,359	35,205	0,658	39,413	**D49**	2,065	33,849	-2,088	46,903	41,404	0,506	33,444
D25	2,160	31,204	-0,984	43,592	52,138	0,447	30,752	**D50**	0,538	12,939	-0,991	35,455	33,823	0,138	12,053

III.10. Calculi of the Water Quality Index (WQI)

The Water Quality Index (WQI) is an extremely coherent, practical and well-structured approach to assessing and reporting data on the overall water quality of a region. The purpose of WQI is to help determine whether groundwater sources are suitable for their intended use.

The assessment of the relevance of water for irrigation is carried out using the Water Quality Index (WQI). Different criteria are taken into account. These elements are evaluated to assess their influence on plant growth and soil health. By combining this information, the water quality for irrigation is assessed using an WQI score.

The water quality index was calculated as follows:

$$WQI = \sum_{n=1}^{n} qi \times Wi \quad \textbf{III.15}$$

- ✓ Wi = Relative weight
- ✓ qi: quality rating

The overall variability of water quality is illustrated by the standardized weight of parameter i as a function of its importance.

$$Wi = \frac{Wi}{\sum_{n=1}^{n} Wi} \quad \textbf{III.16}$$

- ✓ Wi = The weight of each parameter
- ✓ n = Number of parameters

Table III. 15 : Weight of chemical parameters (Algerian standards) [85]

Settings	Algerian standards	Weight (Wi)
PH	≥ 6,5 et ≤ 9	4
TH(°F)	300	2
K^+	12	2
Na^+	200	4
Mg^{2+}	150	3
Ca^{2+}	200	3
NO3-	50	5
Cl^-	500	5
SO_4^{2-}	400	5
TDS	1500	5

The quality rating "qi" is usually a numerical measure or scale that assesses the quality or performance of each criterion.

$$qi = (\frac{Ci}{Si}) \times 100 \quad \textbf{III.17}$$

- ✓ This: the concentration of each chemical parameter
- ✓ If: the Algerian water standard for each chemical parameter

Table III. 16 : WQI interval and water quality classification **[86]**

WQI	Interval Water Type
WQI<50	Excellent water quality
51<WQI<100	Good water quality
101<WQI<200	Poor water quality
201<WQI<300	Very poor water quality
WQI >300	Water unfit for consumption

The results of the 50 drills in our study area revealed the following:

Table III. 17 : Results of the Water Quality Indices of the study area

	PH		TH(°F)		K^+		Na^{2+}		Mg^{2+}		Ca^{2+}		NO_3^-		Cl^-		SO_4^{2-}		TDS		
Water points	**Wi**	**Qi**	**Wi**	**Qi**	**Wi**	**Qi**	**Wi**	**Qi**	**Wi**	**Qi**	**Wi**	**Qi**	**Wi**	**Qi**	**Wi**	**Qi**	**Wi**	**Qi**	**Wi**	**Qi**	**WQI**
D1	0,11	89,56	0,05	14,27	0,05	25,00	0,11	26	0,08	40,00	0,08	38	0,13	46	0,13	18	0,13	57,50	0,13	49,33	42,81
D2	0,11	84,33	0,05	11,57	0,05	16,67	0,11	15	0,08	38,67	0,08	30	0,13	10	0,13	21	0,13	26,00	0,13	37,94	29,86
D3	0,11	83,33	0,05	13,22	0,05	16,67	0,11	9	0,08	32,00	0,08	30	0,13	72	0,13	10	0,13	20,00	0,13	32,61	33,90
D4	0,11	85,22	0,05	18,19	0,05	16,67	0,11	14	0,08	40,00	0,08	36	0,13	82	0,13	14	0,13	32,00	0,13	38,48	40,18
D5	0,11	84,78	0,05	37,22	0,05	258,33	0,11	135	0,08	59,33	0,08	188	0,13	26	0,13	94	0,13	165,00	0,13	156,30	116,24
D6	0,11	87,78	0,05	14,71	0,05	16,67	0,11	53	0,08	29,33	0,08	39	0,13	66	0,13	37	0,13	45,00	0,13	48,79	47,76
D7	0,11	85,89	0,05	19,11	0,05	16,67	0,11	50	0,08	40,00	0,08	72	0,13	32	0,13	43	0,13	93,50	0,13	72,24	56,71
D8	0,11	86,67	0,05	10,64	0,05	8,33	0,11	9	0,08	34,67	0,08	31	0,13	82	0,13	8	0,13	20,00	0,13	35,52	35,35
D9	0,11	91,11	0,05	17,46	0,05	16,67	0,11	9	0,08	26,67	0,08	25	0,13	78	0,13	7	0,13	20,00	0,13	24,85	33,50
D10	0,11	86,22	0,05	18,94	0,05	8,33	0,11	25	0,08	64,67	0,08	43	0,13	132	0,13	32	0,13	75,00	0,13	54,48	60,21
D11	0,11	85,22	0,05	26,59	0,05	50,00	0,11	48	0,08	57,33	0,08	84	0,13	18	0,13	30	0,13	125,00	0,13	79,94	62,44
D12	0,11	78,78	0,05	32,38	0,05	50,00	0,11	85	0,08	61,33	0,08	165	0,13	6	0,13	85	0,13	187,50	0,13	124,24	92,44
D13	0,11	85,44	0,05	20,01	0,05	241,67	0,11	105	0,08	24,00	0,08	70	0,13	40	0,13	74	0,13	69,00	0,13	81,03	75,98
D14	0,11	85,22	0,05	15,01	0,05	25,00	0,11	34	0,08	40,67	0,08	49	0,13	50	0,13	34	0,13	36,50	0,13	54,91	44,76
D15	0,11	84,89	0,05	21,65	0,05	25,00	0,11	39	0,08	33,33	0,08	84	0,13	82	0,13	43	0,13	69,50	0,13	65,21	58,88
D16	0,11	85,22	0,05	19,67	0,05	33,33	0,11	92	0,08	37,33	0,08	63	0,13	80	0,13	57	0,13	81,50	0,13	76,67	68,20
D17	0,11	79,33	0,05	22,83	0,05	50,00	0,11	100	0,08	44,67	0,08	68	0,13	20	0,13	68	0,13	89,50	0,13	85,09	66,16
D18	0,11	79,22	0,05	40,18	0,05	50,00	0,11	362	0,08	56,00	0,08	230	0,13	42	0,13	225	0,13	249,50	0,13	227,09	171,61
D19	0,11	80,56	0,05	48,24	0,05	50,00	0,11	213	0,08	9,33	0,08	140	0,13	44	0,13	129	0,13	125,00	0,13	129,45	104,05
D20	0,11	89,00	0,05	22,96	0,05	50,00	0,11	250	0,08	121,33	0,08	110	0,13	38	0,13	234	0,13	145,00	0,13	168,91	134,88
D21	0,11	83,11	0,05	31,55	0,05	16,67	0,11	140	0,08	22,67	0,08	160	0,13	46	0,13	118	0,13	125,00	0,13	120,79	94,36
D22	0,11	90,89	0,05	38,99	0,05	616,67	0,11	290	0,08	24,00	0,08	166	0,13	14	0,13	178	0,13	215,00	0,13	180,97	166,97
D23	0,11	86,56	0,05	16,10	0,05	25,00	0,11	61	0,08	55,33	0,08	49	0,13	48	0,13	52	0,13	52,50	0,13	66,61	54,76

D24	0,11	91,67	0,05	24,78	0,05	50,00	0,11	103	0,08	38,67	0,08	88	0,13	82	0,13	75	0,13	93,50	0,13	88,91	79,03
D25	0,11	83,33	0,05	16,86	0,05	25,00	0,11	60	0,08	49,33	0,08	56	0,13	82	0,13	46	0,13	66,50	0,13	68,30	60,19
D26	0,11	84,56	0,05	16,58	0,05	83,33	0,11	53	0,08	36,67	0,08	42	0,13	102	0,13	42	0,13	41,00	0,13	55,39	57,58
D27	0,11	81,78	0,05	16,86	0,05	33,33	0,11	26	0,08	46,67	0,08	42	0,13	76	0,13	34	0,13	45,00	0,13	48,73	47,74
D28	0,11	79,67	0,05	13,27	0,05	16,67	0,11	57	0,08	48,00	0,08	46	0,13	94	0,13	54	0,13	52,50	0,13	61,88	57,91
D29	0,11	83,78	0,05	16,56	0,05	100,00	0,11	74	0,08	27,33	0,08	60	0,13	94	0,13	52	0,13	47,50	0,13	65,82	63,76
D30	0,11	81,56	0,05	19,80	0,05	16,67	0,11	42	0,08	32,00	0,08	44	0,13	70	0,13	31	0,13	40,50	0,13	51,39	46,25
D31	0,11	77,44	0,05	15,39	0,05	8,33	0,11	76	0,08	60,67	0,08	48	0,13	166	0,13	67	0,13	69,00	0,13	73,76	75,42
D32	0,11	77,22	0,05	13,95	0,05	16,67	0,11	37	0,08	36,00	0,08	41	0,13	84	0,13	25	0,13	48,00	0,13	48,67	46,78
D33	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
D34	0,11	88,56	0,05	20,85	0,05	33,33	0,11	76	0,08	36,67	0,08	80	0,13	60	0,13	60	0,13	85,00	0,13	76,06	66,37
D35	0,11	84,33	0,05	9,28	0,05	25,00	0,11	18	0,08	36,67	0,08	36	0,13	116	0,13	18	0,13	25,00	0,13	42,42	44,76
D36	0,11	87,00	0,05	13,94	0,05	16,67	0,11	23	0,08	16,00	0,08	50	0,13	116	0,13	20	0,13	31,00	0,13	39,70	45,60
D37	0,11	85,00	0,05	14,04	0,05	25,00	0,11	26	0,08	27,33	0,08	44	0,13	128	0,13	29	0,13	28,00	0,13	43,09	49,33
D38	0,11	90,22	0,05	16,75	0,05	41,67	0,11	140	0,08	32,67	0,08	43	0,13	50	0,13	80	0,13	64,50	0,13	82,73	69,76
D39	0,11	86,56	0,05	13,51	0,05	16,67	0,11	28	0,08	46,67	0,08	40	0,13	34	0,13	21	0,13	52,50	0,13	50,12	41,23
D40	0,11	82,78	0,05	11,59	0,05	75,00	0,11	19	0,08	33,33	0,08	26	0,13	80	0,13	17	0,13	25,00	0,13	37,39	40,88
D41	0,11	87,44	0,05	11,00	0,05	16,67	0,11	14	0,08	35,33	0,08	32	0,13	58	0,13	20	0,13	35,50	0,13	38,61	37,42
D42	0,11	76,67	0,05	10,25	0,05	16,67	0,11	9	0,08	28,00	0,08	27	0,13	74	0,13	9	0,13	19,00	0,13	31,39	32,33
D43	0,11	84,33	0,05	19,16	0,05	33,33	0,11	35	0,08	28,00	0,08	55	0,13	58	0,13	28	0,13	41,00	0,13	53,45	45,62
D44	0,11	85,44	0,05	12,10	0,05	8,33	0,11	17	0,08	48,67	0,08	37	0,13	118	0,13	20	0,13	32,00	0,13	46,48	47,07
D45	0,11	83,89	0,05	17,71	0,05	8,33	0,11	12	0,08	29,33	0,08	29	0,13	96	0,13	11	0,13	20,00	0,13	33,21	37,15
D46	0,11	87,11	0,05	24,24	0,05	25,00	0,11	55	0,08	62,67	0,08	60	0,13	148	0,13	84	0,13	51,00	0,13	72,85	74,06
D47	0,11	85,67	0,05	22,66	0,05	25,00	0,11	91	0,08	69,33	0,08	81	0,13	134	0,13	109	0,13	56,50	0,13	89,58	84,17
D48	0,11	84,89	0,05	32,37	0,05	8,33	0,11	106	0,08	44,67	0,08	160	0,13	74	0,13	141	0,13	75,00	0,13	112,06	91,30
D49	0,11	87,89	0,05	12,40	0,05	16,67	0,11	49	0,08	28,00	0,08	49	0,13	176	0,13	38	0,13	36,50	0,13	50,55	61,58
D50	0,11	85,44	0,05	33,27	0,05	25,00	0,11	12	0,08	20,67	0,08	50	0,13	54	0,13	12	0,13	26,50	0,13	36,06	35,82

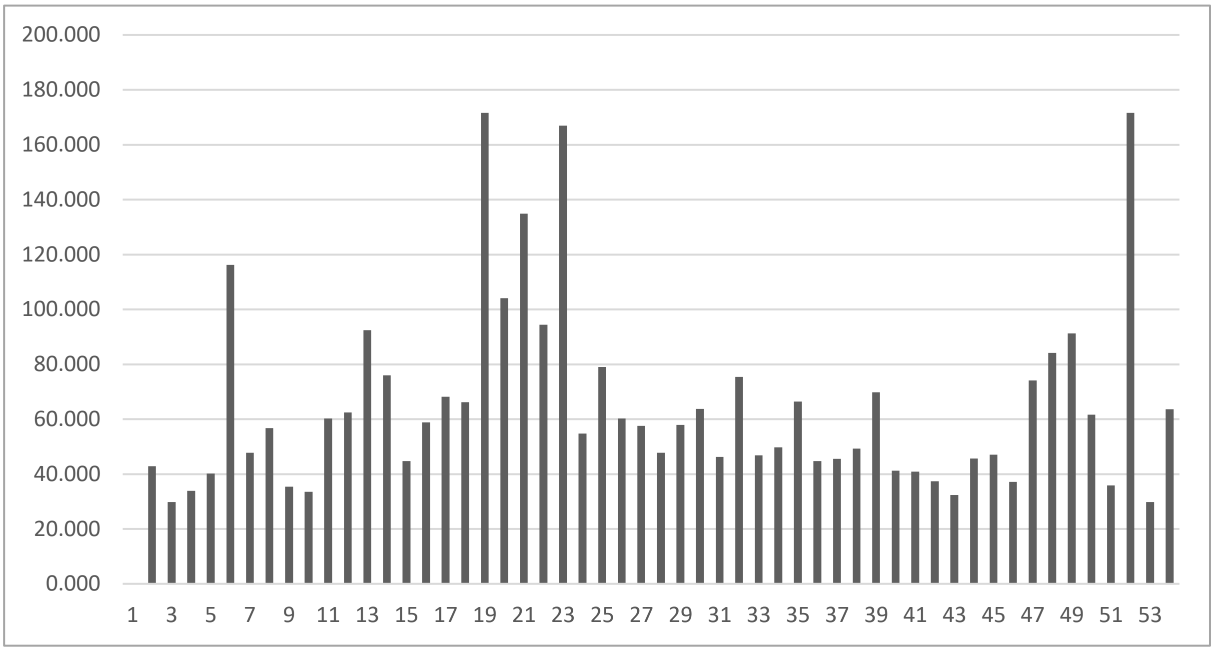

Figure III. 29 : Histogram of the WQI values of the different water points

- Interpretation:

From this table **(Table III.18)** and the histogram it can be seen:

Table III. 18 : **1**Classification

D1. D2. D4. D6. D7. D8. D9. D14. D22. D24. D25. D27. D30. D31. D32. D35. D36. D37. D39. D40. D41. D42. D43. D45. D48	WQI<50	Excellent water quality
D5. D10. D11. D12. D13. D15. D16.D17. D21. D23. D26. D28. D29. D34. D38. D46. D47. D49. D50	51<WQI<100	Good water quality
D3. D18.D19. D20	101<WQI<200	Poor water quality

According to the Water Quality Index (WQI), the measurements obtained for the water points of the Ain Azel zone analyzed fluctuate between 29,855 and 171,610, with an average of 63.9.

These values indicate that most of the water points analyzed are Excellent water quality and Good water quality and considered suitable for irrigation, except: (D3, D18, D19, D20, and D22) These analyses are Poor water quality and are not considered suitable for irrigation, Because it has exceeded quality standards and this is due to the high values of some parameters, such as TDS, TH and Na^{+}.

The TDS evaluates all solid compounds dissolved in water, such as minerals, salts, metals, and so on. Total hardness is essentially a measure of the calcium and magnesium content of water. In case of high hardness, limestone deposits may form, which may have an impact on water quality. Thus, high levels of TDS and TH have a negative effect on the water quality indices of our study.

III.11. Conclusion

The base index (BI) values for most water samples taken from the Mio-Plio-Quaternary aquifer of the study area are consistent and reliable, with the exception of drilling 33, which has a value exceeding the 10 per cent limit. This finding raises concerns about the quality of the water taken from this specific drilling.

Although the majority of the TAC values are within a potentially drinking range (between 2.0 and 5.5 meq/l), some drilling exceeds the recommended limits for human consumption, which requires special attention, and most samples appear to provide drinking water based on their TDS concentrations.

As regards other water quality parameters, such as temperature and pH, they comply with Algerian potability standards, which is reassuring as regards the safety of water for human consumption in the region studied. Electrical conductivity in some boreholes exceeds the maximum recommended limit, indicating excessive mineralization in these waters. Similarly, the hardness of the water varies from mild to moderately hard.

Analyses of the water from the 50 boreholes studied reveal concentrations of various ions, including calcium, magnesium, sodium, potassium, bicarbonates, chlorides, sulphates and nitrates. The results show that these concentrations comply with water quality standards in Algeria. On average, the ion contents are within acceptable ranges, indicating good water quality in the region studied, in terms of chemical composition. In conclusion, the water samples from the boreholes meet the water quality standards in Algeria, except for the boreholes shown in (**Table III. 7**).

To examine the chemical composition of Ain Azel's groundwater, we used diagram software such as Piper, Schoeler-Berkaloff, Stabler-Collins and Stiff.

Using the SSP and RSBC values to classify Mio-Plio-Quaternary water for irrigation, all water points are found to be of superior quality. According to the VAC and KR values, these waters are suitable for irrigation without requiring treatment.

According to the water quality index (WQI), the value of water points in the Ain Azel zone studied varies from 29,855 to 171,610, with an average of 63.9. According to these values, the majority of the water points analyzed have excellent water quality and good water quality, and are considered suitable for irrigation, with the exception of a few water points

Chapter IV:

Groundwater quality mapping

IV.1. Introduction

Groundwater quality assessment in a region is a multidisciplinary process involving data collection, laboratory analysis, comparison with quality standards, mapping and continuous management to ensure the safety and sustainability of groundwater resources.

Groundwater quality mapping is of paramount importance in assessing and managing the health of this resource. It gathers geo-referenced data on water quality, thus providing a visual view of the quality of this resource, which is essential for its sustainable and secure use. **[87]**

The purpose of this chapter is to study the distribution of the physic-chemical characteristics of water from drilling in the Ain Azel region. To achieve this objective, we will use a water quality mapping method using the Geographic Information System (ArcGIS 10.8.2) and based on the chemical analyses of the groundwater of Mio-Plio-Quaternaries.

IV.2. Presentation of ArcGIS

IV.2.1. Definition of ArcGIS

ArcGIS offers a comprehensive solution that facilitates the collection, organization, management, analysis, communication and dissemination of geographic information. ArcGIS plays a key role as a global platform for the development and use of Geographic Information Systems (GIS) to leverage geographic knowledge in government, business, education science and media. ArcGIS provides the opportunity to disseminate geographic data so that it is accessible and usable by anyone. **[88]**

IV.2.2. General Architecture of ArcGIS

ArcGIS can be divided into three main categories (**Figure IV. 1**):

- The organization and management of GIS data are carried out by ArcCatalog;
- ArcMap is the main application of ArcGIS, which allows to both view and process data (analysis, editing) in the "data view" window. The presentation of the maps is done in the "view of the organization" window;
- ArcToolbox is a toolbox where all geo-processing tools are grouped together **[89]**

IV.2.3. ArcMap

ArcMap is software for mapping and analyzing geographic data, created by Esri, a GIS company. It is included in the ArcGIS Desktop suite. Experts in various fields, such as geography, geology, urban planning, environmental management and other related disciplines, frequently use ArcMap to generate, visualize, analyze and share geographic information. Users have the ability to design maps, perform spatial analyses, manage geographic databases, view data in various formats and generate detailed mapping reports through ArcMap. **[89]**

ArcMap is a powerful instrument for groundwater quality mapping and assessment, providing users with the characteristics needed to visualize, analyze and transmit relevant geospatial data in this field.

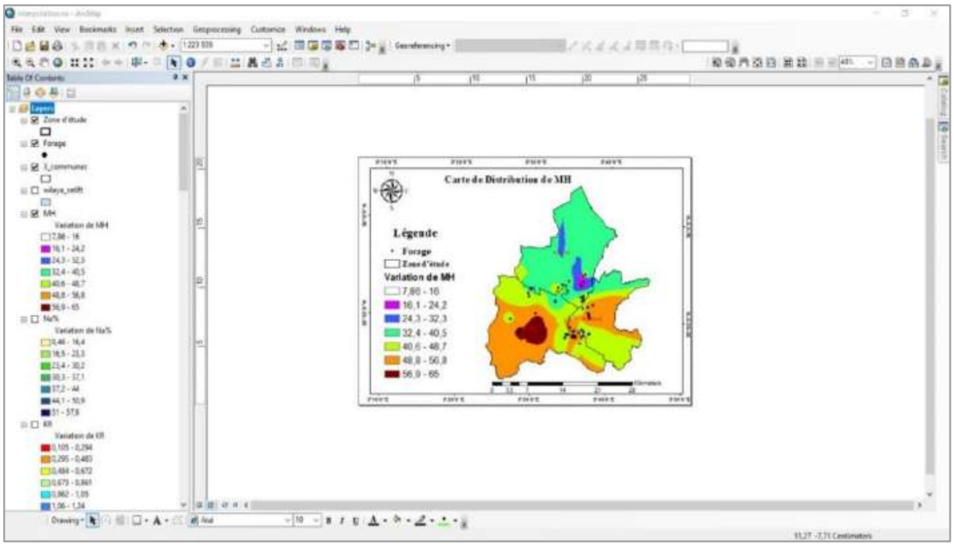

Figure IV. 1: Representation of the ArcMap software interface

IV.3. Presentation of water quality data for the study area

The groundwater in our study area is located in the plain of Ain Azel, and the majority of the boreholes in the study area are located at Ain Azel, although there are some boreholes located at Ain Lahdjer and Beidha Bordj.

The results of the physical and chemical analyses for the drilling of our study area are presented in **(Table A.1)**, Coordinates UTM of the drilling of the study area presented in **(Table IV.1)**:

Table IV. 1 : Coordinates UTM of the boreholes in the study area.

Drilling		coordinate X(UTM)	coordinate Y(UTM)	Drilling		coordinate X(UTM)	coordinate Y(UTM)
Drilling D 1 Ain Azel	D1	726459,37	3969223,34	Drilling D 1 Beidha Bordj	D26	737798,83	3971494,95
Drilling D 2 Ain Azel	D2	726919,19	3967499,83	Drilling D 2 Beidha Bordj	D27	737012,26	3969901,37
Drilling D 3 Ain Azel	D3	723451,44	3966031,97	Drilling D 3 Beidha Bordj	D28	736881,77	3971038,54
Drilling D 4 Ain Azel	D4	723440,66	3965476,67	Drilling D 4 Beidha Bordj	D29	735887,85	3970642,42
Drilling D 5 Ain Azel	D5	725264,74	3973694,82	Drilling D 5 Beidha Bordj	D30	737130,30	3969256,56
Drilling D 6 Ain Azel	D6	724832,12	3972943,72	Drilling D 6 Beidha Bordj	D31	737341,28	3968892,65
Drilling D 7 Ain Azel	D7	724947,46	3972392,03	Drilling D 7 Beidha Bordj	D32	737270,57	3969630,37
Drilling D 8Ain Azel	D8	725386,45	3965988,79	Drilling D 8 Beidha Bordj	D33	737470,06	3965966,28
Drilling D 9 Ain Azel	D9	725461,89	3965798,43	Drilling D 9 Beidha Bordj	D34	737394,60	3965835,43
Drilling D 10 Ain Azel	D10	727762,13	3965432,88	Drilling D 10 Beidha Bordj	D35	736280,35	3966304,29
Drilling D 11 Ain Azel	D11	721447,88	3967801,37	Drilling D 11 Beidha Bordj	D36	735869,12	3966632,82
Drilling D 12 Ain Azel	D12	730310,67	3971728,73	Drilling D 13 Ain Azel	D37	736326,82	3965503,61
Drilling D 1 Ain Lahdjar	D13	735456,15	3972728,16	Drilling D 14 Ain Azel	D38	735308,74	3966001,19
Drilling D 2 Ain Lahdjer	D14	730796,07	3974300,83	Drilling D 15 Ain Azel	D39	734198,60	3966186,85
Drilling D 3 Ain Lahdjer	D15	731580,76	3974999,81	Drilling D 16 Ain Azel	D40	733995,70	3965317,93
Drilling D 4 Ain Lahdjer	D16	732767,56	3975647,51	Drilling D 17 Ain Azel	D41	734250,40	3965171,02
Drilling D 5 Ain Lahdjer	D17	735847,51	3973077,16	Drilling D 18 Ain Azel	D42	734065,04	3965095,56
Drilling D 6 Ain Lahdjer	D18	735237,02	3975281,54	Drilling D 19 Ain Azel	D43	735564,33	3963941,02
Drilling D 7Ain Lahdjer	D19	735473,74	3976737,76	Drilling D 20 Ain Azel	D44	734650,89	3965242,79
Drilling D 8 Ain Lahdjer	D20	735964,36	3977151,50	Drilling D 21 Ain Azel	D45	735881,70	3965244,86
Drilling D 9 Ain Lahdjer	D21	735724,03	3975819,37	Drilling D 22 Ain Azel	D46	733208,21	3965636,65
Drilling D 10 Ain Lahdjer	D22	735372,87	3974884,85	Drilling D 23 Ain Azel	D47	733548,78	3967002,45
Drilling D 11 Ain Lahdjer	D23	735888,69	3972492,64	Drilling D 24 Ain Azel	D48	733034,79	3965540,14
Drilling D 12 Ain Lahdjer	D24	735972,69	3972156,15	Drilling D 25 Ain Azel	D49	732834,54	3965503,75
Drilling D 13 Ain Lahdjer	D25	735549,08	3972051,42	Drilling D 26 Ain Azel	D50	732719,81	3964982,79

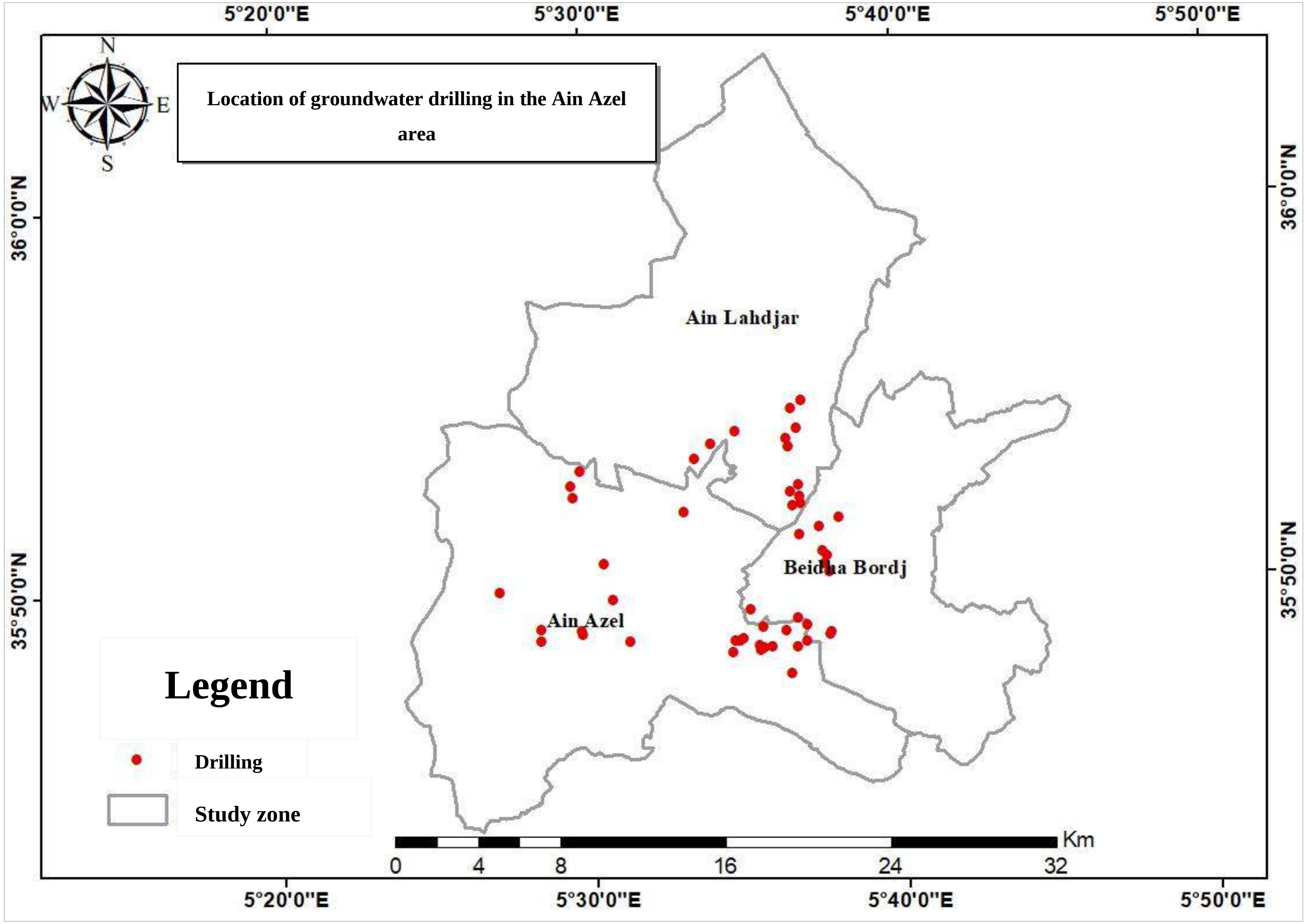

Figure IV. 2 : Location of groundwater drilling in the study area

IV.4. Mapping

In our interpretations of the maps of the Distribution of physic-chemical parameters and the irrigation indices of the drilling waters in our study area, we will rely on the geological map of Algeria, Ain Azel n°. 117, **(Figure A.2)**, and the geological map of Algeria, Ain Lahdjer, n°. 118, **(Figure A.1)**. This is in order to obtain a detailed explanation of the reason for the increase and decrease in the values of the water elements in the plain of Ain Azel.

IV.4.1. Physical parameters

IV.4.1.1. Hydrogen potential pH

After consulting the pH distribution map, we notice a variation in pH between the points of our boreholes due to the difference in the chemical composition of our layer.

- Not all boreholes have exceeded the standards because there is no geological impact that influences our water.

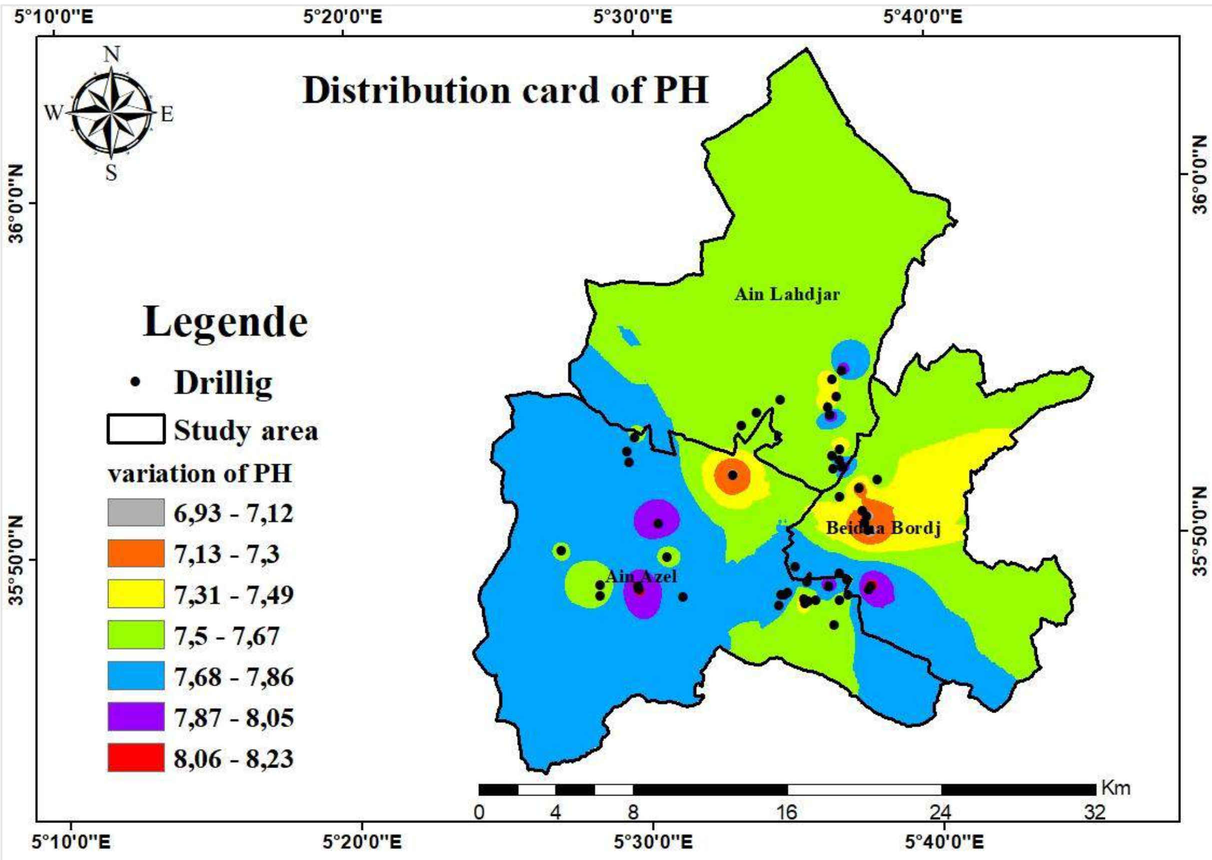

Figure IV. 3 : PH distribution map of the drilling waters of the study area

IV.4.1.2. Electrical conductivity

According to the electrical conductivity distribution map, we find that the majority of our drilling is centered in quaternary and mio-pliocène formation. The majority of our boreholes meet the drinking standards, except for eight boreholes that exceeded the standards.

- Drilling in the northeast region, drilling in the middle of the area, and drilling in the west of the study area exceeded the standards. These deviations from the standards are due to the presence of dissolved ions such as calcium and dissolved salts such as chloride and sulphate in the fine gravel limestone aquifer.
- Drilling in the rest of the region has not exceeded standards because there is no geological impact influencing our water.

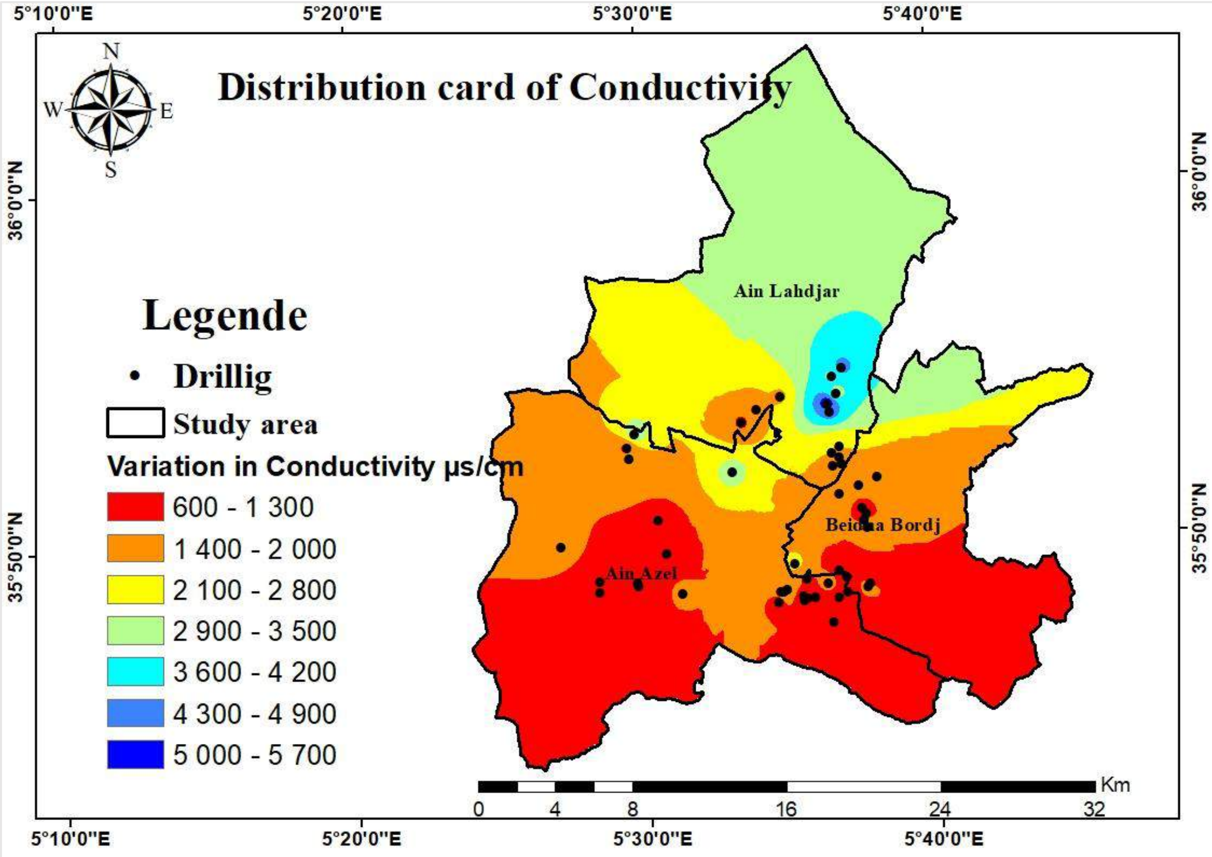

Figure IV. 4 : Bore water distribution map of the bore water of the study area

IV.4.1.3. Hardness

According to the TH distribution map, we find that the majority of our drilling is centered in quaternary and mio-pliocène formation. Most of our boreholes meet 'soft' portability standards, except nine boreholes that are 'moderately soft'

- Drilling in the northeastern region of the study area exceeded standards due to the presence of dissolved calcium and magnesium ions in the fine gravel limestone aquifer.
- Drilling in the rest of the region has not exceeded the "Sweet" standards because there is no geological impact influencing our water.

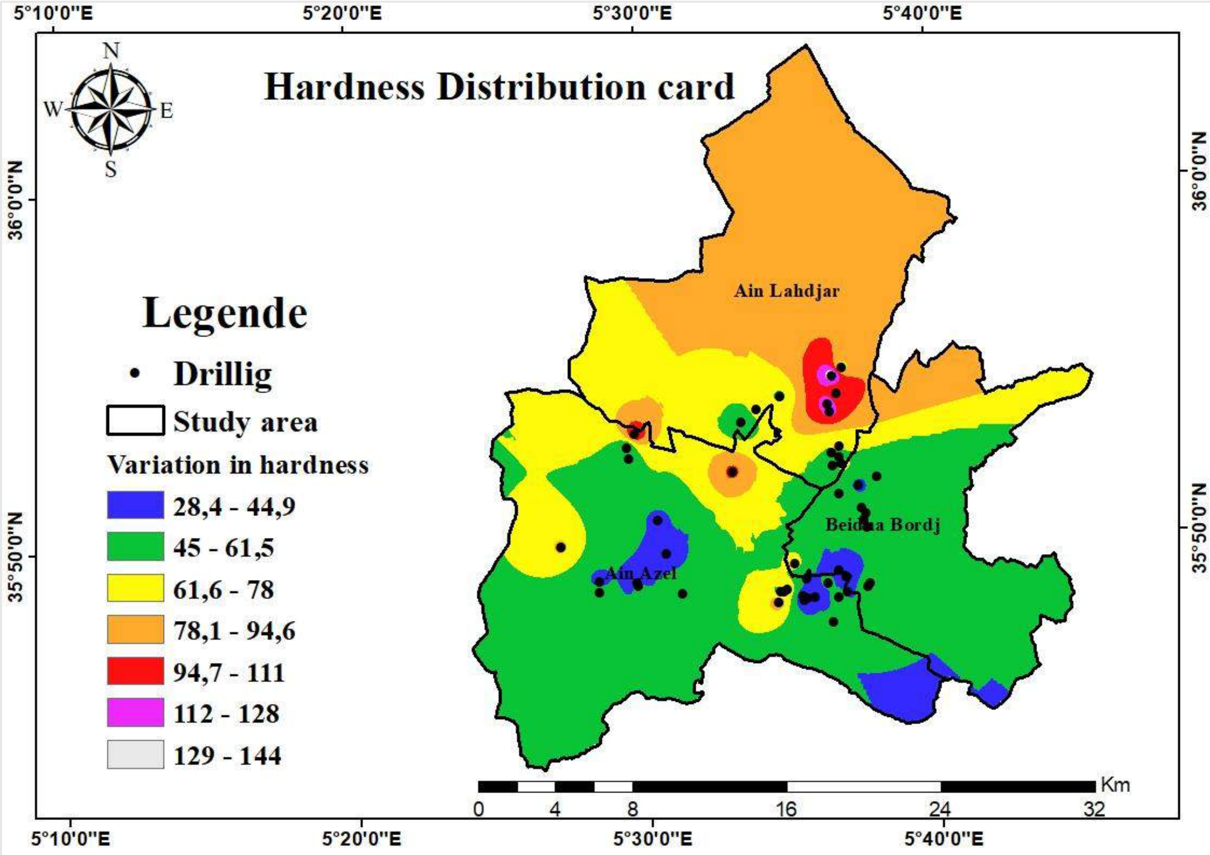

Figure IV. 5 : Distribution map of the TH of the drilling waters of the study area

IV.4.2. Chemical parameters

IV.4.2.1. Cations

➢ **Calcium (Ca^{2+})** :

According to the calcium distribution map, we find that the majority of our drilling is centered in quaternary and mio-pliocène formation. The majority of our boreholes meet the drinking standards, except for eight boreholes that exceeded the standards.

- Drilling in the northeastern region of the study area exceeded standards due to the presence of fine gravel limestone. In other regions, this is due to the presence of calcium dissolved from calcium carbonate in limestone rocks.
- Drilling in the rest of the region has not exceeded standards because there is no geological impact influencing our water.

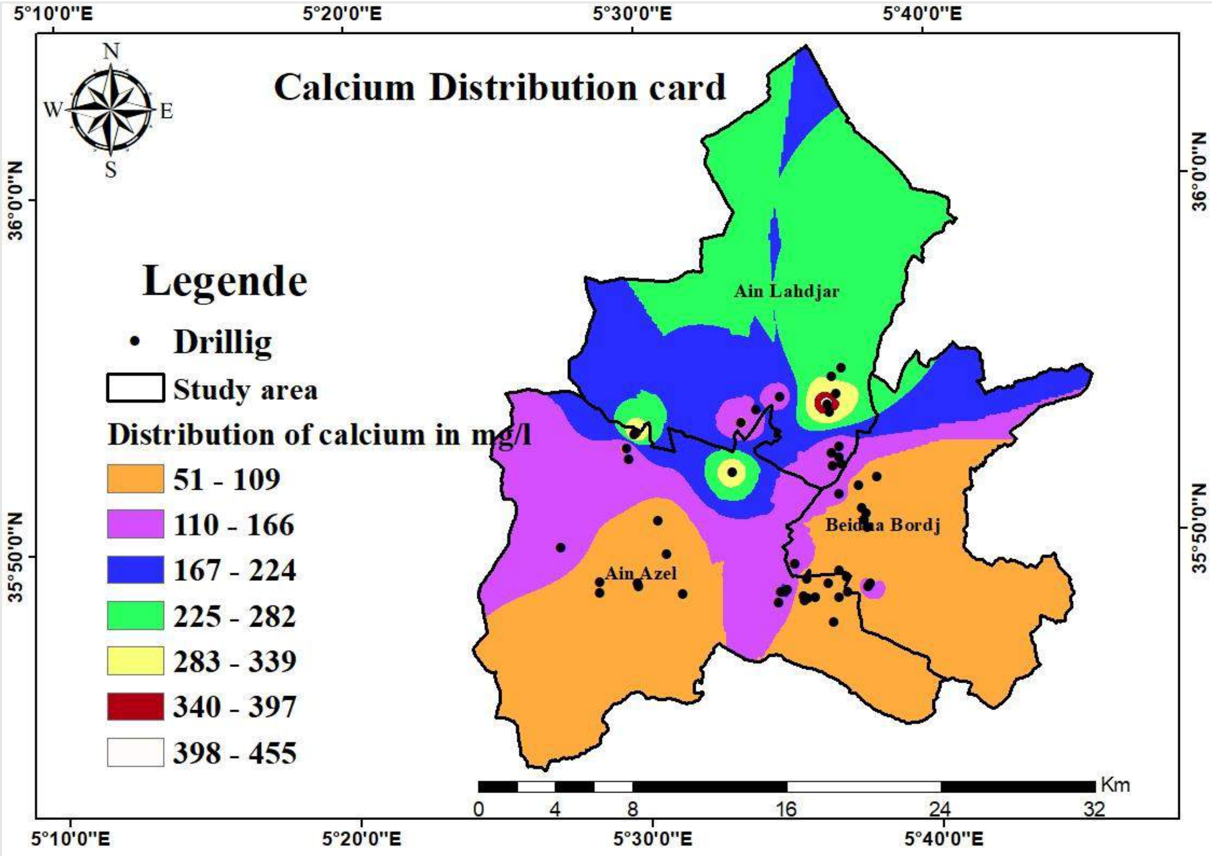

Figure IV. 6 : Distribution map of the bore water Ca^{2+} of the study area

➢ **Magnesium (Mg^{2+})**:

After consulting the magnesium distribution map, we find that the majority of our drilling is centered in quaternary and mio-pliocène formation. The majority of our boreholes meet portability standards, except for one borehole that has exceeded standards.

- The only drilling in the northeastern part of the study area exceeded the standards due to the presence of fine and gravel limestone, and the higher concentration due to the dissolution of magnesium carbonate.
- Drilling in the rest of the region has not exceeded standards because there is no geological impact influencing our water.

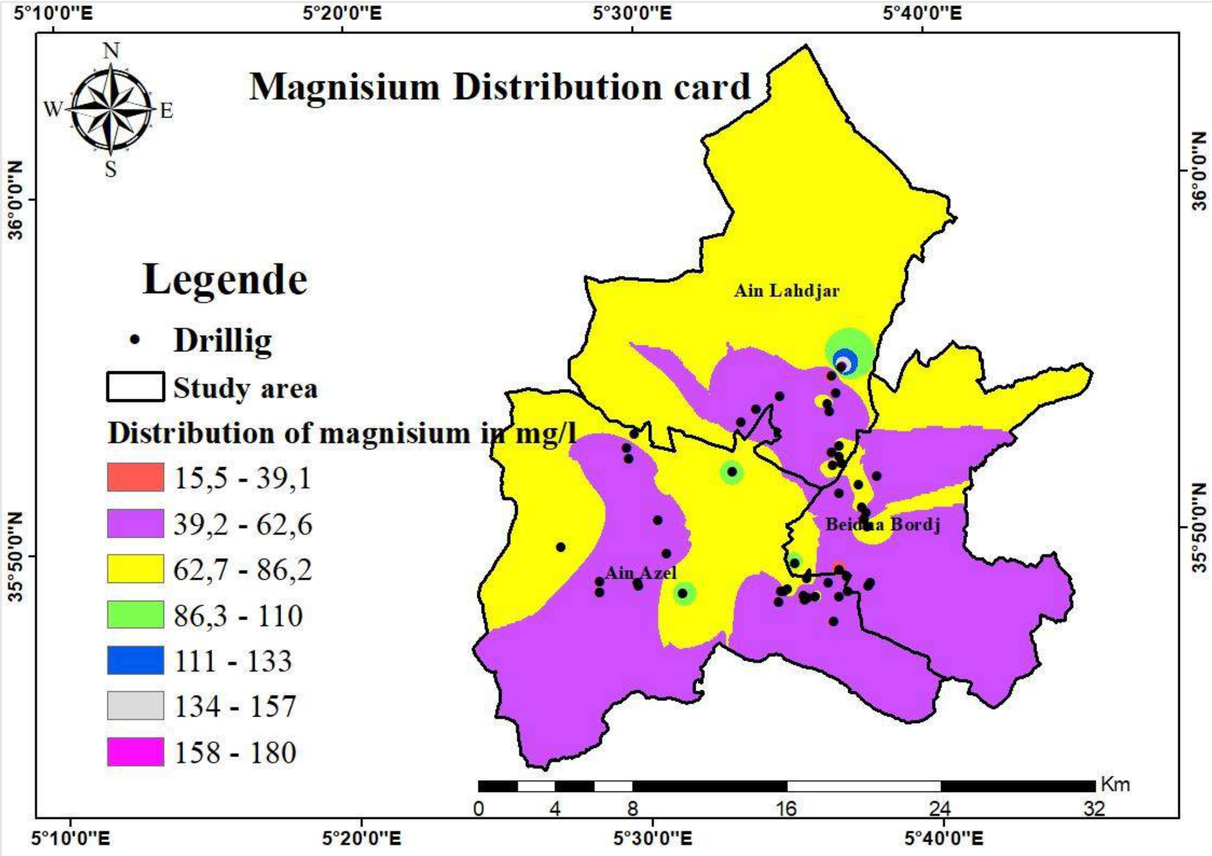

Figure IV. 7 : Distribution map of the bore water Mg^{2+} of the study area

➢ **Sodium (Na^+)** :

According to the sodium distribution map, we find that the majority of our drilling is centered in quaternary and mio-pliocène formation. The majority of our boreholes meet drinking standards, except for ten boreholes that have exceeded standards.

- Drilling in the northeastern region of the study area exceeded standards. The reason is due to the presence of fine gravel limestone, the infiltration of surface water containing dissolved salts, and the dissolution of sodium salts such as sodium chloride and sodium sulphates. This water is of poor quality.
- Drilling in the rest of the region has not exceeded standards because there is no geological impact influencing our water.

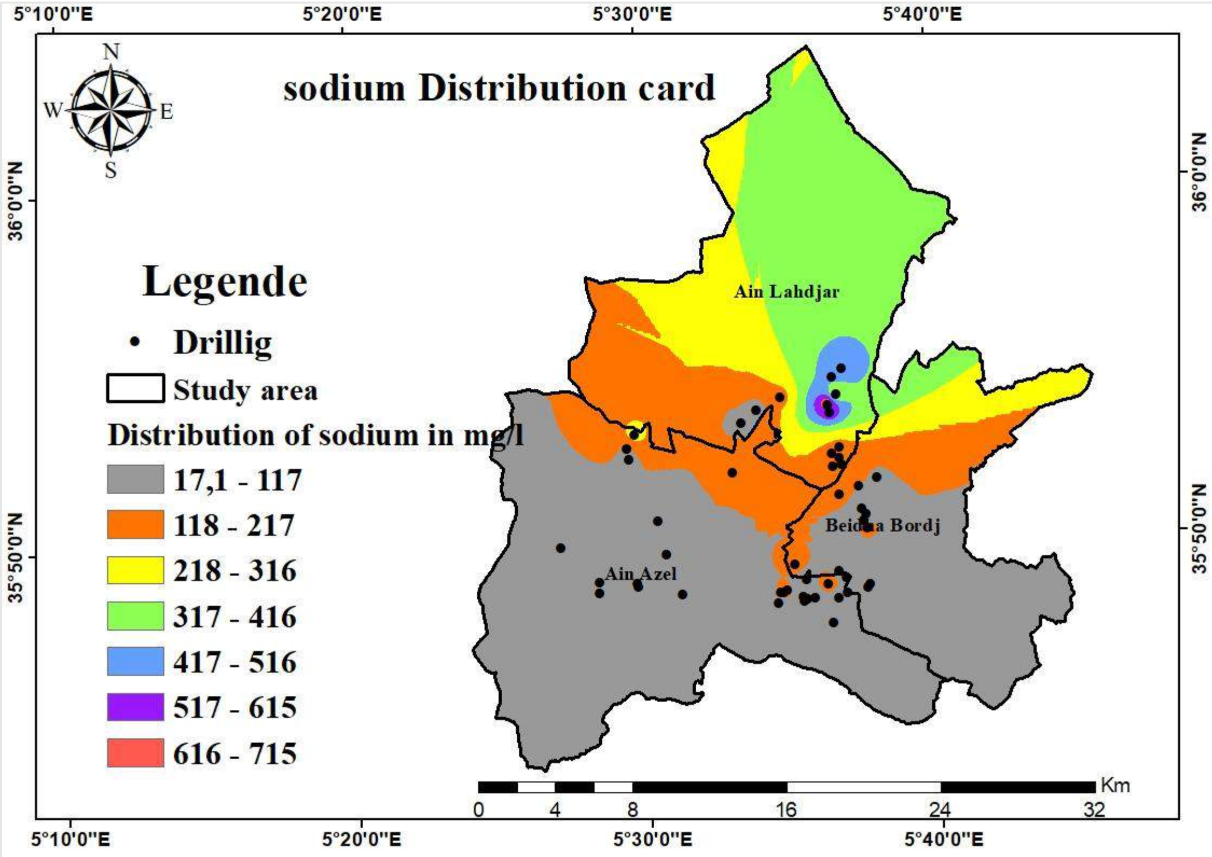

Figure IV. 8 : Distribution map of the bore water Na^+ of the study area

- **Potassium (K^+)** :

After consulting the potassium distribution map, we find that the majority of our drilling is centered in quaternary and mio-pliocène formation. The majority of our boreholes meet the drinking standards, except for three boreholes that exceeded the standards.

- The two boreholes located in the northeast and the borehole located in the west of the study area exceed the standards due to the presence of fine gravel limestone, and interaction with potassium-rich minerals.
- Drilling in the rest of the region has not exceeded standards because there is no geological impact influencing our water.

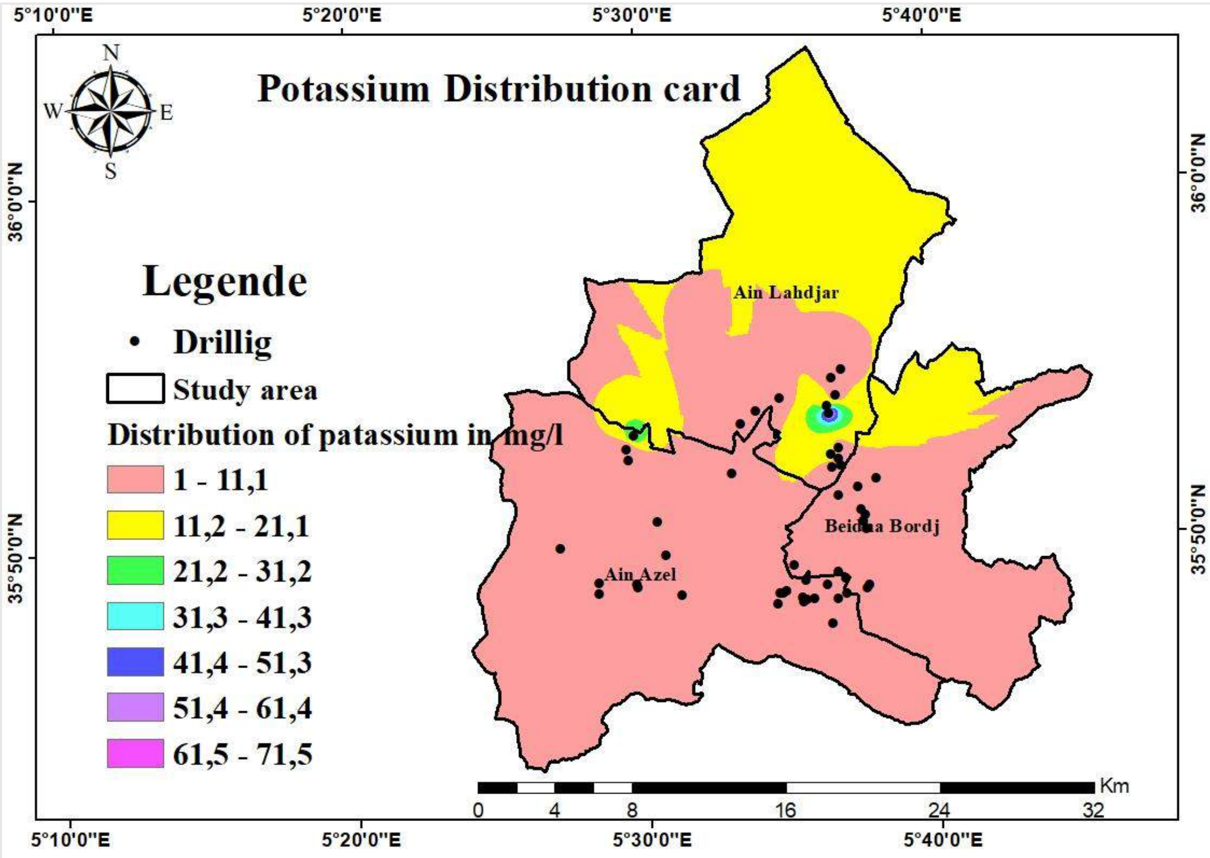

Figure IV. 9 : Distribution map of the bore water K^+ of the study area

IV.4.2.2. Anions

➢ **Chloride (Cl^-)**:

According to the chloride distribution map, we find that the majority of our drilling is centered in quaternary and mio-pliocène formation. The majority of our boreholes meet the drinking standards, except for eight boreholes that exceeded the standards.

- Drilling in the northeastern region of the study area exceeded standards due to the presence of fine and gravel limestone and in other regions, this is due to the presence of soils are often contain high concentrations of chlorides due to dissolution of sodium chlorides and other chloride salts.
- Drilling in the rest of the region has not exceeded standards because there is no geological impact influencing our water.

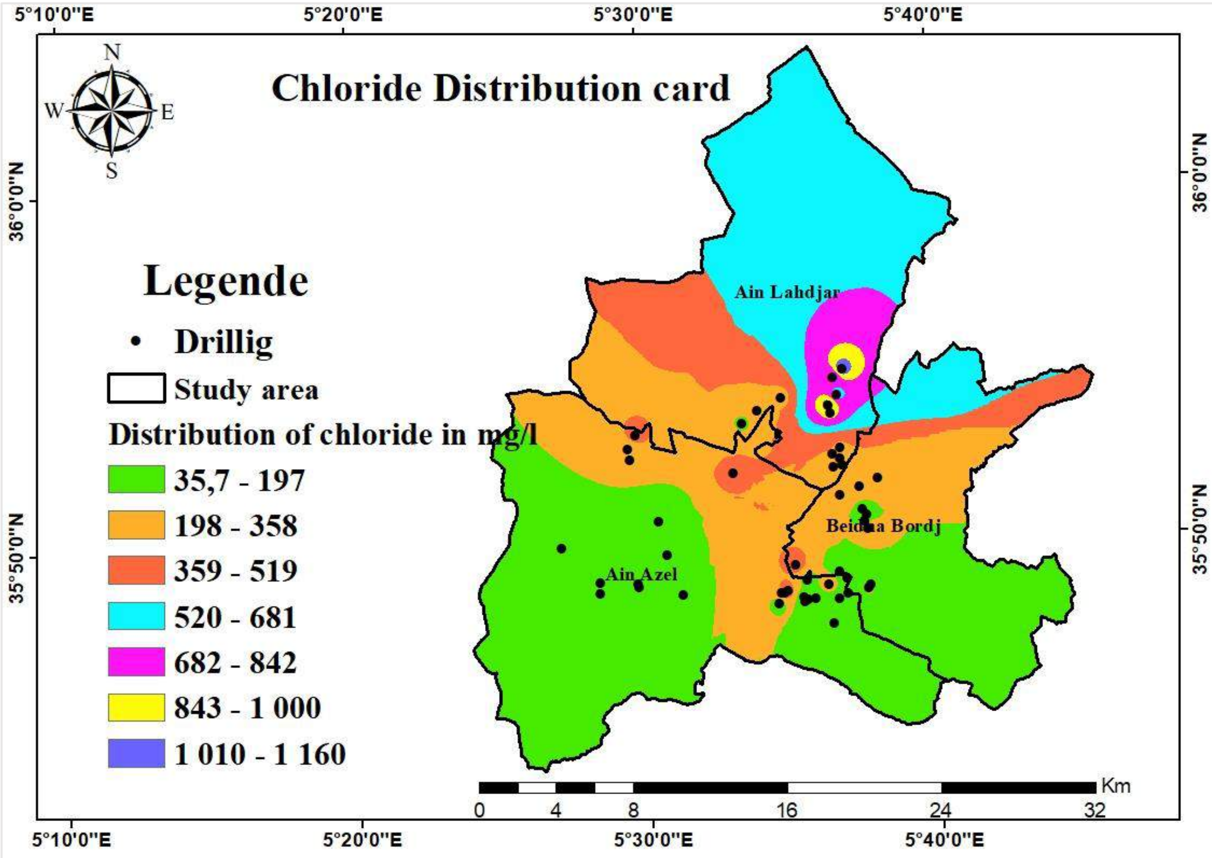

Figure IV. 10 : Distribution map of the bore water Cl^- of the study area

- **Sulphate (SO_4^{2-})** :

After consulting the sulphate distribution map, we find that the majority of our drilling is centered in quaternary and mio-pliocène formation. The majority of our boreholes meet the drinking standards, except for eight boreholes that exceeded the standards.

- Drilling in the northeast, drilling in the middle of the area and drilling in the west of the study area and one exceeded the standards due to the presence of fine and gravel limestone and in other areas, the high concentration of sulphates due to the dissolution of minerals (calcium sulphate) .and the presence of decomposing organic matter and industrial activities.
- Drilling in the rest of the region has not exceeded standards because there is no geological impact influencing our water.

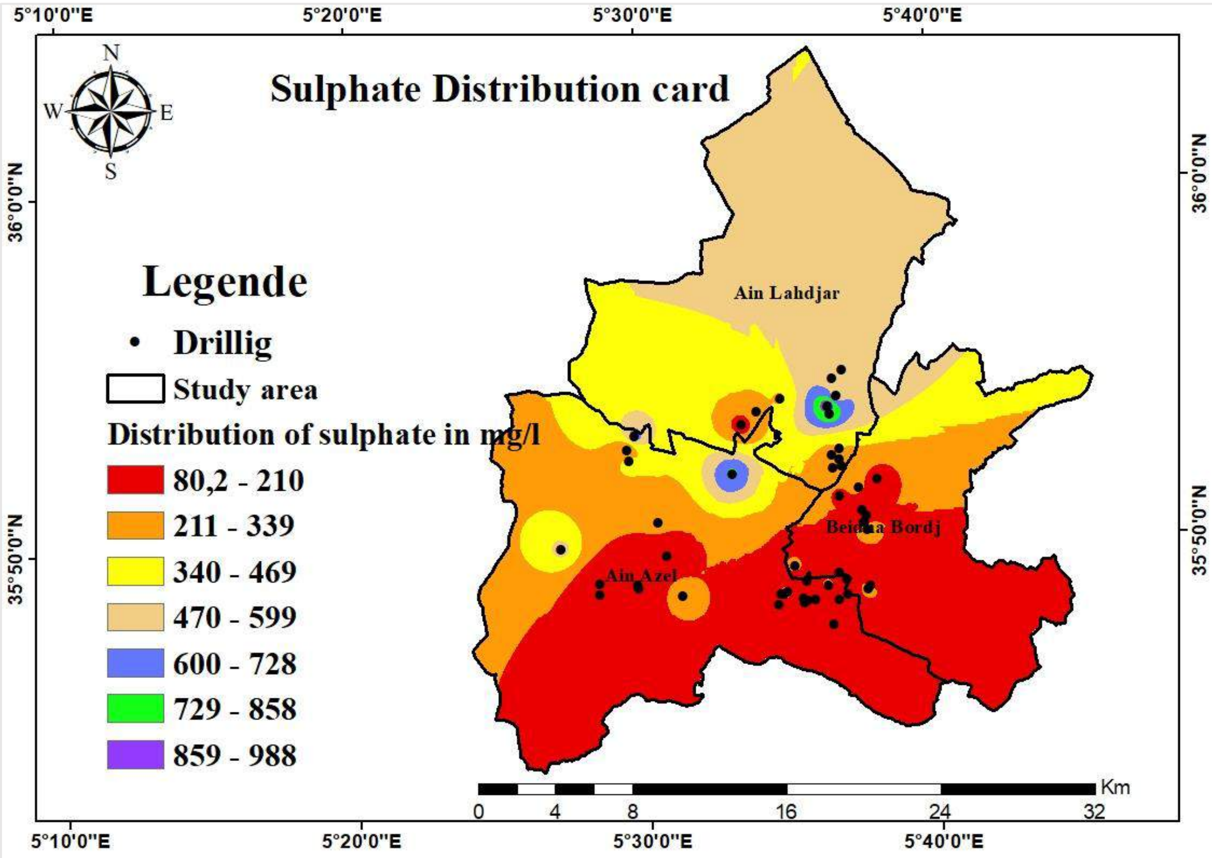

Figure IV. 11 : Distribution map of the bore water SO_4^{2-} of the study area

- **Nitrate (NO_3^-) :**

According to the Nitrate distribution map, we find that the majority of our drilling is centered in the quaternary and mio-pliocène formation. The majority of our boreholes meet drinking standards, except for ten boreholes that have exceeded standards.

- Boreholes located in some areas of the south exceed standards due to the influence of agricultural activities, wastewater discharges, the use of agricultural fertilizers containing nitrates, and the decomposition of organic waste in our study area.
- Drilling in the rest of the region has not exceeded standards because there is no geological impact affecting our water.

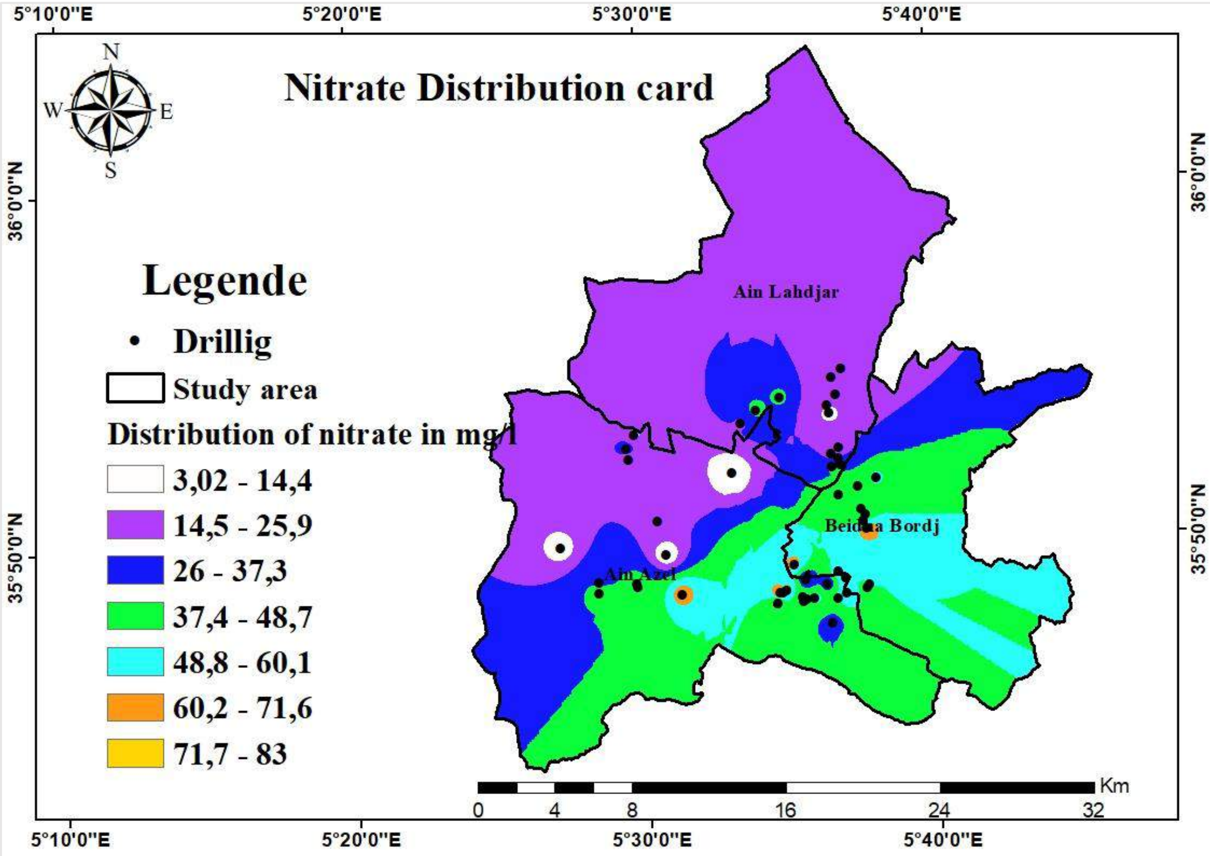

Figure IV. 12 : Distribution map of the bore water NO_3^- of the study area

- **Bicarbonate (HCO_3^-)** :

After consulting the Bicarbonate distribution map, we find that the majority of our drilling is centered in the quaternary and mio-pliocène formation. Most of our boreholes meet potability standards, except one borehole has exceeded standards.

- The only drilling located in the northwest of the study area exceeded the standards due to the presence of dolomites, limestone, sandstone, and massive carbonate lees, as well as the high concentration of bicarbonates due to the dissolution of calcium carbonate, thus forming bicarbonates in water.
- Drilling in the rest of the region has not exceeded standards because there is no geological impact influencing our water.

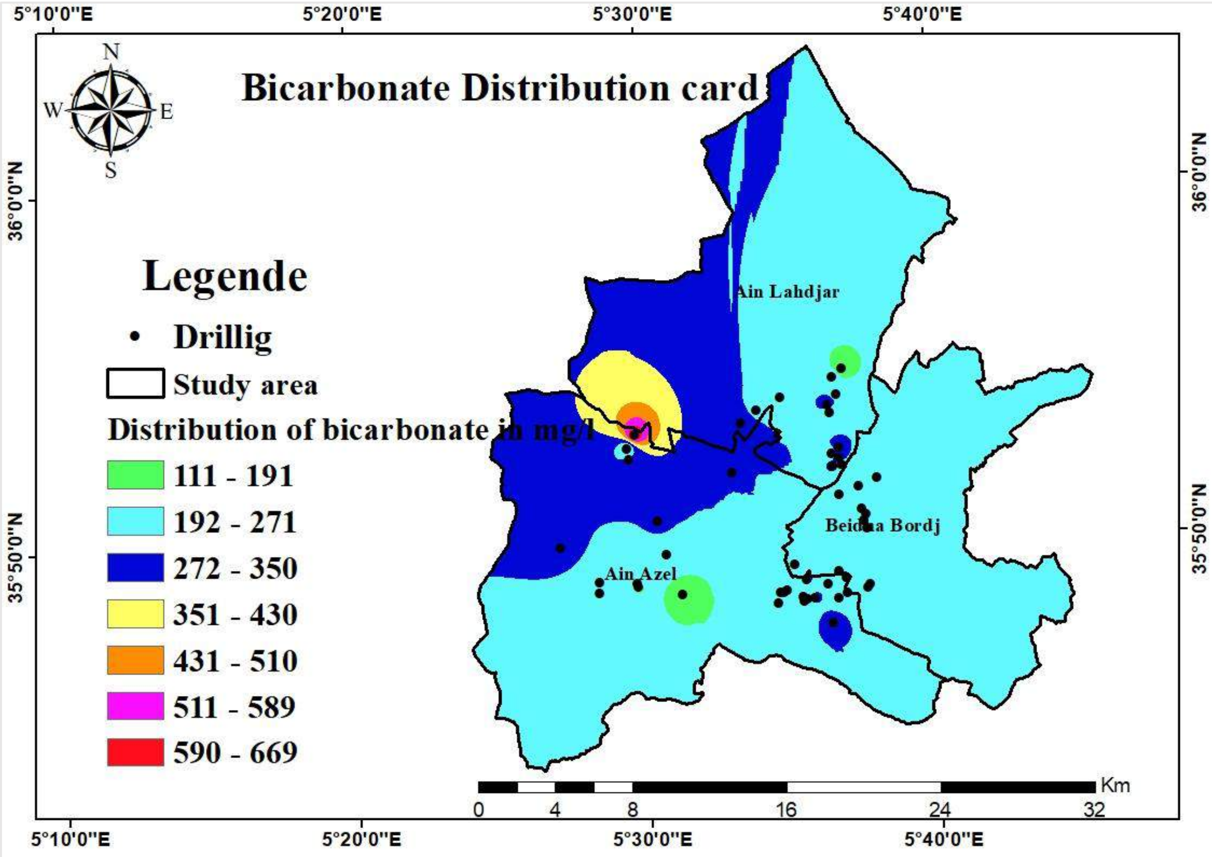

Figure IV. 13 : Distribution map of the bore water HCO_3^- of the study area

IV.4.3. Irrigation indices

IV.4.3.1. Sodium absorption ratio (SAR)

According to the SAR distribution map we notice that our index is in the norm with a small variation from one drilling to another, the latter is returned to the diversity of geological formations in our layer.

SAR is a measure of the relative concentration of sodium ions relative to calcium and magnesium ions in irrigation water.

- Not all drilling has exceeded the standards because there is a low alkalinity risk and we do not find a geological impact that influences our index.

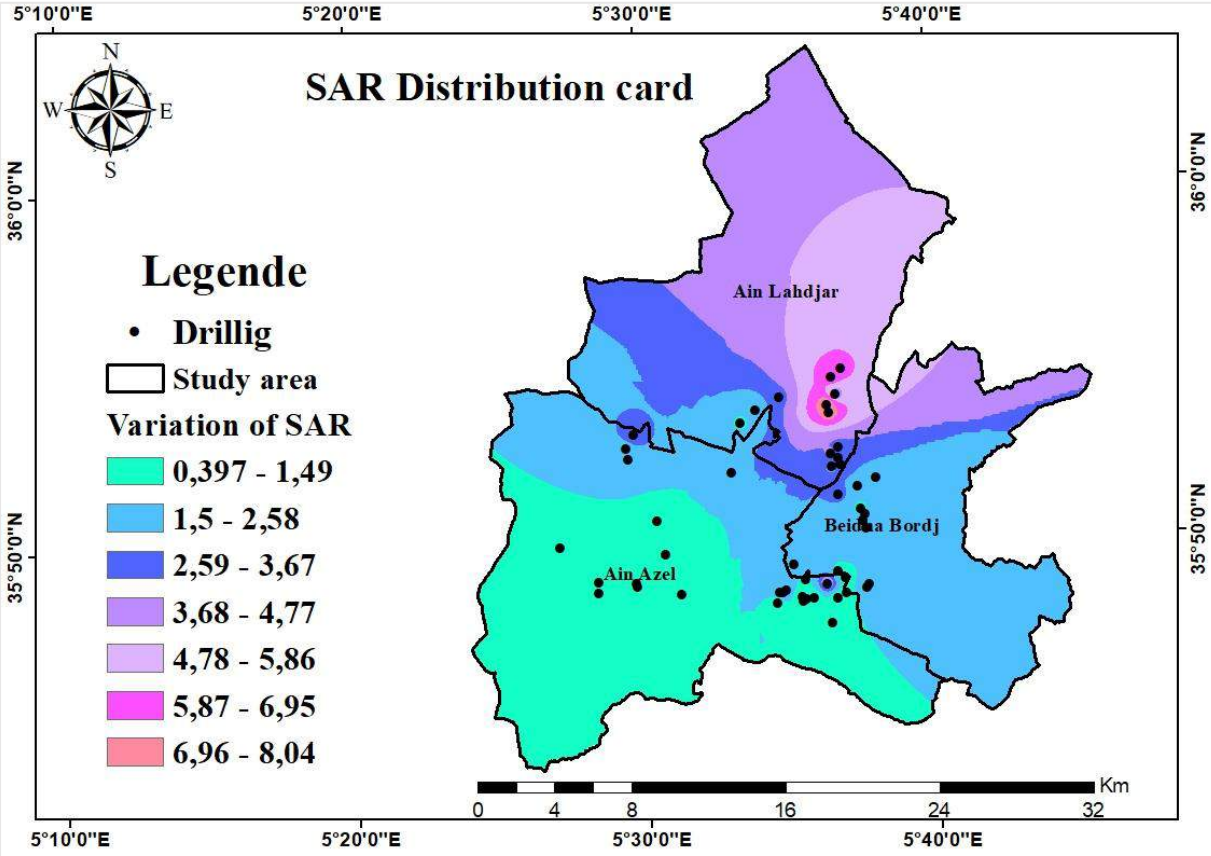

Figure IV. 14 : SAR distribution map of the drilling waters of the study area

IV.4.3.2. Residual sodium bicarbonate (RSBC)

According to the distribution map of the RSBC we notice that our index is in the standards with a small variation from one drilling to another, the latter is returned to the diversity of geological formations in our layer.

- Not all boreholes have exceeded the standards because we do not find a geological impact that influences our index. This is due to the low saturation of sodium bicarbonate in the study area.

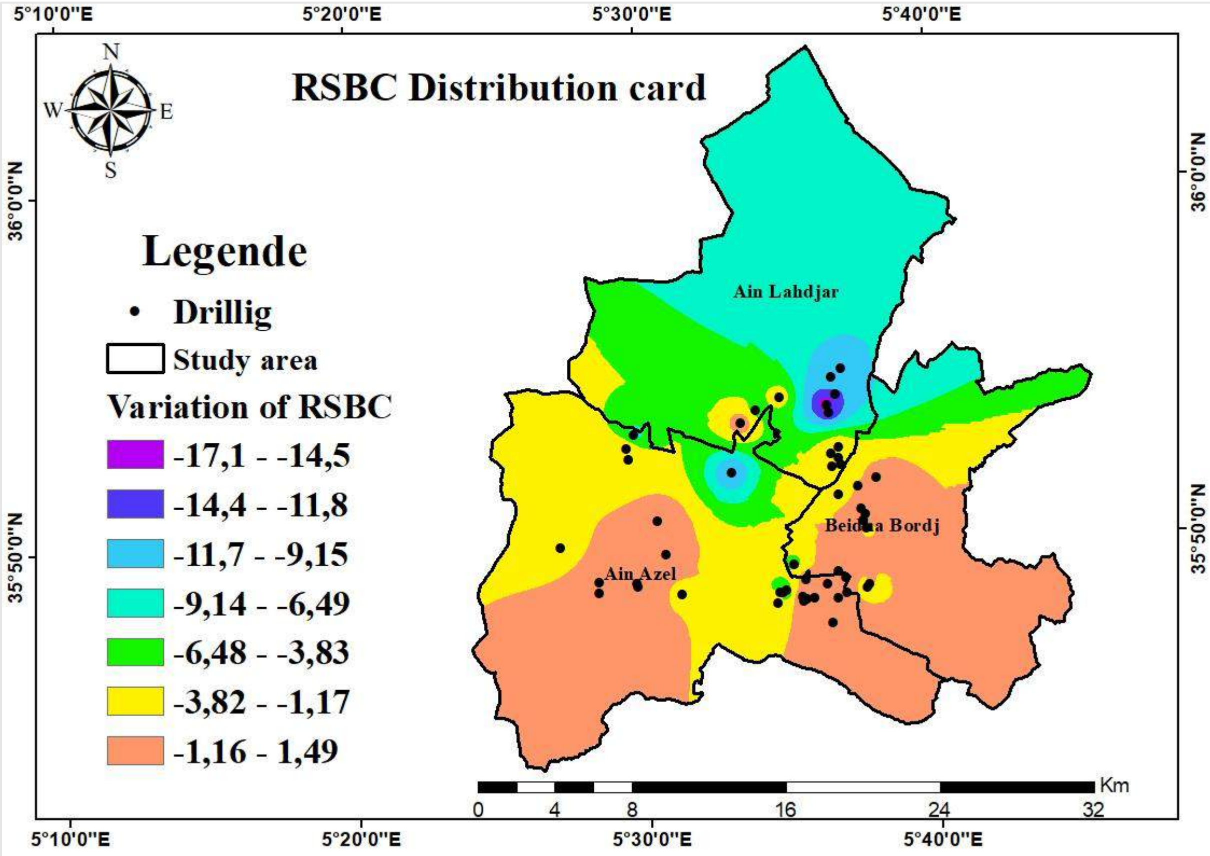

Figure IV. 15 : Distribution map of the bore water RSBC of the study area

IV.4.3.3. Percentage of soluble sodium (SSP)

According to the SSP distribution map, the majority of our boreholes meet irrigation standards. Except six boreholes exceeded the standards.

- Drilling in the northeastern region of the study area exceeded standards due to the presence of fine and gravel limestone, the infiltration of surface water containing dissolved salts, and the high proportion of sodium in the water. This water is of acceptable quality.
- Drilling in the rest of the region has not exceeded standards because there is no geological impact influencing our water. This water is of good or excellent quality.

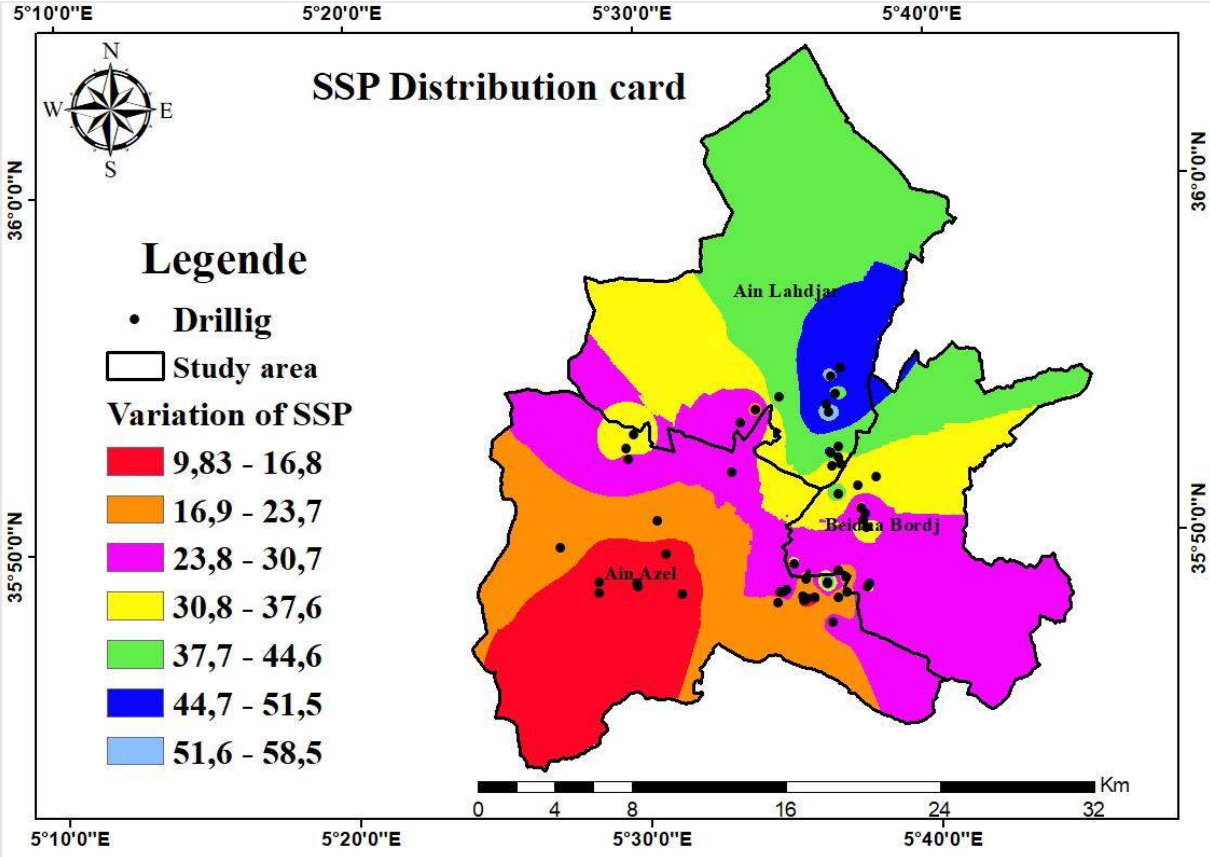

Figure IV. 16 : SSP distribution map of the drilling waters of the study area

IV.4.3.4. Rapport by Kelly (KR)

After consulting the distribution map of KR, we find that the majority of our drilling is centered in the quaternary and mio-pliocène formation. The majority of our irrigation-friendly drilling, except for three drills, exceeded the standards.

- The three boreholes located in the northeastern part of the study area exceed the standards due to the high presence of calcium, magnesium in irrigation water in the fine gravel limestone aquifer.
- Drilling in the rest of the region has not exceeded standards because there is no geological impact influencing our water.

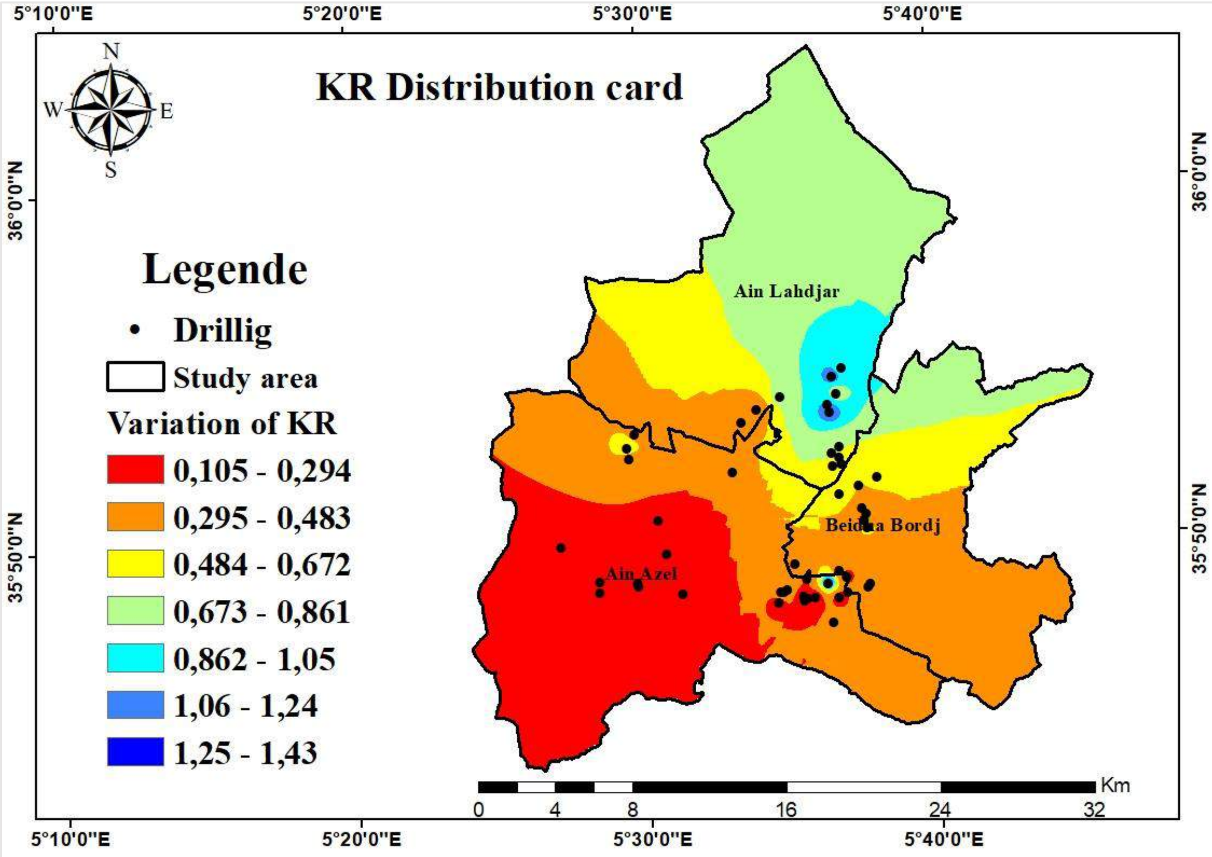

Figure IV. 17 : KR distribution map of the drilling waters of the study area

IV.4.3.5. Magnesium risk (VAS)

According to the IVD distribution map, we find that our drilling is centered in the quaternary and mio-pliocène formation. 50% of our drilling is very useful for irrigation, and 50% of our drilling is unsuitable for irrigation.

- Drilling in the southwestern region and parts of the southeastern study area is above standard due to the high relative concentration of magnesium ions relative to calcium ions in water. This water is of poor quality
- Drilling in the rest of the region has not exceeded standards because there is no geological impact influencing our water.

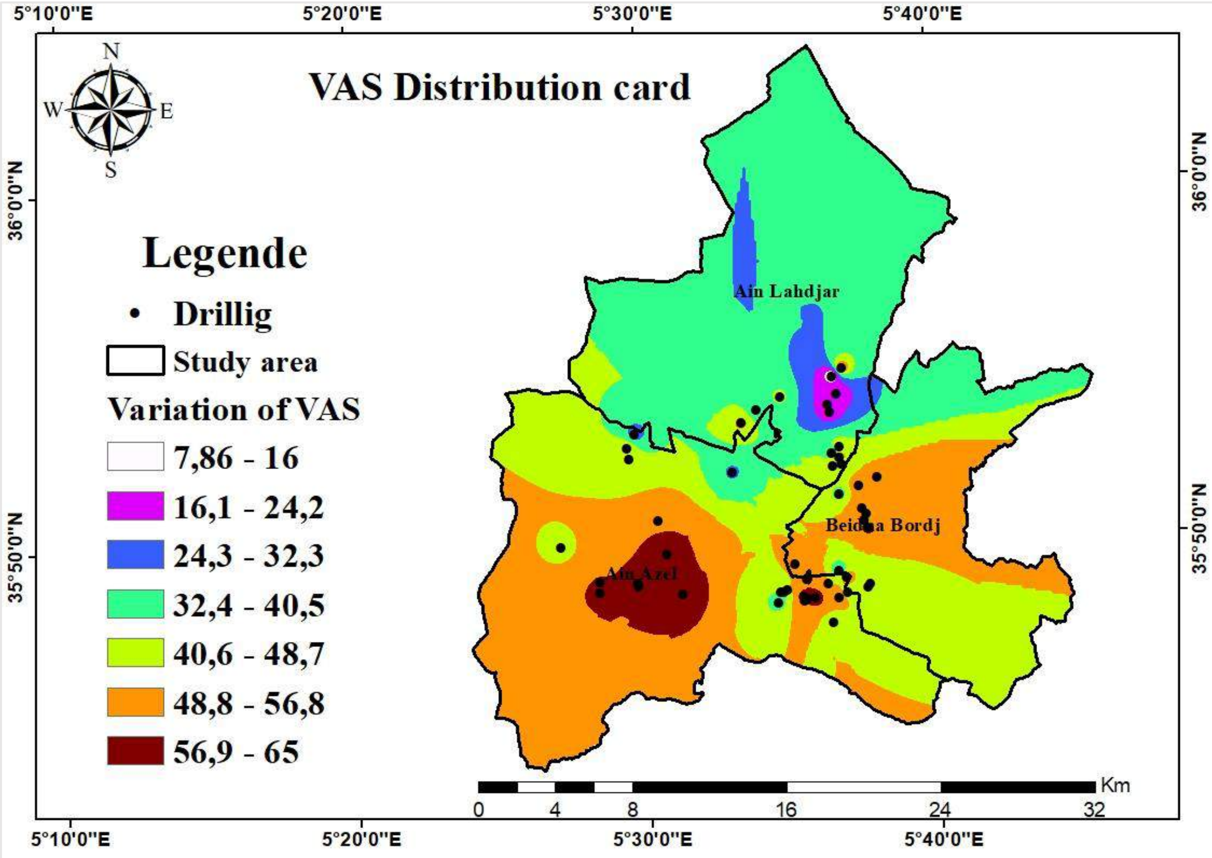

Figure IV. 18 : Map of the distribution of the VAS of the drilling waters of the study area

IV.4.3.6. Permeability index (IP)

This index is noted in irrigation standards, according to the IP distribution map, there is a variation in the results caused by the chemical composition of the web.

- Not all boreholes have exceeded the standards because we do not find a geological impact that influences our index. This is the low levels of bicarbonates, and a low infiltration of water into the soil, in the study area.

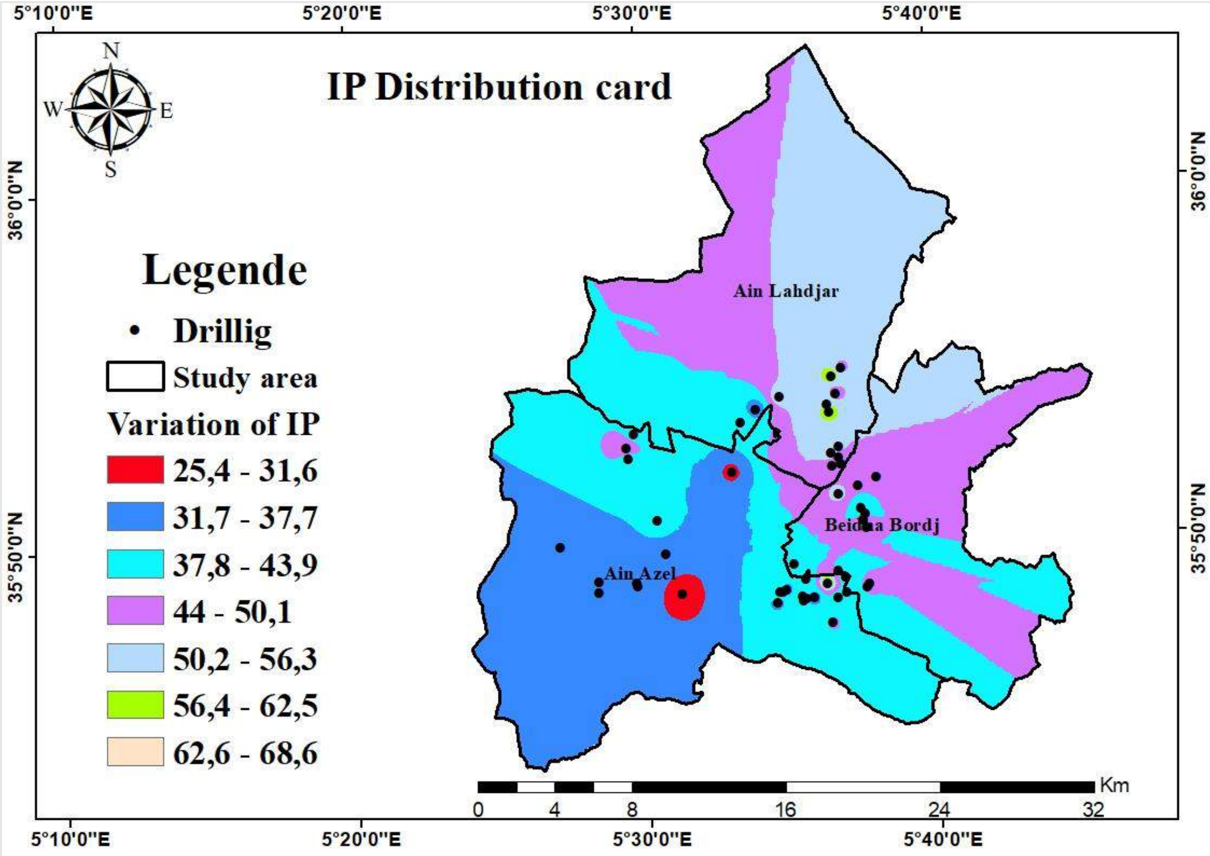

Figure IV. 19 : IP distribution map of the drilling waters of the study area

IV.4.4. Water Quality Index (WQI)

According to the IQE distribution map, we find that the majority of our drilling is centered in quaternary and mio-pliocène formation. Most of our boreholes meet irrigation standards for "excellent and good quality," with the exception of four boreholes that have an irrigation quality deemed "poor."

- Drilling in the northwestern region of the study area exceeds the standards due to the presence of dissolved calcium and magnesium ions in the fine gravel limestone aquifer.
- Drilling in the rest of the region has not exceeded standards because there is no geological impact influencing our water.

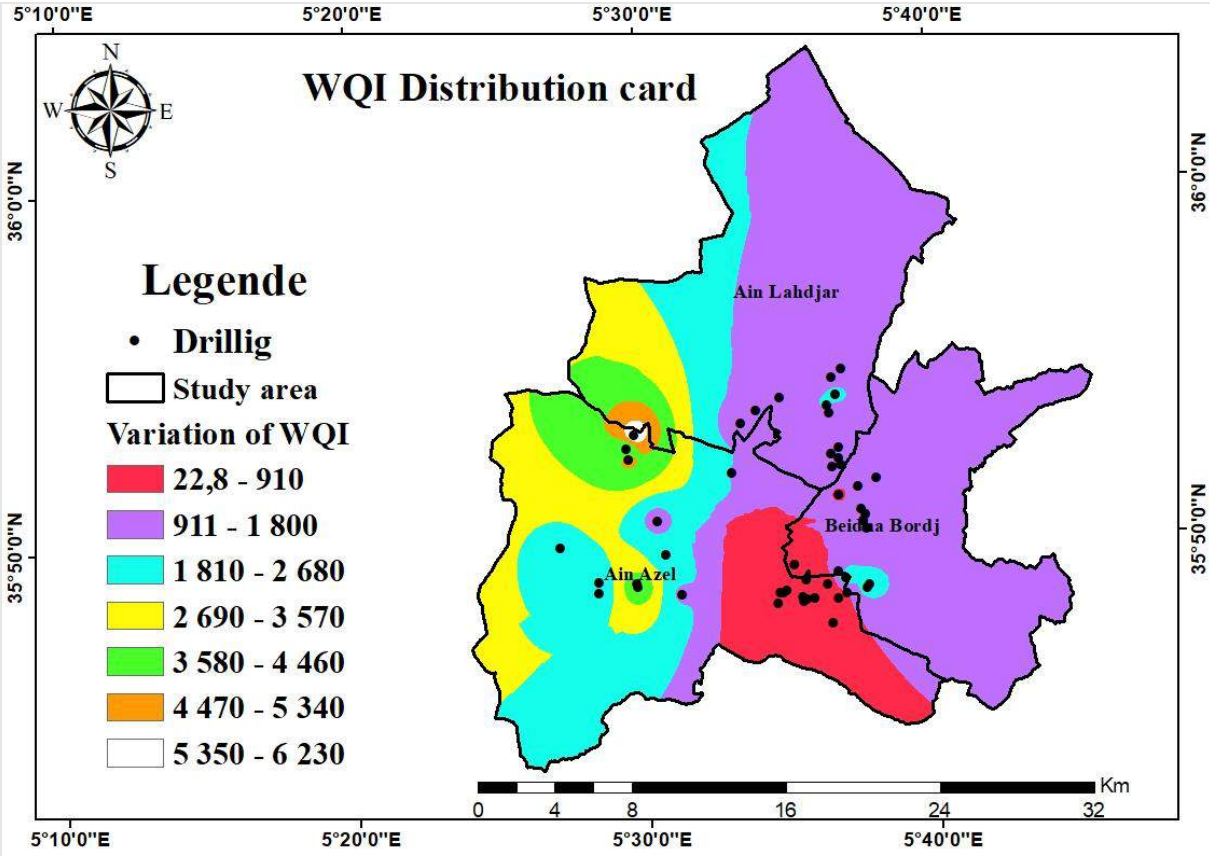

Figure IV. 20 : WQI distribution map of the drilling waters of the study area

IV.5. Conclusion

In this chapter we examined the distribution of the various elements that characterize groundwater in the Ain Azel region. Through the results obtained we can conclude that:

- An average pH of 7.63 suggests that they are slightly basic waters and an average electrical conductivity of 1736 µs/cm signifying that they are high-minerality conducting waters, and an average hardness of 59.72 ° F signifying that they are hard to very hard waters.

- The high values of PH is good in our region are related the difference chemical composition of our web.
- The high values of conductivity and hardness that characterize the north of the region are related to the lithological nature of the gypsum and limestone formations.

It is also noted that:

- The high values in all ions associated with nitrate, which characterize the north of the region, are also related to the lithological nature of the gypsum and limestone formations.
- High nitrate levels in part of the south of the region mean that it is a pollution index.
- Values of the SAR index is good in the region are related the relative concentration of sodium ions relative to calcium and magnesium ions in water
- The high values of the SSP index that characterize the northeastern region are related to the presence of fine gravel limestone, the infiltration of surface water containing dissolved salts. And the proportion of sodium in water
- The values of the index of RSBC is good in the region are related the diversity of geological formations in our layer.
- The values of the IP index is good in our region are related to the low saturation of sodium bicarbonate in the study area.
- The high values of the VAS index that characterize the southwest and parts of the southeastern region are related to the high relative concentration of magnesium ions relative to calcium ions in water.
- The high values of the KR index that characterize the northeastern region are related to the high presence of calcium, magnesium cations in irrigation water in the fine and gravel limestone aquifer
- The high values of the index of IQE that characterize the northwest of the region are related to the presence of dissolved calcium and magnesium ions in the fine gravel limestone aquifer.

General conclusion

General conclusion

This study focused on the Mio-Plio-Quaternary aquifers in the Ain Azel area south of Sétif, in eastern Algeria.

There is a semi-arid climate at Ain Azel, with an annual average rainfall of 365 mm and average temperatures of 14.62 °C. A study of monthly precipitation data shows a downward trend in the precipitation curve relative to temperature, particularly from June to August.

Two major aquifer systems are mainly involved in the study area: a surface aquifer corresponding to the formations of the Mio-Plio-Quaternary and a complex of deep aquifers of the Lower Cretaceous, the Hauterivian and the Barrémien, which play an essential role in the water supplementation of the region.

Most water samples from the Mio-Plio-Quaternary aquifer in the study area have consistent and reliable base index (BI) values, with the exception of drilling 33, which exceeds the 10% limit. This observation raises concerns about the quality of the water collected in this particular borehole.

Although most concentrations of (TAC) are within a potentially drinking range (between 2.0 and 5.5 meq/l), some drilling exceeds the recommended limits for human consumption, which requires special attention, and most samples appear to provide drinking water based on their TDS concentrations.

Other water quality criteria, such as temperature and pH, meet Algerian drinking water standards, thus ensuring water safety for human consumption in the region studied. Some waters have electrical conductivity above the maximum recommended limit, suggesting excessive mineralization in these waters. The hardness of the water can also vary from mild to moderately hard.

Water samples from the 50 boreholes studied showed calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulphate and nitrate ion contents. The findings indicate that these levels meet water quality standards in Algeria. In the region studied, ion concentrations are on average at acceptable levels, indicating good water quality in terms of chemical composition. In summary, water abstraction from drilling meets water quality standards in Algeria, with the exception of drilling referred to in **(Table III. 7)**.

Based on the international and local standard, and considering the physicochemical characteristics, most of the water collected in the study area is suitable for consumption, while some water points are unfit for consumption.

To classify the waters of the Mio-Plio-Quaternary to irrigation, the SSP and RSC values show that all the water points are of superior quality. According to the VAS and KR data, these waters can be used for irrigation without the need for treatment. Apart from a few boreholes, which are few and must be treated.

Through the results obtained after the mapping we can conclude that:

- **For consumption :**

- The northern region and especially the northeastern part of the study area (east of Ain Lahdjer) is characterized by poor water quality.
- The central region of the study area characterized by medium quality water.
- The southern region, in particular the south-eastern region (Beidha Bordj and east of Ain Azel) is characterized by good water quality and water quality decreases every time we go north,
- While the western region (west of Ain Azel and west of Ain Lahdjer) in general we can say that its water quality is good
- Agricultural activities in the study area are the main cause of groundwater pollution, precisely in agricultural areas which are located in certain southern regions (central Beidha Bordj area); where we recorded very high concentrations of NO_3^- in drilling water.

- **For irrigation:**

- The northern region and especially the northeastern part of the study area (east of Ain Lahdjer) is also characterized by poor water quality.
- The central region of the study area characterized by medium quality water.
- The southern region, in particular the south-eastern region (Beidha Bordj and eastern Ain Azel), is characterized by good water quality, although some parts have marginal quality. In contrast, the southwestern region of Ain Azel is characterized by an average water quality due to the risk of magnesium.

We have proposed various solutions to the water quality problems in the Ain Azel region:

- For boreholes where water quality is considered to be good, it is important to regularly monitor the quality of the boreholes to identify any changes and to take preventive action if necessary.
- It is essential to promote sustainable agricultural practices, such as the rational use of fertilizers and pesticides, crop rotation, and the adoption of soil conservation methods to limit the run-off and infiltration of pollutants into groundwater.
- There is a need for programmed to raise farmers' awareness of good agricultural practices and the importance of preserving water quality.
- Regular studies of potential sources of pollution, such as industrial and agricultural activities, are essential to identify and reduce the risk of contamination.
- It is recommended to adopt an integrated water resources management approach, involving coordination between different actors (government, local authorities, farmers, etc.) for sustainable and equitable water use.

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Apendice

Apendice

Table A. 1 : Parameters of physical and chemical analyzes in (meq/l)

	Physical parameters					Chemical parameters								
Water points	**PH**	**CE (µS)**	**T (°C)**	**RS**	**TH (°F)**	**K^+**	**Na^+**	**Mg^{2+}**	**Ca^{2+}**	**NO_3^-**	**Cl^-**	**SO_4^{2-}**	**CO_3^-**	**HCO_3-**
D1	8,06	1100	19	698	42,821	0,077	2,218	4,936	3,792	0,371	2,539	4,789	/	4,605
D2	7,59	900	19	588	34,715	0,051	1,305	4,772	2,994	0,081	2,962	2,165	/	4,294
D3	7,5	700	19	464	39,651	0,051	0,783	3,949	2,994	0,581	1,41	1,666	/	3,999
D4	7,67	900	19	598	54,575	0,051	1,218	4,936	3,593	0,661	1,975	2,665	/	3,835
D5	7,63	3500	19	2290	111,662	0,793	11,744	7,322	18,713	0,21	13,258	13,741	/	10,996
D6	7,9	1100	19	774	44,142	0,051	4,611	3,62	3,892	0,532	5,219	3,748	/	2,901
D7	7,73	1600	19	1080	57,319	0,051	4,35	4,936	7,186	0,258	6,065	7,787	/	4,605
D8	7,8	800	19	524	31,923	0,026	0,739	4,278	3,094	0,661	1,128	1,666	/	4,802
D9	8,2	600	19	386	52,376	0,051	0,783	3,291	2,495	0,629	0,987	1,666	/	2,393
D10	7,76	1500	19	930	56,833	0,026	2,131	7,98	4,291	1,064	4,513	6,246	/	2,294
D11	7,67	1800	19	1260	79,761	0,153	4,132	7,075	8,383	0,145	4,231	10,41	/	4,998
D12	7,09	3100	19	1960	97,144	0,153	7,395	7,569	16,467	0,048	11,989	15,615	/	4,49
D13	7,69	2100	19	1320	60,023	0,742	9,134	2,962	6,986	0,323	10,437	5,746	/	4,195
D14	7,67	1200	19	786	45,019	0,077	2,914	5,019	4,89	0,403	4,795	3,04	/	5,506
D15	7,64	1600	19	1040	64,952	0,077	3,349	4,114	8,383	0,661	6,065	5,788	/	3,999
D16	7,67	1900	19	1214	58,998	0,102	8,003	4,607	6,287	0,645	8,039	6,787	/	3,999
D17	7,14	2100	19	1364	68,486	0,153	8,699	5,512	6,786	0,161	9,591	7,454	/	4,703
D18	7,13	5800	19	3664	120,529	0,153	31,492	6,911	22,954	0,339	31,735	20,779	/	5,392
D19	7,25	3300	19	2100	144,727	0,153	18,486	1,152	13,972	0,355	18,195	10,41	/	3,999
D20	8,01	4600	19	2880	68,876	0,153	21,749	14,973	10,978	0,306	33,004	12,076	/	1,803
D21	7,48	3100	19	1956	94,649	0,051	12,179	2,797	15,968	0,371	16,643	10,41	/	3,999
D22	8,18	4500	19	2888	116,977	1,893	25,228	2,962	16,567	0,113	25,106	17,905	/	3,392

D23	7,79	1600	19	1066	48,31	0,077	5,307	6,828	4,89	0,387	7,334	4,372	/	4,9
D24	8,25	2200	19	1400	74,352	0,153	8,917	4,772	8,782	0,661	10,578	7,787	/	3,802
D25	7,5	1700	19	1088	50,569	0,077	5,22	6,088	5,589	0,661	6,488	5,538	/	4,605
D26	7,61	1400	19	880	49,753	0,256	4,611	4,525	4,192	0,823	5,924	3,415	/	3,835
D27	7,36	1100	19	766	50,576	0,102	2,218	5,759	4,192	0,613	4,795	3,748	/	3,392
D28	7,17	1500	19	974	39,82	0,051	4,959	5,923	4,591	0,758	7,616	4,372	/	3,507
D29	7,54	1600	19	1046	49,685	0,307	6,438	3,373	5,988	0,758	7,334	3,956	/	4,392
D30	7,34	1200	19	800	59,389	0,051	3,61	3,949	4,391	0,564	4,372	3,373	/	4,507
D31	6,97	1900	19	1188	46,165	0,026	6,612	7,487	4,79	1,339	9,45	5,746	/	2,999
D32	6,95	1200	19	774	41,849	0,051	3,219	4,443	4,092	0,677	3,526	3,998	/	3,802
D33	8,2	900	19	644	44,082	0,153	3,045	4,278	4,291	1	1,551	2,165	/	4,605
D34	7,97	1900	19	1214	62,545	0,102	6,612	4,525	7,984	0,484	8,463	7,079	/	3,507
D35	7,59	900	19	634	27,837	0,077	1,522	4,525	3,593	0,935	2,539	2,082	/	4,703
D36	7,83	900	19	566	41,816	0,051	2,001	1,974	4,99	0,935	2,821	2,582	/	3,294
D37	7,65	1000	19	666	42,112	0,077	2,218	3,373	4,391	1,032	4,09	2,332	/	3,392
D38	8,12	2000	19	1284	50,252	0,128	12,179	4,031	4,291	0,403	11,283	5,372	/	4,294
D39	7,79	1200	19	798	40,528	0,051	2,436	5,759	3,992	0,274	2,962	4,372	/	4,703
D40	7,45	900	19	576	34,776	0,23	1,609	4,114	2,595	0,645	2,398	2,082	/	3,999
D41	7,87	900	19	588	32,995	0,051	1,218	4,36	3,144	0,468	2,821	2,956	/	3,605
D42	6,9	700	19	476	30,75	0,051	0,783	3,455	2,695	0,597	1,269	1,582	/	3,999
D43	7,59	1200	19	800	57,474	0,102	3,045	3,455	5,489	0,468	3,949	3,415	/	5,293
D44	7,69	1100	19	700	36,313	0,026	1,479	6,006	3,643	0,952	2,821	2,665	/	4,9
D45	7,55	700	19	500	53,138	0,026	1,044	3,62	2,894	0,774	1,551	1,666	/	3,9
D46	7,84	1900	19	1188	72,721	0,077	4,785	7,733	5,988	1,193	11,848	4,247	/	2,901
D47	7,71	2500	19	1550	67,98	0,077	7,916	8,556	8,084	1,081	15,374	4,705	/	3,097
D48	7,64	2900	19	1810	97,117	0,026	9,221	5,512	15,968	0,597	19,887	6,246	/	3,392
D49	7,91	1200	19	792	37,203	0,051	4,219	3,455	4,89	1,419	5,36	3,04	/	2,802
D50	7,69	800	19	524	99,816	0,077	1,044	2,55	4,99	0,435	1,693	2,207	/	3,999

Table A. 2 : Classification of indices of saturation of forages in Ain Azel

Water points	PH	PHs	IL	Classification	IC	Classification	IR	Classification
D1	8,06	7,18	0,88	Encrusting	1,32	Very resistant to corrosion	6,3	Slightly corrosive
D2	7,59	7,28	0,31	Encrusting	0,85	Average corrosion	6,97	Slightly corrosive
D3	7,5	7,3	0,2	Encrusting	0,59	Average corrosion	7,1	Encrusting
D4	7,67	7,26	0,41	Encrusting	0,95	Average corrosion	6,85	Slightly corrosive
D5	7,63	6,25	1,38	Encrusting	1,85	Very resistant to corrosion	4,87	Encrusting
D6	7,9	7,36	0,54	Encrusting	2,19	Very resistant to corrosion	6,82	Slightly corrosive
D7	7,73	6,95	0,78	Encrusting	2,35	Very resistant to corrosion	6,17	Slightly corrosive
D8	7,8	7,21	0,59	Encrusting	0,46	Average corrosion	6,62	Slightly corrosive
D9	8,2	7,58	0,62	Encrusting	0,9	Average corrosion	6,96	Slightly corrosive
D10	7,76	7,45	0,31	Encrusting	3,71	Very resistant to corrosion	7,14	Encrusting
D11	7,67	6,86	0,81	Encrusting	2,51	Very resistant to corrosion	6,05	Slightly corrosive
D12	7,09	6,68	0,41	Encrusting	4,81	Very resistant to corrosion	6,27	Slightly corrosive
D13	7,69	7	0,69	Encrusting	2,61	Very resistant to corrosion	6,31	Slightly corrosive
D14	7,67	7	0,67	Encrusting	0,99	Average corrosion	6,33	Slightly corrosive
D15	7,64	6,93	0,71	Encrusting	2,21	Very resistant to corrosion	6,22	Slightly corrosive
D16	7,67	7,07	0,6	Encrusting	2,7	Very resistant to corrosion	6,47	Slightly corrosive
D17	7,14	6,98	0,16	Encrusting	2,6	Very resistant to corrosion	6,82	Slightly corrosive
D18	7,13	6,53	0,6	Encrusting	6,8	Very resistant to corrosion	5,93	Encrusting
D19	7,25	6,78	0,47	Encrusting	4,88	Very resistant to corrosion	6,31	Slightly corrosive
D20	8,01	7,29	0,72	Encrusting	15,85	Very resistant to corrosion	6,57	Slightly corrosive
D21	7,48	6,73	0,75	Encrusting	4,68	Very resistant to corrosion	5,98	Encrusting
D22	8,18	6,83	1,35	Encrusting	8,98	Very resistant to corrosion	5,48	Encrusting
D23	7,79	7,07	0,72	Encrusting	1,64	Very resistant to corrosion	6,35	Slightly corrosive
D24	8,25	6,97	1,28	Encrusting	3,44	Very resistant to corrosion	5,69	Encrusting
D25	7,5	7,05	0,45	Encrusting	1,91	Very resistant to corrosion	6,6	Slightly corrosive

D26	7,61	7,22	0,39	Encrusting	1,66	Very resistant to corrosion	6,83	Slightly corrosive
D27	7,36	7,27	0,09	Encrusting	1,81	Very resistant to corrosion	7,18	Encrusting
D28	7,17	7,24	-0,07	Aggressive	2,33	Very resistant to corrosion	7,31	Encrusting
D29	7,54	7,02	0,52	Encrusting	1,74	Very resistant to corrosion	6,5	Slightly corrosive
D30	7,34	7,12	0,22	Encrusting	1,23	Very resistant to corrosion	6,9	Slightly corrosive
D31	6,97	7,31	-0,34	Aggressive	3,49	Very resistant to corrosion	7,65	Encrusting
D32	6,95	7,23	-0,28	Aggressive	1,52	Very resistant to corrosion	7,51	Encrusting
D33	8,2	7,11	/	/	/	/	6,02	/
D34	7,97	7,03	0,94	Encrusting	3,22	Very resistant to corrosion	6,09	Slightly corrosive
D35	7,59	7,17	0,42	Encrusting	0,71	Average corrosion	6,75	Slightly corrosive
D36	7,83	7,18	0,65	Encrusting	1,21	Very resistant to corrosion	6,53	Slightly corrosive
D37	7,65	7,23	0,42	Encrusting	1,29	Very resistant to corrosion	6,81	Slightly corrosive
D38	8,12	7,2	0,92	Encrusting	2,57	Very resistant to corrosion	6,28	Slightly corrosive
D39	7,79	7,15	0,64	Encrusting	1,24	Very resistant to corrosion	6,51	Slightly corrosive
D40	7,45	7,37	0,08	Encrusting	0,82	Average corrosion	7,29	Encrusting
D41	7,87	7,34	0,53	Encrusting	1,21	Very resistant to corrosion	6,81	Slightly corrosive
D42	6,9	7,34	-0,44	Aggressive	0,55	Average corrosion	7,78	Encrusting
D43	7,59	6,96	0,63	Encrusting	1,02	Very resistant to corrosion	6,33	Slightly corrosive
D44	7,69	7,16	0,53	Encrusting	0,83	Average corrosion	6,63	Slightly corrosive
D45	7,55	7,32	0,23	Encrusting	0,63	Average corrosion	7,09	Encrusting
D46	7,84	7,23	0,61	Encrusting	3,51	Very resistant to corrosion	6,62	Slightly corrosive
D47	7,71	7,1	0,61	Encrusting	4	Very resistant to corrosion	6,49	Slightly corrosive
D48	7,64	6,79	0,85	Encrusting	4,77	Very resistant to corrosion	5,94	Encrusting
D49	7,91	7,28	0,63	Encrusting	2,04	Very resistant to corrosion	6,65	Slightly corrosive
D50	7,69	7,09	0,6	Encrusting	0,76	Average corrosion	6,49	Slightly corrosive

Table A. 3 : Classification of water from Ain Azel boreholes according to CE

Water points	CE (µS)	Class	Quality	Water points	CE (µS)	Class	Quality
D1	1100	3	High salinity	**D26**	1400	3	High salinity
D2	900	3	High salinity	**D27**	1100	3	High salinity
D3	700	3	High salinity	**D28**	1500	3	High salinity
D4	900	3	High salinity	**D29**	1600	3	High salinity
D5	3500	4	Very high salinity	**D30**	1200	3	High salinity
D6	1100	3	High salinity	**D31**	1900	3	High salinity
D7	1600	3	High salinity	**D32**	1200	3	High salinity
D8	800	3	High salinity	**D33**	/	/	/
D9	600	3	High salinity	**D34**	1900	3	High salinity
D10	1500	3	High salinity	**D35**	900	3	High salinity
D11	1800	3	High salinity	**D36**	900	3	High salinity
D12	3100	4	Very high salinity	**D37**	1000	3	High salinity
D13	2100	3	High salinity	**D38**	2000	3	High salinity
D14	1200	3	High salinity	**D39**	1200	3	High salinity
D15	1600	3	High salinity	**D40**	900	3	High salinity
D16	1900	3	High salinity	**D41**	900	3	High salinity
D17	2100	3	High salinity	**D42**	700	3	High salinity
D18	5800	4	Very high salinity	**D43**	1200	3	High salinity
D19	3300	4	Very high salinity	**D44**	1100	3	High salinity
D20	4600	4	Very high salinity	**D45**	700	3	High salinity
D21	3100	4	Very high salinity	**D46**	1900	3	High salinity
D22	4500	4	Very high salinity	**D47**	2500	4	Very high salinity
D23	1600	3	High salinity	**D48**	2900	4	Very high salinity
D24	2200	3	High salinity	**D49**	1200	3	High salinity
D25	1700	3	High salinity	**D50**	800	3	High salinity

Table A. 4 : Classification of water from Ain Azel boreholes according to SAR

Water points	SAR	Class	Quality	Water points	SAR	Class	Quality
D1	1,062	1	Alkalinity risk is low	**D26**	2,209	1	Alkalinity risk is low
D2	0,662	1	Alkalinity risk is low	**D27**	0,995	1	Alkalinity risk is low
D3	0,420	1	Alkalinity risk is low	**D28**	2,163	1	Alkalinity risk is low
D4	0,590	1	Alkalinity risk is low	**D29**	2,976	1	Alkalinity risk is low
D5	3,255	1	Alkalinity risk is low	**D30**	1,768	1	Alkalinity risk is low
D6	2,379	1	Alkalinity risk is low	**D31**	2,669	1	Alkalinity risk is low
D7	1,767	1	Alkalinity risk is low	**D32**	1,558	1	Alkalinity risk is low
D8	0,385	1	Alkalinity risk is low	**D33**	/	/	/
D9	0,460	1	Alkalinity risk is low	**D34**	2,644	1	Alkalinity risk is low
D10	0,860	1	Alkalinity risk is low	**D35**	0,756	1	Alkalinity risk is low
D11	1,486	1	Alkalinity risk is low	**D36**	1,072	1	Alkalinity risk is low
D12	2,133	1	Alkalinity risk is low	**D37**	1,126	1	Alkalinity risk is low
D13	4,096	1	Alkalinity risk is low	**D38**	5,970	1	Alkalinity risk is low
D14	1,309	1	Alkalinity risk is low	**D39**	1,103	1	Alkalinity risk is low
D15	1,340	1	Alkalinity risk is low	**D40**	0,879	1	Alkalinity risk is low
D16	3,429	1	Alkalinity risk is low	**D41**	0,629	1	Alkalinity risk is low
D17	3,508	1	Alkalinity risk is low	**D42**	0,446	1	Alkalinity risk is low
D18	8,150	1	Alkalinity risk is low	**D43**	1,440	1	Alkalinity risk is low
D19	6,723	1	Alkalinity risk is low	**D44**	0,673	1	Alkalinity risk is low
D20	6,038	1	Alkalinity risk is low	**D45**	0,578	1	Alkalinity risk is low
D21	3,976	1	Alkalinity risk is low	**D46**	1,827	1	Alkalinity risk is low
D22	8,074	1	Alkalinity risk is low	**D47**	2,745	1	Alkalinity risk is low
D23	2,192	1	Alkalinity risk is low	**D48**	2,814	1	Alkalinity risk is low
D24	3,425	1	Alkalinity risk is low	**D49**	2,065	1	Alkalinity risk is low
D25	2,160	1	Alkalinity risk is low	**D50**	0,538	1	Alkalinity risk is low

Table A. 5 Classification of water from Ain Azel boreholes according to SSP

Water points	SSP	Class	Quality	Water points	SSP	Class	Quality
D1	20,821	2	Good	**D26**	35,828	2	Good
D2	14,865	1	Excellent	**D27**	18,911	1	Excellent
D3	10,723	1	Excellent	**D28**	32,271	2	Good
D4	12,951	1	Excellent	**D29**	41,877	3	Eligible
D5	32,503	2	Good	**D30**	30,508	2	Good
D6	38,294	2	Good	**D31**	35,091	2	Good
D7	26,635	2	Good	**D32**	27,701	2	Good
D8	9,402	1	Excellent	**D33**	/	/	/
D9	12,600	1	Excellent	**D34**	34,927	2	Good
D10	14,949	1	Excellent	**D35**	16,457	1	Excellent
D11	21,706	2	Good	**D36**	22,758	2	Good
D12	23,898	2	Good	**D37**	22,815	2	Good
D13	49,819	3	Eligible	**D38**	59,657	3	Eligible
D14	23,187	2	Good	**D39**	20,322	2	Good
D15	21,516	2	Good	**D40**	21,521	2	Good
D16	42,661	2	Good	**D41**	14,465	1	Excellent
D17	41,855	2	Good	**D42**	11,943	1	Excellent
D18	51,447	3	Eligible	**D43**	26,027	2	Good
D19	55,207	3	Eligible	**D44**	13,490	1	Excellent
D20	45,769	3	Eligible	**D45**	14,103	1	Excellent
D21	39,458	2	Good	**D46**	26,161	2	Bonne
D22	58,138	3	Eligible	**D47**	32,449	2	Good
D23	31,478	2	Good	**D48**	30,094	2	Good
D24	40,091	2	Good	**D49**	33,849	2	Good
D25	31,204	2	Good	**D50**	12,939	1	Excellent

Table A. 6 : Classification of water from Ain Azel boreholes according to RSBC

Water points	RSBC	Class	Quality	Water points	RSBC	Class	Quality
D1	0,813	1	Satisfying	**D26**	-0,357	1	Satisfying
D2	1,300	1	Satisfying	**D27**	-0,799	1	Satisfying
D3	1,005	1	Satisfying	**D28**	-1,084	1	Satisfying
D4	0,242	1	Satisfying	**D29**	-1,596	1	Satisfying
D5	-7,716	1	Satisfying	**D30**	0,116	1	Satisfying
D6	-0,992	1	Satisfying	**D31**	-1,791	1	Satisfying
D7	-2,581	1	Satisfying	**D32**	-0,290	1	Satisfying
D8	1,708	1	Satisfying	**D33**	/	/	/
D9	-0,102	1	Satisfying	**D34**	-4,477	1	Satisfying
D10	-1,997	1	Satisfying	**D35**	1,111	1	Satisfying
D11	-3,385	1	Satisfying	**D36**	-1,696	1	Satisfying
D12	-11,977	1	Satisfying	**D37**	-0,999	1	Satisfying
D13	-2,791	1	Satisfying	**D38**	0,002	1	Satisfying
D14	0,616	1	Satisfying	**D39**	0,711	1	Satisfying
D15	-4,385	1	Satisfying	**D40**	1,404	1	Satisfying
D16	-2,289	1	Satisfying	**D41**	0,462	1	Satisfying
D17	-2,083	1	Satisfying	**D42**	1,304	1	Satisfying
D18	-17,562	1	Satisfying	**D43**	-0,196	1	Satisfying
D19	-9,973	1	Satisfying	**D44**	1,257	1	Satisfying
D20	-9,175	1	Satisfying	**D45**	1,006	1	Satisfying
D21	-11,969	1	Satisfying	**D46**	-3,087	1	Satisfying
D22	-13,175	1	Satisfying	**D47**	-4,986	1	Satisfying
D23	0,010	1	Satisfying	**D48**	-12,576	1	Satisfying
D24	-4,980	1	Satisfying	**D49**	-2,088	1	Satisfying
D25	-0,984	1	Satisfying	**D50**	-0,991	1	Satisfying

Table A. 7 : Classification of water from Ain Azel boreholes according to IP

Water points	IP	Class	Quality	Water points	IP	Class	Quality
D1	39,867	2	GOOD	**D26**	49,290	2	GOOD
D2	37,230	2	GOOD	**D27**	33,365	2	GOOD
D3	36,017	2	GOOD	**D28**	44,150	2	GOOD
D4	32,586	2	GOOD	**D29**	54,013	2	GOOD
D5	39,864	2	GOOD	**D30**	47,974	2	GOOD
D6	52,082	2	GOOD	**D31**	44,171	2	GOOD
D7	39,436	2	GOOD	**D32**	43,977	2	GOOD
D8	36,131	2	GOOD	**D33**	/	/	/
D9	35,467	2	GOOD	**D34**	44,373	2	GOOD
D10	25,315	2	GOOD	**D35**	38,289	2	GOOD
D11	32,505	2	GOOD	**D36**	42,562	2	GOOD
D12	30,269	2	GOOD	**D37**	40,672	2	GOOD
D13	58,603	2	GOOD	**D38**	69,512	2	GOOD
D14	41,027	2	GOOD	**D39**	37,783	2	GOOD
D15	33,756	2	GOOD	**D40**	43,390	2	GOOD
D16	52,932	2	GOOD	**D41**	35,734	2	GOOD
D17	51,758	2	GOOD	**D42**	40,136	2	GOOD
D18	55,110	2	GOOD	**D43**	44,586	2	GOOD
D19	60,952	2	GOOD	**D44**	33,184	2	GOOD
D20	48,409	2	GOOD	**D45**	39,942	2	GOOD
D21	45,820	2	GOOD	**D46**	35,058	2	GOOD
D22	60,483	2	GOOD	**D47**	39,405	2	GOOD
D23	44,171	2	GOOD	**D48**	36,035	2	GOOD
D24	48,359	2	GOOD	**D49**	46,903	2	GOOD
D25	43,592	2	GOOD	**D50**	35,455	2	GOOD

Table A. 8 : Classification of water from Ain Azel boreholes according to MH

Water points	MH	Class	Quality	Water points	MH	Class	Quality
D1	56,552	2	Marginal	**D26**	51,912	2	Marginal
D2	61,446	2	Marginal	**D27**	57,876	2	Marginal
D3	56,877	2	Marginal	**D28**	56,337	2	Marginal
D4	57,876	2	Marginal	**D29**	36,033	1	Adapted
D5	28,124	1	Adapted	**D30**	47,349	1	Adapted
D6	48,188	1	Adapted	**D31**	60,981	2	Marginal
D7	40,722	1	Adapted	**D32**	52,055	2	Marginal
D8	58,032	2	Marginal	**D33**	/	/	/
D9	56,877	2	Marginal	**D34**	36,173	1	Adapted
D10	65,030	2	Marginal	**D35**	55,741	2	Marginal
D11	45,769	1	Adapted	**D36**	28,351	1	Adapted
D12	31,490	1	Adapted	**D37**	43,444	1	Adapted
D13	29,773	1	Adapted	**D38**	48,437	1	Adapted
D14	50,647	2	Marginal	**D39**	59,060	2	Marginal
D15	32,917	1	Adapted	**D40**	61,320	2	Marginal
D16	42,289	1	Adapted	**D41**	58,107	2	Marginal
D17	44,819	1	Adapted	**D42**	56,185	2	Marginal
D18	23,140	1	Adapted	**D43**	38,632	1	Adapted
D19	7,616	1	Adapted	**D44**	62,246	2	Marginal
D20	57,698	2	Marginal	**D45**	55,570	2	Marginal
D21	14,906	1	Adapted	**D46**	56,360	2	Marginal
D22	15,166	1	Adapted	**D47**	51,419	2	Marginal
D23	58,270	2	Marginal	**D48**	25,661	1	Adapted
D24	35,205	1	Adapted	**D49**	41,404	1	Adapted
D25	52,138	2	Marginal	**D50**	33,823	1	Adapted

Table A. 9 : Classification of water from Ain Azel boreholes according to KR

Water points	KR	Class	Quality	Water points	KR	Class	Quality
D1	0,254	1	Suitable	**D1**	0,529	1	Suitable
D2	0,168	1	Suitable	**D2**	0,223	1	Suitable
D3	0,113	1	Suitable	**D3**	0,472	1	Suitable
D4	0,143	1	Suitable	**D4**	0,688	1	Suitable
D5	0,451	1	Suitable	**D5**	0,433	1	Suitable
D6	0,614	1	Suitable	**D6**	0,539	1	Suitable
D7	0,359	1	Suitable	**D7**	0,377	1	Suitable
D8	0,100	1	Suitable	**D8**	/	/	/
D9	0,135	1	Suitable	**D9**	0,529	1	Suitable
D10	0,174	1	Suitable	**D10**	0,188	1	Suitable
D11	0,267	1	Suitable	**D11**	0,287	1	Suitable
D12	0,308	1	Suitable	**D12**	0,286	1	Suitable
D13	0,918	1	Suitable	**D13**	1,463	2	Not suitable
D14	0,294	1	Suitable	**D14**	0,250	1	Suitable
D15	0,268	1	Suitable	**D15**	0,240	1	Suitable
D16	0,735	1	Suitable	**D16**	0,162	1	Suitable
D17	0,707	1	Suitable	**D17**	0,127	1	Suitable
D18	1,054	2	Not suitable	**D18**	0,340	1	Suitable
D19	1,222	2	Not suitable	**D19**	0,153	1	Suitable
D20	0,838	1	Suitable	**D20**	0,160	1	Suitable
D21	0,649	1	Suitable	**D21**	0,349	1	Suitable
D22	1,292	2	Not suitable	**D22**	0,476	1	Suitable
D23	0,453	1	Suitable	**D23**	0,429	1	Suitable
D24	0,658	1	Suitable	**D24**	0,506	1	Suitable
D25	0,447	1	Suitable	**D25**	0,138	1	Suitable

Table A. 10 : Classification of Ain Azel drilling water quality indices

Water points	WQI	Interval Water type	Water points	WQI	Interval Water type
D1	42,814	Excellent water quality	**D26**	57,580	Good water quality
D2	29,855	Excellent water quality	**D27**	47,740	Excellent water quality
D3	33,898	Excellent water quality	**D28**	57,906	Good water quality
D4	40,185	Excellent water quality	**D29**	63,759	Good water quality
D5	116,243	Poor water quality	**D30**	46,253	Excellent water quality
D6	47,758	Excellent water quality	**D31**	75,421	Good water quality
D7	56,706	Good water quality	**D32**	46,775	Excellent water quality
D8	35,347	Excellent water quality	**D33**	/	/
D9	33,498	Excellent water quality	**D34**	66,365	Good water quality
D10	60,207	Good water quality	**D35**	44,763	Excellent water quality
D11	62,441	Good water quality	**D36**	45,597	Excellent water quality
D12	92,436	Good water quality	**D37**	49,330	Excellent water quality
D13	75,981	Good water quality	**D38**	69,759	Good water quality
D14	44,762	Excellent water quality	**D39**	41,228	Excellent water quality
D15	58,879	Good water quality	**D40**	40,875	Excellent water quality
D16	68,203	Good water quality	**D41**	37,425	Excellent water quality
D17	66,156	Good water quality	**D42**	32,328	Excellent water quality
D18	171,610	Poor water quality	**D43**	45,621	Excellent water quality
D19	104,052	Poor water quality	**D44**	47,068	Excellent water quality
D20	134,881	Poor water quality	**D45**	37,150	Excellent water quality
D21	94,364	Good water quality	**D46**	74,057	Good water quality
D22	166,966	Poor water quality	**D47**	84,168	Good water quality
D23	54,762	Good water quality	**D48**	91,297	Good water quality
D24	79,034	Good water quality	**D49**	61,577	Good water quality
D25	60,186	Good water quality	**D50**	35,819	Excellent water quality

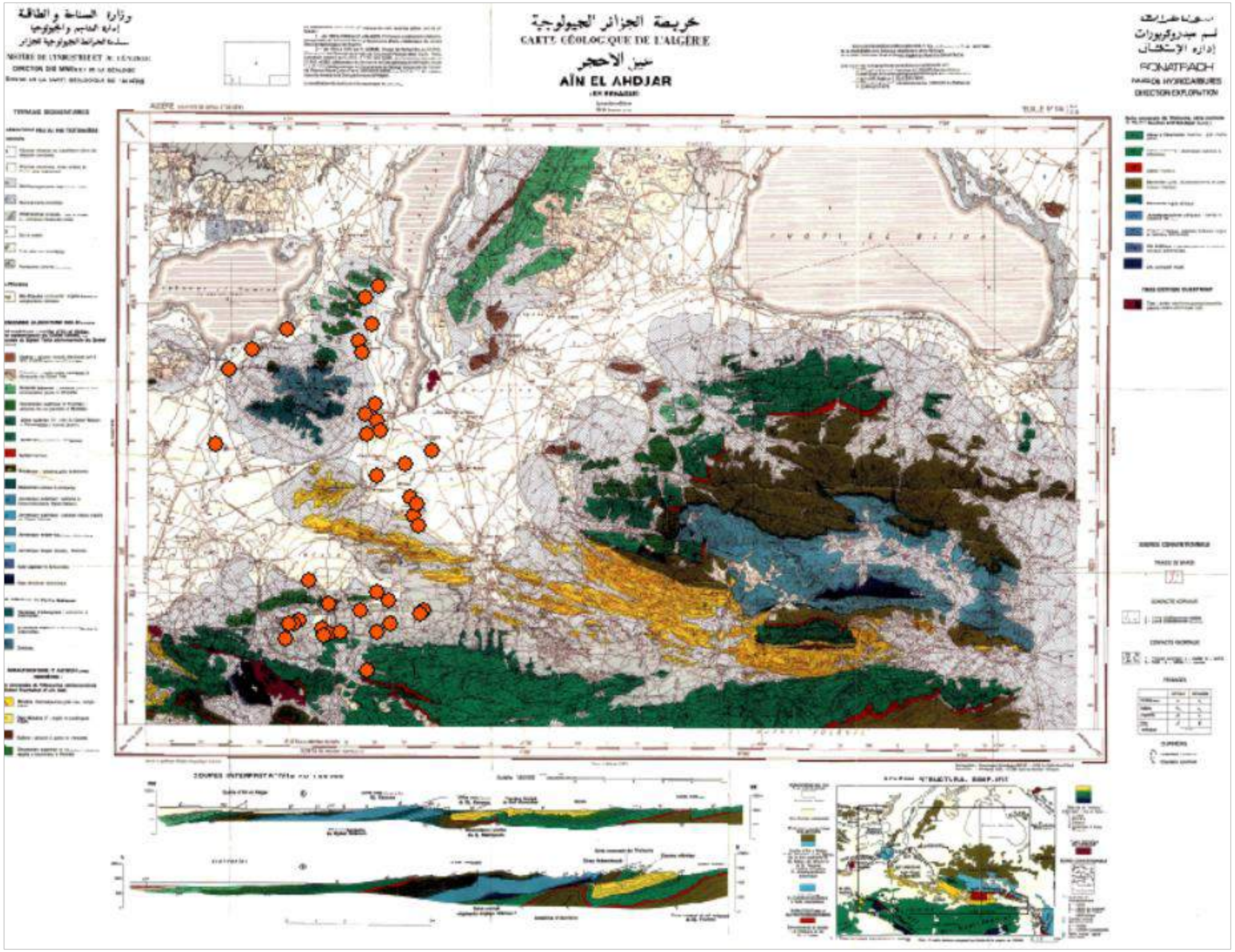

Figure A. 1 : Location of drilling in the study area on the geological map of Algeria, Ain Lahdjer n ° 118 **[52]**

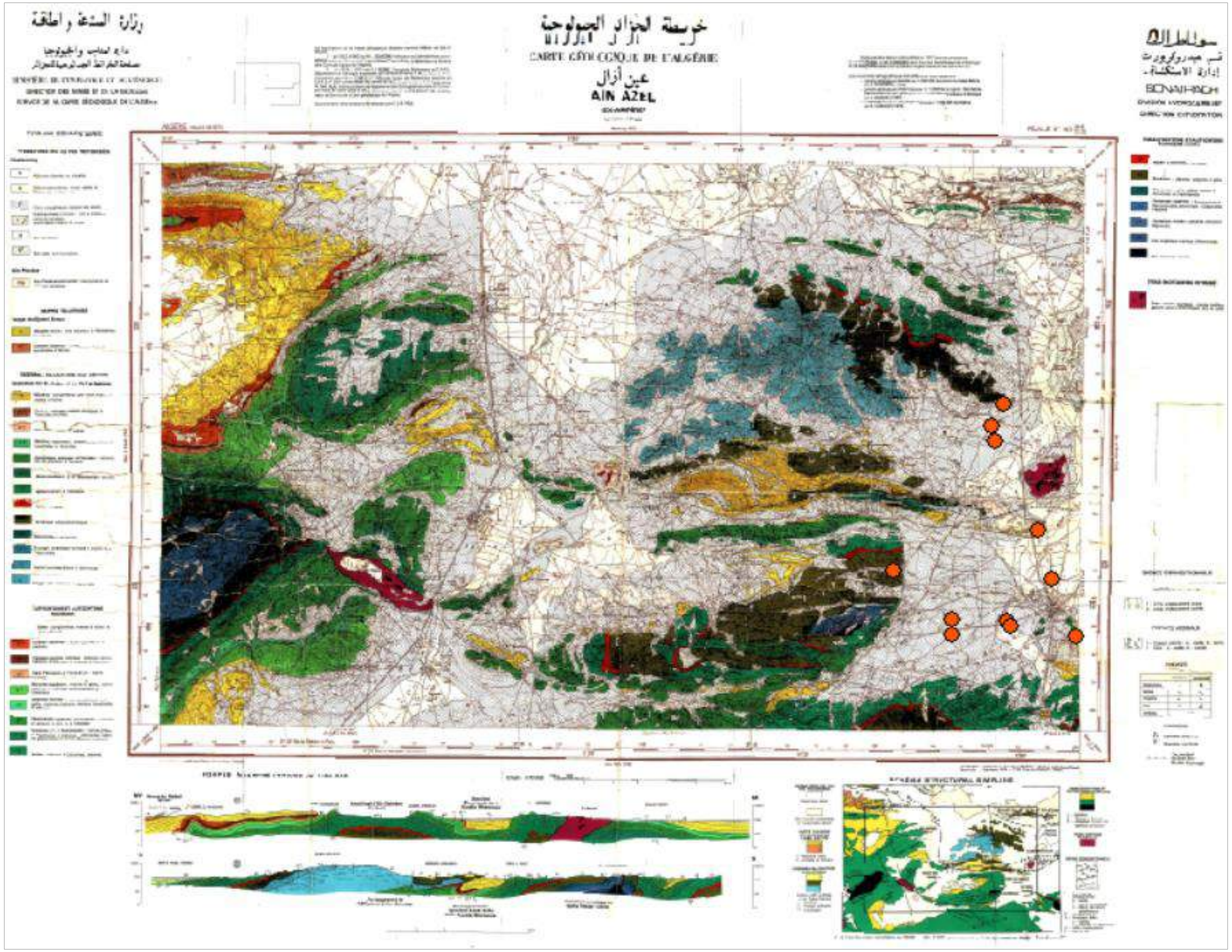

Figure A. 2 : Location of drilling in the study area on the geological map of Algeria, Ain Azel n ° 117 **[52]**