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وزارة التعليم العالي و البحث العلمي

NATIONAL HIGHER SCHOOL FOR HYDRAULICS

"The MujahidAbdellah ARBAOUI"

المدرسة الوطنية العليا للري
"المجاهد عبد الله عرباوي"

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MEMOIRE DE FIN D'ETUDES

Pour l'obtention du diplôme d'Ingénieur d'Etat en Hydraulique

Option : IRRIGATION ET DRAINAGE AGRICOLE.

THEME :

DIMENSIONNEMENT D'UN SYSTEME DE DRAINAGE AGRICOLE POUR LE PERIMETRE DE ZOUIA (200HA), W. TLEMCEN

Présenté par :

BOURAS Akram

Devant les membres du jury

Nom et Prénoms	Grade	Qualité
KAHLERRAS Djillali	MCA	Président
BENKACI ALI Tarek	MCB	Membre
BENLATRECH Tarek	MCA	Membre
BOUZIANE Omar	MAA	Membre
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Session : Septembre 2024

الجمـهـوريـة الجزائـريـة الـديـمـقـراطـيـة الـشـعـبـيـة
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END-OF-STUDIES THESIS

For the attainment of the State Engineer diploma in Hydraulics

<u>Option :</u> IRRIGATION AND AGRICULTURAL DRAINAGE.

<u>THEME :</u>

DIMENSIONING OF AN AGRICULTURAL DRAINAGE SYSTEM FOR THE ZOUIA PERIMETER (200 HA), W. TLEMCEN

<u>Presented by</u>:

BOURAS Akram

<u>Before the members of the jury</u>

FULL NAME	Grade	Quality
KAHLERRAS Djillali	**MCA**	President
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MEDDI Mohamed	**Professor**	Supervisor

Session : September 2024

Dedication

First and foremost, I dedicate this thesis project to my wonderful parents, for their constant support, their encouragements in times of challenge and for their guidance in the face of uncertainty, without them and their sacrifices I would not be where I am today, May ALLAH bless you with a long and happy life;

To my siblings, Rym, Idris and Safa, for all the time and memories we shared growing up Together;

To my family and my grandparents Lakhdar, Abbas, Zohra -ALLAH have mercy on their soul- and Fatma, and also El Hadj Ahmedezin may ALLAH bless you with many more years of joy and good health;

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- Mr BENLATRECH Tarek, for honoring us with their presence as a member of the evaluation jury.
- Mr BOUZIANE Omar, for honoring us with their presence as a member of the evaluation jury.

ملخص

تتناول هذه المذكرة دراسة الصرف الزراعي لمنطقة زوية ببلدية بني بوسعيد بولاية تلمسان. يركز هذا البحث على تقليل مستوى المياه الجوفية الناتجة عن الامطار الشديدة إلى مستويات ملائمة لنمو المحاصيل، بالإضافة إلى الحد من ملوحة التربة من خلال عمليات غسل التربة. هذه الإجراءات تهدف إلى تعزيز كفاءة الأنشطة الزراعية وتحسين استدامة الإنتاج الزراعي في المنطقة.

كلمات مفتاحية: الري، الزراعات، شبكة الصرف الزراعي.

Résumé

Cette thèse se concentre sur l'étude du drainage agricole de la région de Zouia, situé dans la commune de Beni Bousaid, Willaya de Tlemcen. L'objectif principal de cette recherche est de réduire le niveau des eaux souterraines résultant des crues critiques à des niveaux convenables pour la croissance des cultures et de diminuer la salinité du sol par des opérations de lessivage. Ces interventions visent à renforcer l'efficacité des activités agricoles et à promouvoir la durabilité de la production agricole dans la région.

Mots clés : Irrigation, les cultures, réseau de drainage.

Abstract

This thesis examines agricultural drainage in the Zouia region, located in the municipality of Beni Boussaid in the province of Tlemcen. The research aims to lower the water table resulting from critical rainfall to levels conducive to crop growth and to reduce soil salinity through soil leaching operations. These measures are intended to enhance the efficiency of agricultural practices and improve the sustainability of agricultural production in the region.

Key words: Irrigation, crops, drainage network.

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Plan IV: Longitudinal Profile of the Collector A.

General Introduction:

Over the past decades land drainage has evolved as a mature technique to control water logging and salinity and to reclaim agricultural lands. Where drainage has been applied it has proven to be a technically and economically feasible methodology to increase yields and consequently the income of farmers. As a secondary effect it safeguards the productivity of the soil and protects the environment from deterioration.

The Zouia Field does not have a uniform topography, it contains a couple of peaks, with the lowest elevations forming the Zouia River and several adjacent chabbas. The approach presented in this thesis was developed to study the drainage system of this area with the aim of revitalizing agronomic activity in this region despite the awkward terrain.

Our study is divided into two main sections:

The first section includes:

- Presenting the area where the perimeter is located.
- Analyzing the climatic components, with a particular focus on the essential hydrological analysis.
- Assessing the soil's potential through the determination of its physico-chemical properties, its suitability, and evaluating the quality of the water.
- Determining the water requirements of crops along with the necessary leaching dose to remove salts.

The second section covers the technical study, which includes:

- Selecting the drainage system that is best suited for our terrain.
- Mapping out the network and sizing the diameters of drains and collectors.
- Finally, providing management and maintenance recommendations for the drainage network.

Chapter I:

Presentation of the Study Area

I. Introduction:

A thorough understanding and in-depth analysis of various factors are crucial for successfully developing a hydro-agricultural project. This entails a careful consideration of natural elements such as climatic conditions, soil type, and water resources to effectively characterize the area and maximize the potential of the studied perimeter. In this context, we now present the relevant parameters and natural factors to provide a comprehensive overview of the area.

II. Location and Description of the Study Area:

II. 1. Geographical location:

The Wilaya of Tlemcen is situated along the northwest coast of the country, featuring a 120 km coastline. It borders Morocco and spans between latitudes 34°25' and 35°25' North, and longitudes 0°55' and 2°30' West, encompassing an area of 9,023 Km^2. Its geographical boundaries are as follows:

- North: Mediterranean Sea
- Northeast: Aïn Témouchent province
- East: Sidi Bel-Abbès province
- West: Algerian-Moroccan border
- South: Naâma province

The study area is located in the southern region of Tlemcen province in the municipality of Beni Boussaid.

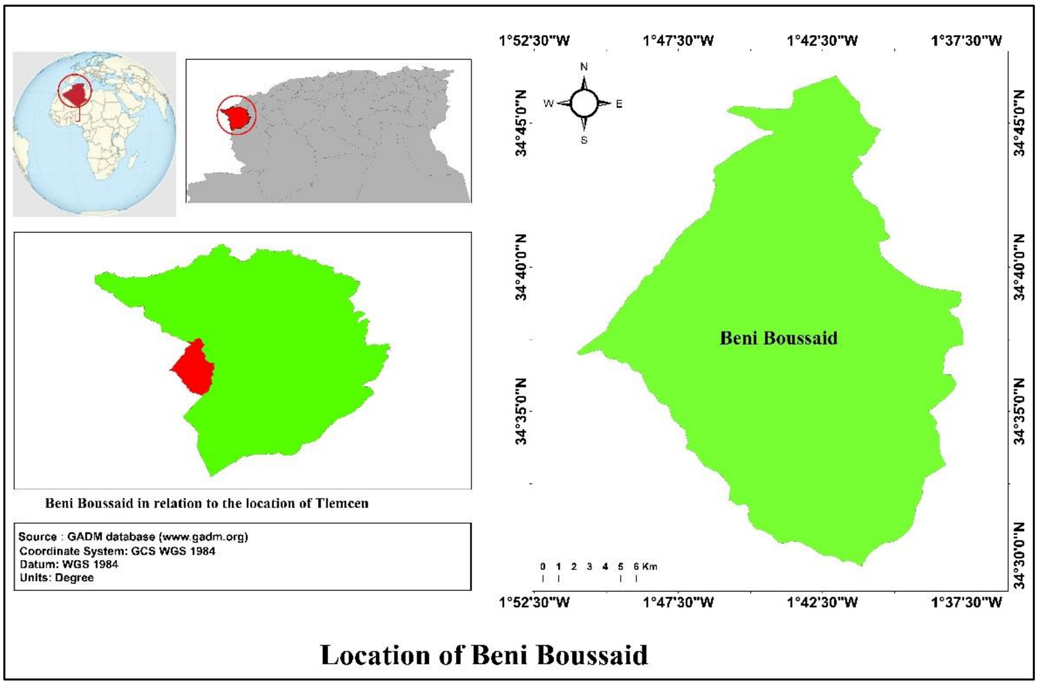

Figure I.1: Geographical Location of the Municipality of Beni Bousaid and the Willaya of Tlemcen.

II. 2. Description of the Study Area:

This area is part of the Ghar Roubane mountains, characterized by distinct geographical boundaries. To the north, it is bordered by the Maghnia plain, while the High Tafna lies to the east. The western boundary is marked by the Touissit-Boubeker depression, and the High Plateaus define the southern edge. These natural features collectively shape the unique topography of the region.

Figure I.2: Satellite Map of the Delimitation Zouia Perimeter (source: google earth, imagery date: 09/27/2024).

III. Landscape and Environmental Characteristics:

III. 1. Geomorphology/Relief:

The region consists of the Ghar Roubane mountains, indicating a predominantly mountainous terrain. Furthermore, the presence of the Maghnia plain to the north, the High Tafna to the east, the Touissit-Boubeker depression to the west, and the High Plateaus to the south highlights the diverse landscape surrounding the area.

III. 2. Geology:

These areas are primarily composed of carbonates, including limestone and dolomite, which are heavily fractured and karstified, reflecting their extensive geological history.

Additionally, the region contains formations such as clays, sandstones, shales, and other types of limestone and dolomite dating back to the Paleozoic era. The landscape has been shaped by successive large-scale geological processes over time.

IV. Hydrology:

The water supply for our study area will be sourced from the Zouia Dam, situated approximately 88 km south of the city of Tlemcen along the Zouia River, at a minimum altitude of 711 meters.

V. Climatological Study:

Meteorological and climatological data are vital for effective irrigation planning. Analyzing climate data helps assess essential factors like precipitation and temperature, which affect the hydrological balance and the water needs of crops. For our study area, climate analysis utilizes data from the Maghnia weather station, located nearby. This data spans over twenty years, covering the period from 1992 to 2018, and is sourced from the National Meteorological Organization (ONM) and the National Agency for Hydraulic Resources (ANRH).

V. 1. Choice of the meteorological station:

In our study, we relied on the climatological station closest to the perimeter to ensure high climatic accuracy, in our case it was the Maghnia Station.

Table I.1: Maghnia Meteorological Station

Meteorological Station	Longitude	Latitude	Altitude (m)	Observation Period	Observation Duration
Maghnia	1,78°	34,82°	426	1985-2016	31 years

V. 2. Temperature:

Temperature is a key factor in determining irrigation water needs and in selecting the appropriate type and system of irrigation. The temperature data for the studied region are provided in the table below.

Table I.2: Monthly Temperatures (°C).

T°c	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Max	24.9	21.9	17.8	14.5	12.7	14.3	14.7	18.1	21.2	25.3	28.4	29.3
Min	22.7	19.3	13.1	10.4	9.7	8.8	12.9	14.7	17.6	20.4	24.8	26.7
Avg	23.9	20.6	15.5	12.2	11.3	11.7	13.9	16.6	19.5	22.9	26.5	27.5

(Source : ONM Algiers)

With:

- Min Temp: average of all observed minimum temperatures for each month in °C.
- Max Temp: average of all observed maximum temperatures for each month in °C.

- Avg Temp: monthly average temperature in °C.

Understanding these temperature values and their ranges is essential for selecting appropriate irrigation methods and crops. The figure below illustrates the monthly temperatures for the area.

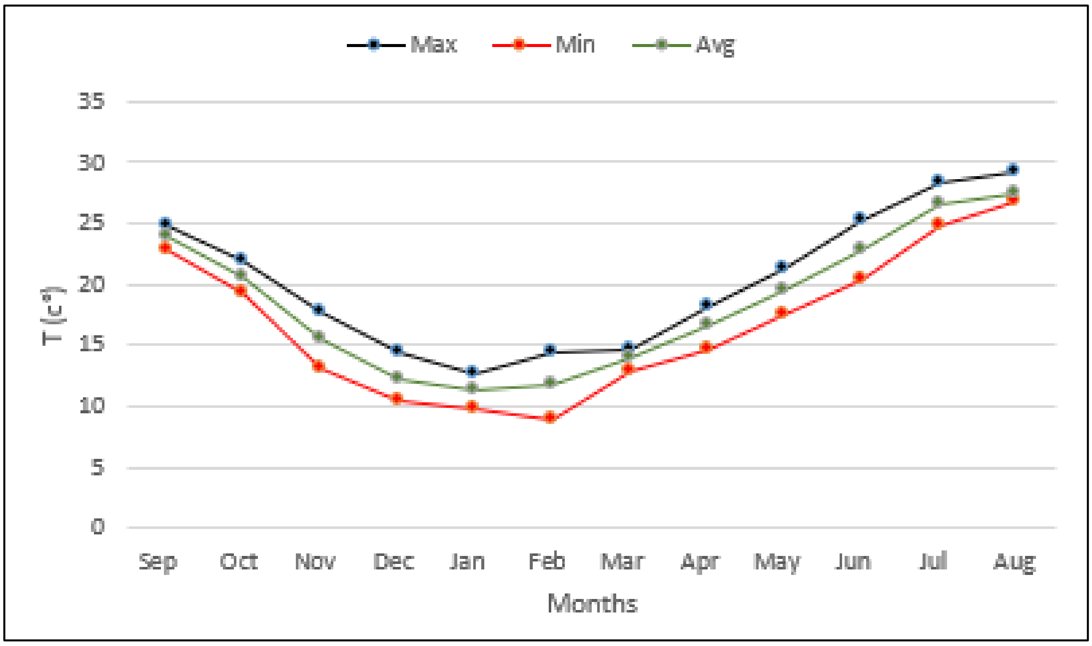

Figure I.3: Monthly Temperature Variations.

Interpretation:

Figure I.3 shows that the lowest average temperature is observed in January, at 11.3°C, while the highest average temperature occurs in August, at 27.5°C. The annual average temperature is approximately 18.5°C. Notably, the warm season, with average temperatures exceeding 18.5°C, lasts for six months, from May to October. The cold season spans the remaining months, from November to April.

V. 3. Precipitation:

Monthly rainfall is crucial for irrigation as it helps quantify the water balance necessary for calculating irrigation doses and requirements. The average annual precipitation is estimated to be 265.25mm.

Table I.3: Average Monthly Precipitation (mm).

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Year
P (mm)	14,23	34,06	55,44	41,89	51,35	46,17	38,16	26,28	20,21	3,70	0,51	3,81	335,97

(Source: ANRH Algiers)

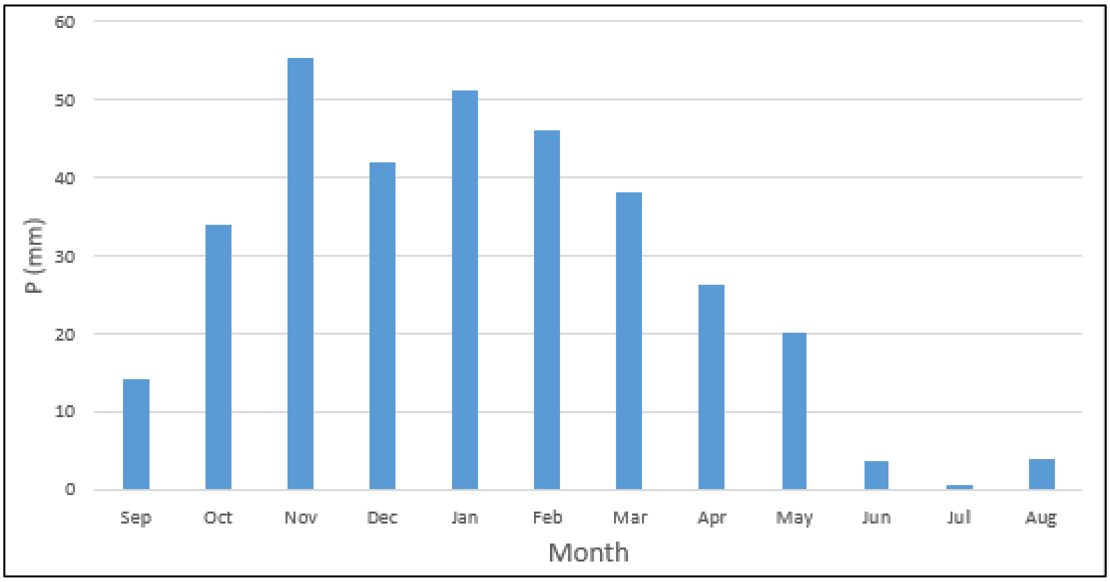

Figure I.4: Histogram of Average Monthly Precipitation (mm).

Interpretation:

The annual precipitation distribution shows significant variability. Rainfall amounts change monthly, with the majority occurring between October and April, while the summer months are considerably drier. As a result, it is improbable that rainfall alone can satisfy the water requirements of crops, making irrigation essential in this region.

V. 4. Humidity:

Relative humidity is another crucial factor in the vegetation development cycle. The study area is relatively humid due to its proximity to the Mediterranean Sea. Indeed, humidity levels exceed 50% throughout the entire year.

Table I.4: Air Relative Humidity (%)

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
H (%)	69.6	72.8	74.5	77.0	78.2	77.6	75.3	73.4	67.1	63.1	59.1	61.7

(Source : ONM Algiers)

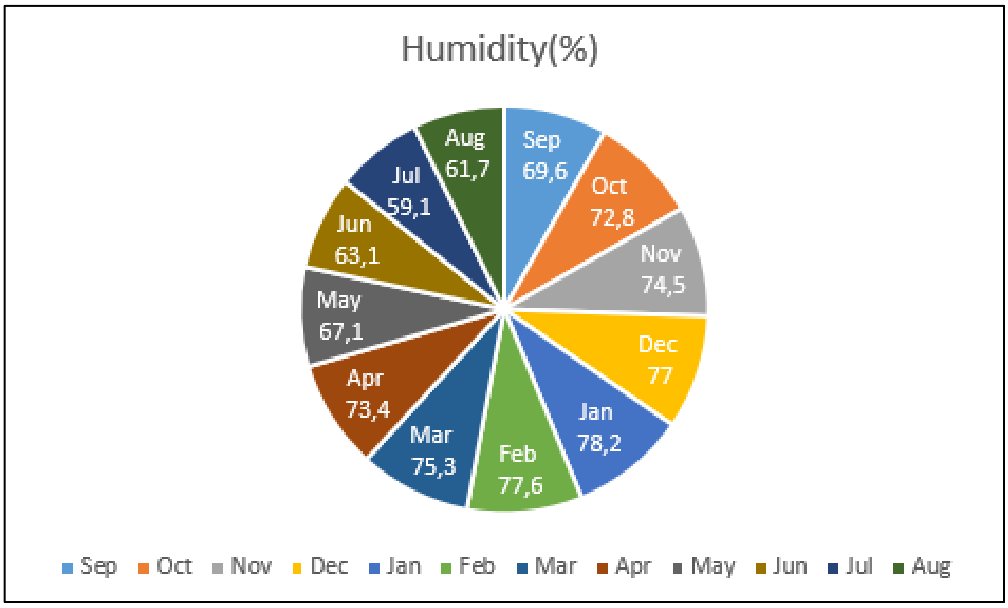

Figure I.5: relative air humidity %

Interpretation:

Based on the data represented in the figure above, January has the highest humidity level at 78.2%, making it the most humid month. In contrast, July is the driest month, with humidity levels falling to 59.1%.

V. 5. Wind:

Wind is known to directly influence the soil, vegetation, and other factors such as evapotranspiration, as well as their impact on sprinkler irrigation. The wind condition data is shown in the following table:

Table I.5: Average and Maximum Wind Speeds (m/s)

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Year
Max	2.94	3.28	2.81	3.21	3.19	3.50	3.86	3.06	3.17	3.22	3.22	3.22	3.11
Average	2.47	2.47	2.25	2.57	2.39	2.64	2.61	2.67	2.69	2.64	2.72	2.69	2.61

(Source : ONM Algiers)

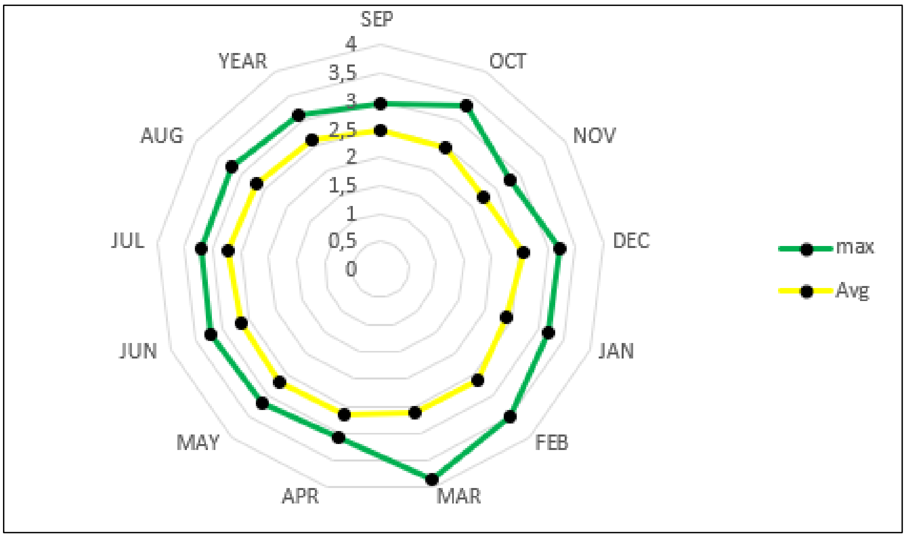

Figure I.6: Monthly Distribution of Average Speed (m/s).

Interpretation:

Wind speed remains relatively low throughout the year, with monthly averages ranging from 2,25 m/s in November to 2,72 m/s in July. The windiest months are July, Aug, May, with monthly averages of 2,72 m/s and 2,69 m/s, respectively. However, there are periods when wind speeds can be extremely high, particularly in March, where maximum speeds can reach up to 3,86 m/s. It is crucial to consider these peak values when planning and implementing infrastructure, crops, and activities that could be affected by strong winds.

V. 6. Evaporation:

Evaporation is a gradual process in which a liquid transforms into a gas, resulting in a reduction in the surrounding temperature.

Table I.6: Average Monthly Evaporation in mm

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	year
Evaporation	186.2	118.8	78.8	63.3	58.2	56.4	88.9	104.8	146.6	201.1	276.0	266.4	137.13

(Source : ONM Algiers)

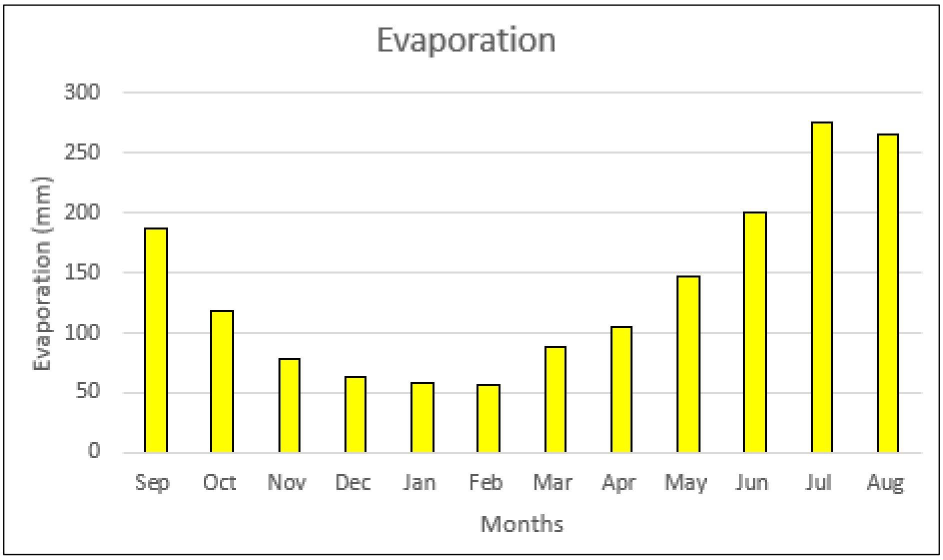

Figure I.7: Average Evaporation Variations (1992-2018)

Interpretation:

Evaporation reaches maximum values of 276mm in the month of July due to high temperatures, on the other hand it reaches minimal values of 56.4mm in the month of February due to low temperatures. The average annual evaporation is 137.13mm.

V. 7. Sunshine duration:

Sunshine duration, or insolation, refers to the length of time the soil is exposed to solar radiation. The average monthly and daily values are shown in the following table:

Table I.7: Average Insolation

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Hours/day	8.83	7.61	6.58	5.94	6.57	7.08	7.82	8.89	8.83	10.67	10.76	10.25

(Source : ONM Algiers)

Interpretation:

The summer period of June, July, August has the highest values of insolation, which is to be expected due to longer daylight hours and less atmospheric scattering.

V. 8. Agro-Meteorological Indices:

To determine the type of climate and the interaction of its various variables and their effects on plants, two essential factors are considered: rainfall and temperature, knowing these two factors we can calculate two key indices: the Martonne index and Emberger's ombrothermic quotient. These indices are extensively used for climate assessment.

V. 8. 1. Martonne aridity index:

This index provides valuable information about the region's aridity, which is essential for understanding its impact on irrigation practices. It is a key tool for planning agricultural production and managing water resources:

$$I = \frac{P}{T + 10} \qquad \text{I.1}$$

With:

- I: Climatic Index.
- P: Average Annual Precipitation (mm).
- T: Average Annual Temperature (°C).

Application:

$$\mathrm{I} = \frac{335{,}97}{18.5 + 10} = 11{,}79$$

Table I.8: Climate Classification according to Martonne

Values of I	Climate Type	Irrigation
I < 5	Desert	Essential
5 < I < 10	Very Dry	Essential
10 < I < 20	Dry	Often Essential
20 < I < 30	Relatively Humid	Occasionally Useful
I > 30	Humid	Unnecessary

According to the table above, that shows climate type classification and the necessity for irrigation according to the values of the climate index:

10 < I < 20 therefor our climate is dry, and irrigation is Often essential.

V. 8. 2. Bagnols and Gaussen Index:

The ombrothermic diagram is structured as follows:

The months of the year are plotted on the x-axis, while temperatures are depicted on the y-axis to the right of the scale, and precipitation, scale doubled in value, is shown on the left of the scale.

The area enclosed by the two curves delineates the period and duration of the dry season. Determining this period is of great significance for hydrogeology to estimate water requirements.

Table I.9: Monthly Average Temperature and Rainfall Values

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
P (mm)	14,23	34,06	55,44	41,89	51,35	46,17	38,16	26,28	20,21	3,70	0,51	3,81
T (°C)	23.9	20.6	15.5	12.2	11.3	11.7	13.9	16.6	19.5	22.9	26.5	27.5
2T	47.8	41.2	31	24.4	22.6	23.4	27.8	33.2	39	45.8	53	55

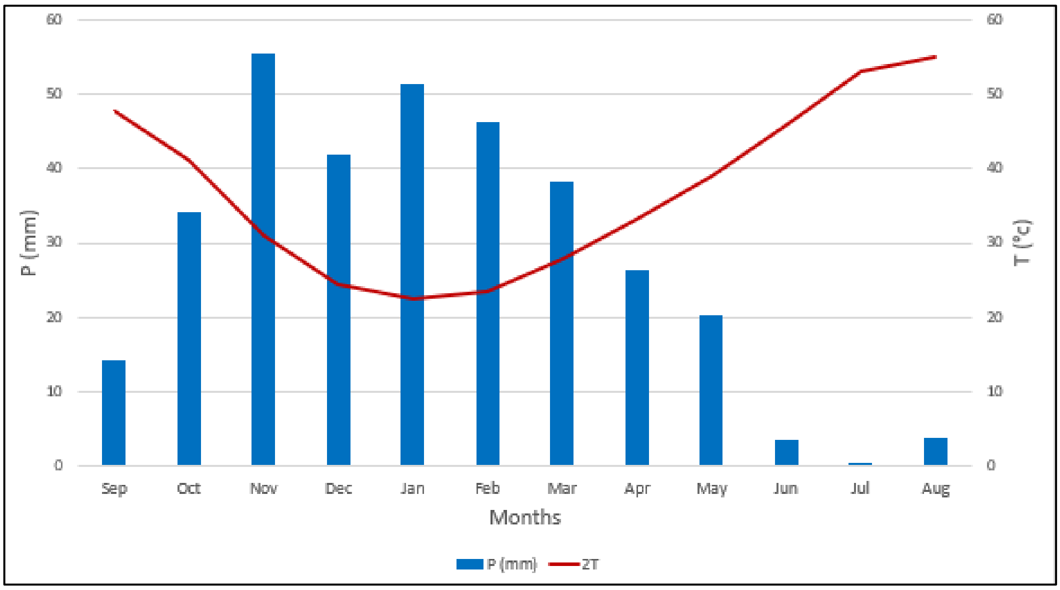

Figure I.8: Gaussen's Climagram.

It is evident that for the Maghnia station, which corresponds to the Zouia perimeter, the dry period extends from mid-March to mid-October. During these 7 months, irrigation is essential.

V. 8. 3. Emberger Rainfall Quotient (1955):

This index aims to determine the bioclimatic zone:

$$Q = \frac{2000 \times P}{M^2 - m^2} \quad \text{I.2}$$

With:

- Q: Emberger's rainfall coefficient.
- P: Average annual precipitation (in millimeters), P = 335,97 mm.
- M: Average of the maximum temperatures (in Kelvin), M = 29.3°c.
- m: Average of the minimum temperatures (in Kelvin), m = 8.8° c.

Application:

$$Q = \frac{2000 \times 335{,}97}{302.45^2 - 281.95^2} = 56{,}09$$

By plotting the value of Q= 43 on Emberger's bioclimatic diagram and considering the average minimum temperature of the coldest month (8.8°C), we can confirm that our region falls within the semi-arid zone.

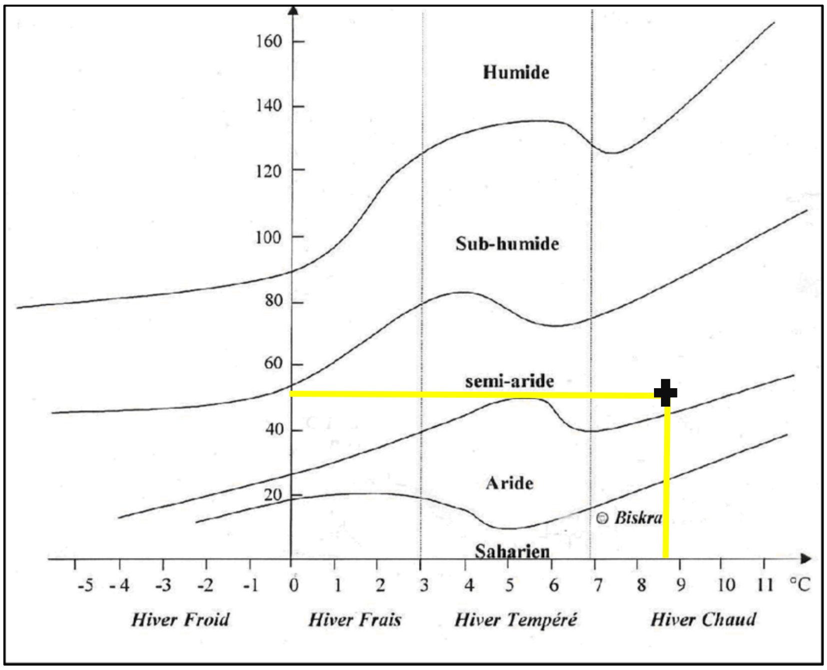

Figure I.9: Emberger Bioclimatic Diagram

V. 8. 4. Interpretation of climatic indices:

In our study, the Martonne index of 11,79 indicates a dry climate, while the Emberger index of 56,09 confirms this observation, therefor an irrigation system is needed.

VI. Conclusion:

Based on the analysis of climatic, hydrological, and hydrographic parameters, we can conclude that our study area has a dry climate with variable rainfall in terms of volume and distribution over time. The hydrological year is characterized by a Slightly rainy cold winter and a hot, dry summer. Given the aridity of the study area, it is essential to implement an irrigation system to support crop development and intensify agriculture yield in the Zouia plain.

The combination of water salinity and sudden critical precipitation leads to soil degradation, reduced crop yields, and waterlogging. In Irrigated perimeter in arid and semi-arid regions, Salinity is a major issue, it harms plants by inhibiting water absorption, while heavy rainfall overwhelms the plants, causing flooding and erosion. In this case a drainage network is designed to remove leaching water containing accumulated salts in the soil and also excess critical precipitation water.

Chapter II:

Soil and Water Resources

I. Introduction:

Pedology is the scientific study concerned with the formation, classification, description, and cartography of soils. A comprehensive understanding of soils is crucial for sustainable land and natural resource management. It enables the determination of the physical, chemical, and biological characteristics of soil, including texture, structure, pH, organic matter content, and nutrient levels.

II. Soil Resources:

II. 1. Introduction:

The study of soil resources aims to comprehend the nature and properties of soils to determine their potential and limitations for agricultural, forestry, or construction purposes. In a development project, several characteristics must be taken into consideration, including:

- Soil depth, which governs the thickness of layers accessible to roots and subsequently the available water reserve.
- Soil texture or particle size distribution and stone content, which influence water retention.
- Soil structure and porosity of soil horizons, which dictate the permeability of the environment and overall ease of irrigation.
- Chemical characteristics (PH, EC, SAR) that impact the agricultural possibilities of the irrigated area.

II. 2. Soil classification:

The classification employed in this study follows the framework established by the Soil Pedology and Cartography Commission of France (C.P.C.S, 1967). This classification system primarily relies on determining the higher units (class, subclass, group, subgroup) as well as the lower units (family and series), providing users with a convenient tool for assessing functional characteristics.

Our soil is composed primarily of Yellow Clay, it derives its bright color from the copper and zinc elements it contains.

These soils often have a good water and nutrient retention capacity, which can be beneficial for plant growth. However, they can also be prone to compaction and slow drainage, which can negatively affect crops.

The soil is also rich in limestone, inherited from the parent material predominantly composed of limestone. The limestone content varies with the soil texture.

Pedogenetic Factors:

The two predominant factors in the soil formation of the Zouia area are Precipitation and limestone.

- **Limestone**: The soils in the area are rich in limestone. Several zones characterized by powdery limestone crusts have been identified.

- **Precipitation:** Precipitation plays a crucial role in soil formation, as it causes the leaching of limestone into deeper soil layers and contributes to soil erosion.

II. 3. Morphological Characteristics:

Several profiles were analyzed, the characteristics of profile 1 are detailed and summarized as follows:

Profile 1 :

- **Class**: Calcimagnesian Soils
- **Subclass**: Carbonate Soils
- **Group**: Calcareous Brown Soils
- **Subgroup**: Modal
- **Family**: Calcareous Colluvium with a balanced texture
- **Series**: Deep
- **Type**: Clay loam Soil.

Depth :

The horizons are categorized based on their depth as follows:

- **0 – 15 cm:** Fresh, yellow soil with a balanced silty clay texture, massive to medium polyhedral structure, compact, low porosity, presence of roots and fine rootlets, detectable organic matter, reacts positively to HCl, clear transition.

- **15 – 37 cm:** Fresh to dry, light yellow, balanced texture, coarse polyhedral structure, compact, hard, low porosity, few roots and fine rootlets, detectable organic matter, low biological activity, presence of whitish limestone spots, a thin layer of gravel and limestone of various diameters, reacts positively to HCl, clear transition.

- **37 – 120 cm:** Fresh, light yellow, medium polyhedral structure, fairly developed, prismatic to massive structure, low porosity, few roots and fine rootlets, presence of whitish spots with some gravel, effervesces strongly with HCl.

II. 4. Physico-Chemical Soil Analysis:

Conducting a physico-chemical analysis in the laboratory has allowed us to gain a better understanding of the characteristics of our soil.

Table II.1: Laboratory Analysis of the Profiles.

Depth (cm)	0-15	15-37	37-120
Clay (Argile)%	30	33	33
Fine Silt (Limon fin) %	28	24	24
Coarse Silt (Limon grossier) %	12	12	11
Fine Sand (Sable fin) %	16	16	16

Coarse Sand (Sable grossier) %		15	14	14
Real Density		2,61	2,47	2.48
Ph		7,24	7,21	7,22
C.E mmhos/cm		2,51	2,22	1,95
K Hénin Permeability		1.89	2.50	2.92
$pF_{4.2}$		14.29	13.5	13.62
$pF_{2.5}$		25.85	24.95	25.16
C ‰		19.1	14.6	15.0
N ‰		1.93	1.61	1.60
C/N		9.89	9.06	9.37
Total Ca CO_3		47.10	47.03	47.58
Activ Ca CO_3		15.25	15.25	15.5
P_2O_5 total ‰		2.64	2.35	2.35
Absorptive Complex (meq/100g)	Ca^{++}	25.80	25.65	24.98
	Mg^{++}	3.83	4.39	4.06
	Na^{+}	2.55	4.25	3.33
	K^{+}	1.18	0.75	0.85
	T	14.47	17.50	13.74

(Source: ONID, Tlemcen)

To note: We notice that the salinity of the soil is lower than 4mmhos/cm which means the soil is not considered saline, and does not require capital leaching. However, it might need maintenance leaching to keep the salinity levels low for a better crop yield.

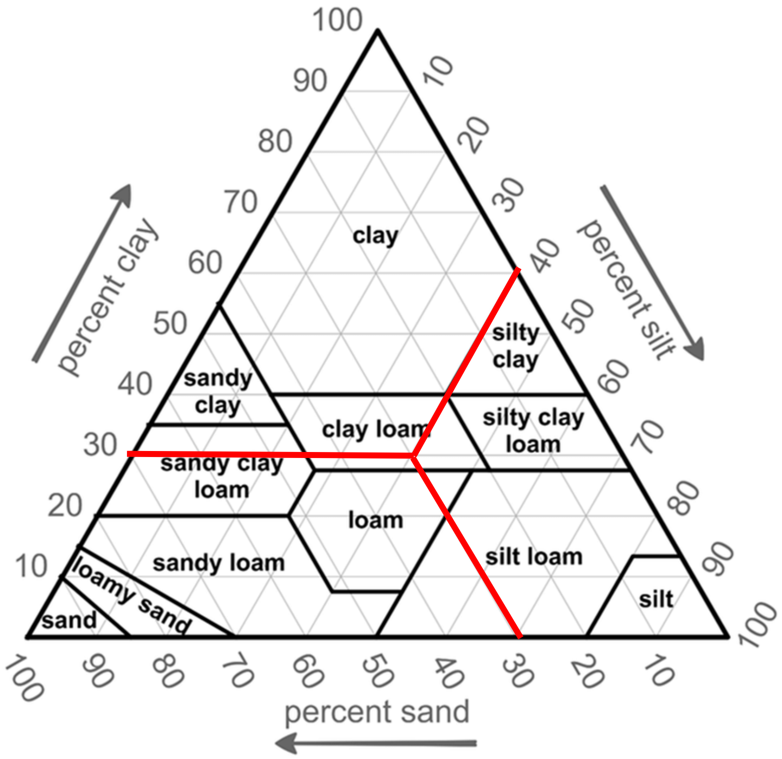

Figure II.1: Textural Analysis of the Studied Soils (USDA texture triangle)

Interpretation of the results:

According to the USDA Texture Triangle illustrated above, our soil has a clay loamy texture.

The hydrodynamic properties are presented in the following table:

Table II.2: Hydrodynamic Properties of the Soil

Texture	Clay loam
Field capacity moisture (Hcc)	27%
Wilting point moisture (HPF)	13%
Permeability	7 mm/h
Soil Density	1.3

III. Water Resources:

III. 1. Introduction:

The initially planned water resource, upon which the hydro-agricultural development study of the Zouia perimeter in the Tlemcen province was based, consists of water allocation from the Beni Bousaid dam. The analysis of water resources holds a crucial position, as the expansion of irrigation is closely linked to the availability of water resources.

III. 2. The Surface Water Resources:

III. 2. 1. presentation of the Zouia Dam:

The zouia river runs in a South-North direction. The zouia Dam, with a capacity of 2.3 hm3, is constructed on the Zouia Oued, 3 kilometers south of the Beni Boussaid town. Its primary purpose is to supply irrigation water to the perimeters in the proximity.

III. 2. 2. Characteristics of the Zouia Dam:

The Zouia Dam is a small dam capable of storing up to 2.3 million cubic meters of water. Its normal water level is maintained at an altitude of 714 m.

III. 2. 3. Irrigation water qualities:

It is necessary to study the quality of irrigation water before any agricultural development project. To do this, it is essential to check certain key factors, which include:

- PH.
- Salinity risk.
- Sodium (Sodium Absorption Ratio or SAR).
- Carbonates and bicarbonates Ca, Mg.
- Toxic anions.

Table II.3: Irrigation water quality parameters.

Characteristics	Symbol	Values	
PH		7.9	
Cations et Anions		(mg/l)	(meq/l)
Chloride	Cl-	311	8,7702
Sulfate	$SO4^{2-}$	550	11,44
Bicarbonate	HCO3	122	2,0008
Sodium	Na^{+}	95	4,1325
Magnesium	Mg++	43	3,5389
Calcium	Ca++	75	3,7425
Potassium	K+	14	0,3584
Nitrate	$NO3^{-}$	11	0,1771

Source: ONID

III. 2. 4. Classification of irrigation water:

III. 2. 4. 1. Electrical conductivity:

Electrical conductivity is a characteristic related to the mobility of ions and thus allows for the assessment of water salinity. It is measured at a temperature of 25°C and expressed in milli siemens per centimeter (mS/cm). Water salinity can be classified into four levels of danger based on its electrical conductivity:

Table II.4: Classification of water based on Electrical conductivity.

Class	Electrical Conductivity EC (mmhos/cm)	Water quality	Suitability for crops
C1	EC≤ 0,25	Water of Low Salinity Risk	Suitable for all crops
C2	0,25< EC≤0,75	Water of Average Salinity risk	Suitable for moderately tolerant plants
C3	0,75< EC≤2,25	Water of high Salinity Risk	Suitable only for well-drained soils and tolerant plants.
C4	EC>2,25	Water of very high Salinity risk	The water is difficult to use on well-drained soils.

The water from the Zouia Dam, intended for irrigation has an average electrical conductivity of **EC = 1.34 mmhos/cm**, which puts it in the C3 class, rendering it at high risk for use for irrigation purposes.

III. 2. 4. 2. The Sodium Adsorption Ratio (SAR):

SAR is a measure used in assessing the suitability of water for irrigation. It helps determine the potential for soil degradation due to sodium accumulation when using irrigation water containing high sodium levels.

A high SAR can cause soil particle dispersion especially in clays, a phenomenon also known as deflocculation. which may reduce soil permeability and affect crop growth.

$$SAR = \frac{Na^+}{\sqrt{\frac{Mg^{2+} + Ca^{2+}}{2}}} \qquad \text{II.1}$$

With:

- Na^+: sodium in meq/l (1 meq/l = 0.0435 mg/l)
- Ca^{2+}: calcium in meq/l (1 meq/l = 0.0499 mg/l)
- Mg^{2+}: magnesium in meq/l (1 meq/l = 0.0823 mg/l)

Application :

$$SAR = \frac{4.1325}{\sqrt{\frac{3.54 + 3.74}{2}}} = 2.17$$

Table II.5: Classification of water based on SAR (for low EC).

Class	SAR	Alkalinization Risk
S_1	SAR≤10	Low Risk
S_2	10<SAR≤18	Medium Risk
S_3	18<SAR≤26	High Risk
S_4	SAR>26	Very High Risk

According to the table above, **SAR = 2.17** ≤ 10, Class S1, indicating a low risk of alkalinity.

III. 2. 4. 3. Irrigation Water Classification:

We use the following diagram to classify the irrigation waters from the Zouia Dam based on the results of the electrical conductivity calculation (EC = 1.34 mmhos/cm) and the sodium absorption ratio of the irrigation water (SAR = 2.17).

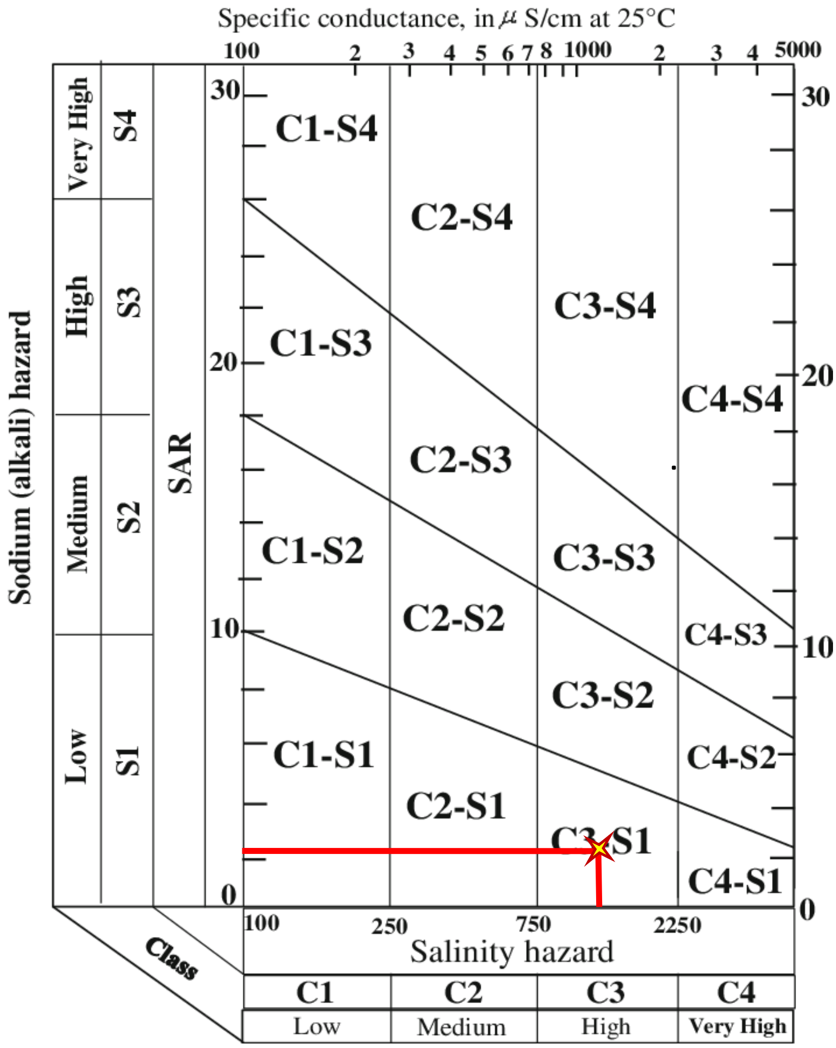

Figure II.2: USSL diagram for classification of irrigation waters (United States Salinity Laboratory Staff, 1954).

Interpretation:

The water from the Zouia Dam falls in the (S1-C3) category which presents a low alkaline risk (S1), indicating it can be used with minimal risk of harmful sodium accumulation for practically all soil types. However, it poses a high risk of salinity, requiring attention. High salt concentration may render this water unsuitable for certain soil and crop types, potentially necessitating special measures such as adequate drainage and the selection of tolerant plants. It's crucial to consider these characteristics when utilizing water from the Zouia Dam for irrigation, especially concerning the judicious choice of crops and the implementation of water management practices aimed at minimizing the negative effects of salinity.

III. 3. Hydrology:

The hydrological study allows for the analysis of the rainfall pattern and the determination of monthly rainfall with an 80% frequency (dry year).

III. 3. 1. Overview of the Maghnia Rain Gauge Station:

The rain gauge stations selected for estimating precipitation in the watershed were chosen based on their geographical location and observation period.

For our precipitation analysis, the dataset from the Maghnia station was utilized. This station provides a thorough and accurate representation of the study area's conditions.

Table II.6: Characteristics of the Pluviometric Station (ANRH, Algiers).

Meteorological Station	Longitude	Latitude	Altitude (m)	Observation Period	Observation Duration
Maghnia	1,78°	34,82°	426	1985-2016	31 Years

Table II.7: Series of Monthly Average Rainfall (mm).

Years	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	**Total**
1985-1986	0,3	0	49,8	47,3	37,3	87,2	70,5	38	2,1	1,3	0	1,6	**335,4**
1986-1987	34,2	56,4	83,7	34,2	28,7	118,3	4,9	2	12,2	0	5,2	0	**379,8**
1987-1988	8,6	39,8	19,6	29,3	21,6	13,3	6,1	18,1	9,8	14,8	0	0	**181**
1988-1989	12,4	1,5	19,9	0	31,6	18,4	93,5	25,2	12,2	0,4	0	0	**215,1**
1989-1990	12,8	2,9	11,9	62,2	135,5	0	37,7	36,3	17,5	0,6	0	0	**317,4**
1990-1991	18,5	10,5	58,7	30,3	61	49,2	114,3	16,3	7,1	0	0	0	**365,9**
1991-1992	2,8	21,2	67	18,02	14,8	17	80,6	9,1	55,3	27,1	0	0	**312,92**
1992-1993	0,2	12,1	24,4	18,2	0	122,8	31,3	28,5	69,6	3,4	0	0	**310,5**
1993-1994	7	33,5	94,6	3,9	46,5	43,5	4,7	13,1	15,9	0	2	0	**264,7**
1994-1995	23,9	10,9	19,1	17,1	18,7	54,2	90,8	20	0,1	3,7	0	0,1	**258,6**
1995-1996	1,8	30,5	8,8	47	57,6	107,7	24,6	12,1	22,1	0	0	1,6	**313,8**
1996-1997	32,9	5,1	10	31,9	125,1	0	0,2	42,6	7,2	2,9	1,4	12,7	**272**
1997-1998	43,8	17,6	47,8	34,3	27,1	28,5	20	22,7	55,8	0	0,6	3,5	**301,7**
1998-1999	10,6	3,4	40,9	2,9	65,1	87,7	115,1	0	0,3	0	0	0	**326**
1999-2000	19,1	12,3	85,5	59	0,4	0	4	10,6	17,7	0	0	0	**208,6**
2000-2001	8,8	335,9	71,2	18,9	36,9	56	5,2	1,7	10,7	0	0	0	**545,3**
2001-2002	7,5	11,4	111,7	32,8	3,2	5,7	16,2	52,4	35,7	0	0	53,5	**330,1**
2002-2003	0	21,7	81,8	9,5	94,8	100,5	23,3	21,1	12,4	0,1	0,5	0	**365,7**
2003-2004	3,3	24,1	56,2	99,3	39,6	23,2	46,1	23,1	47,6	8,5	0	9,5	**380,5**
2004-2005	0	42,1	51,6	76,4	29,9	69,3	40,4	14,5	0	0	0	4	**328,2**
2005-2006	5,6	10,4	28,7	29,4	64,2	50,2	0	32,2	39,5	5	0,5	0	**265,7**
2006-2007	11,7	7,6	8,2	58,5	12,9	61,7	43,5	83,1	3,3	0	0	1,3	**291,8**
2007-2008	13,7	62,5	66,2	0	8	32,9	26,7	7	23,3	5	0,7	0	**246**
2008-2009	18,09	71	83,1	122,3	84,6	34,6	29,9	38	5,5	0	0	6	**493,09**
2009-2010	43	1	14,5	57,2	91,9	38,5	56,8	34,8	7	15,3	0	7,3	**367,3**
2010-2011	4,7	50,7	38,8	17	39,6	27,7	37,7	48,9	34,7	7,9	0	0,6	**308,3**

2011-2012	1,5	52,3	88,3	38	30,5	32,7	19,3	37,4	4,5	0	4,3	7,1	**315,9**
2012-2013	20,3	63,1	178,5	17,3	127,5	29,5	37,3	87,7	46	0	0	3,1	**615,3**
2013-2014	32,8	0	75	126,6	82,3	29,3	49,9	6,5	20,5	15	0	0	**437,9**
2014-2015	27	10,2	67,6	117,8	123,5	45,4	14,3	5,4	10,8	0	0	2,5	**424,5**
2015-2016	3,5	34,8	16,8	0	24,4	54,2	34,1	22,3	27,6	1	0	0	**218,7**
Average	**14,23**	**34,06**	**55,44**	**41,89**	**51,35**	**46,17**	**38,16**	**26,28**	**20,21**	**3,70**	**0,51**	**3,81**	**335,97**

(Source: ANRH Algiers, Series 1985-2016)

III. 3. 2. Homogeneity of the Rainfall Series:

Before beginning any analysis of hydrological data, it is crucial to ensure data consistency, as interruptions in the rainfall recordings at the station can complicate their use. Therefore, it is essential to verify the consistency of the data series.

To verify the homogeneity of the rainfall series, the Wilcoxon Test is utilized. The process for conducting this verification is as follows:

Divide the complete series into two sub-series, X and Y, where N1 and N2 represent the sizes of these sub-series, typically with N1 being larger than N2.

Next, we make the sub-series X union Y by ranking the original rainfall data in descending order. Now each value in the ranked series is then assigned a rank and we precise to which sub series it belongs to.

According to Wilcoxon, the series is considered homogeneous with a 95% probability if the following relationship is met:

$$\mathbf{W_{min} < W_x < W_{max}}$$

Where:

W_x: Sum of ranks of the sub-series X.

$$W_{min} = \left(\frac{(N_1 + N_2 + 1) \times N_1}{2} - 1.96 \times \left(\frac{N_1 \times N_2 \times (N_1 + N_2 + 1)}{12}\right)^{0.5}\right) \quad \text{II.2}$$

$$W_{max} = (N1 + N2 + +1) \times N1 - W_{min} \quad \text{II.3}$$

The results of the Wilcoxon test are detailed as follows:

Table II.8: Homogeneity Test of the Rainfall Series

Original Series	Series X (mm)	Series Y (mm)	Ordered X U Y	Series of origin	Rank
335,4	335,4	365,7	181	X	1
379,8	379,8	380,5	208.6	X	2
181	181	328,2	215.1	X	3
215,1	215,1	265,7	218.7	Y	4
317,4	317,4	291,8	246	Y	5
365,9	365,9	246	258.6	X	6
312,92	312,92	493,09	264.7	X	7
310,5	310,5	367,3	265.7	Y	8
264,7	264,7	308,3	272	X	9
258,6	258,6	315,9	291.8	Y	10
313,8	313,8	587,4	301.7	X	11
272	272	437,9	308,3	Y	12
301,7	301,7	424,5	310.5	X	13
326	326	218,7	312.92	X	14
208,6	208,6		313.8	X	15
545,3	545,3		315.9	Y	16
330,1	330,1		317.4	X	17
365,7			326	X	18
380,5			328.2	Y	19
328,2			330.1	X	20
265,7			335.4	X	21
291,8			365.7	Y	22
246			365.9	X	23
493,09			367.3	Y	24
367,3			379.8	X	25
308,3			380.5	Y	26
315,9			424.5	Y	27
615.3			437.9	Y	28
437,9			493.09	Y	29
424,5			545.3	Y	30
218,7			615.3	X	31

According to the table:

- $N_2 = 14$
- $N_1 = 17$
- $W_x = 236$
- $W_{min} = 222.62$
- $W_{max} = 321.38$

Therefore: $222.62 < W_x < 321.38$

Wilcoxon's condition is satisfied, confirming the homogeneity of the annual average precipitation series from the Maghnia Station.

III. 3. 3. Adjustment of the annual rainfall series:

Th fitting law for annual rainfall that we are going t use is as:

- Gaussian or normal distribution.

This probability law depends on one parameter: the mean (μ)

We performed the calculations using the HYFRAN software.

III. 3. 3. 1. Adjustment using Gauss's law:

The calculation process includes several steps:

1. Sample values are sorted in ascending order.
2. Each sorted value is assigned a rank number.
3. The experimental frequency is calculated using methods such as the Hazen formula or the Cunnane formula.

The Gaussian reduced variable is determined by:

$$U = \frac{x - \overline{x}}{\delta} \qquad \text{II.4}$$

Calculation of Empirical Characteristics of the Distribution ($\overline{x}$, C_v, C_s):

The coefficient of variation is determined by:

$$C_v = \frac{\delta}{\overline{\overline{x}}} \qquad \text{II.5}$$

The equation of the Henry line on Gaussian probability paper:

$$XP\% = +\delta \times UP\% \qquad \text{II.6}$$

Where:

- $XP\%$: Precipitation at probability $P\%$
- $UP\%$: Reduced Gaussian variable.
- $\overline{x}$: Arithmetic mean.
- δ: Standard deviation.

The results obtained are represented in the table and figure bellow:

Table II.9: Adjustment to Gauss's law

Gauss's law				
T	**Q**	**XT**	**Standard Deviation**	**Confidence Interval (95%)**
100.0	0.9900	555	33.5	489-620
50.0	0.9800	529	30.6	469-589
20.0	0.9500	489	26.6	437-542
10.0	0.9000	455	23.4	409-501
5.0	0.8000	413	20.1	373-452
3.0	0.6667	373	18.0	338-409
2.0	0.5000	332	17.2	299-366
1.25	0.2000	282	18.4	246-318

With:

- Q: non-exceedance probability.
- T: Time period.
- XT: Theorical precipitation.

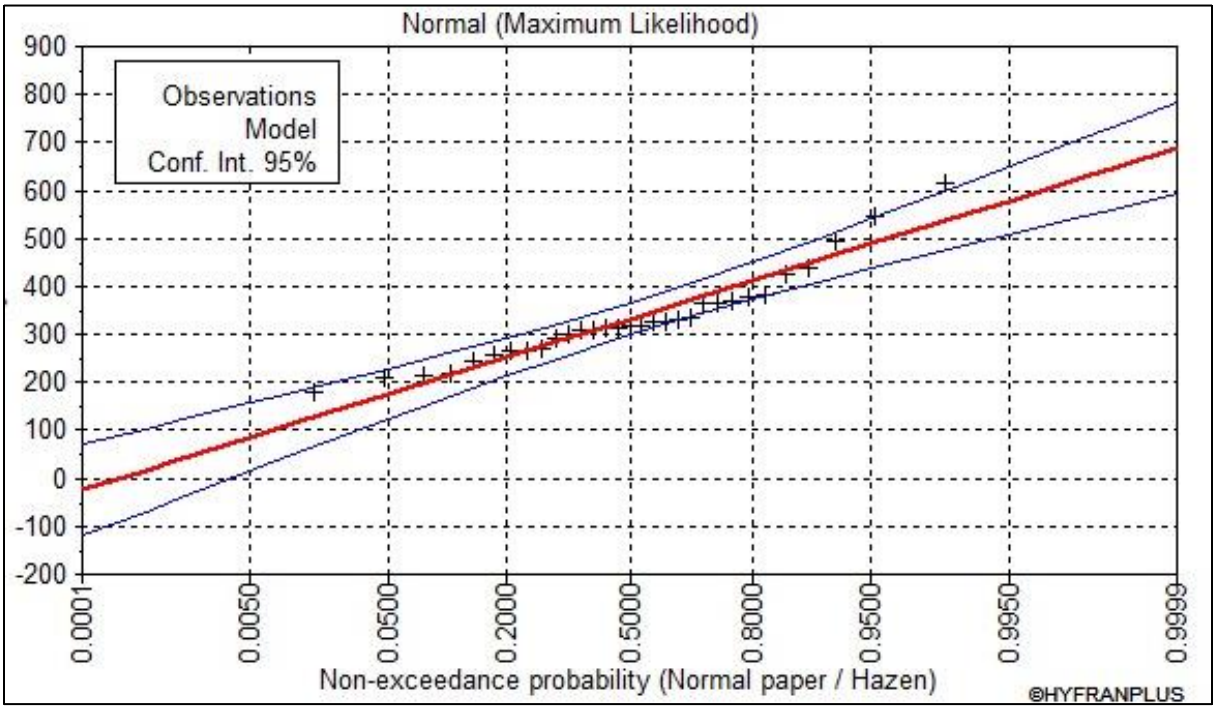

Figure III.1: Adjustment of annual rainfall to Gauss's law

Validity test for gauss's law (Chi squared test):

When selecting a law to fit the statistical distribution of the sample, that law approximately represents the studied sample. The error incurred by adopting a specific law is a goodness-of-fit error. Therefore, it is crucial to compare the goodness of fit of different laws to choose the best fit. One of the most commonly used tests is the chi-square ($\chi2$) test.

Let's consider a sample of N values, sorted in ascending or descending order, that we want to study, and for which a distribution law F(X) has been determined. We divide this sample into a certain number of classes K, with each class containing Ni experimental values. The number Vi represents the theoretical number of values in a sample of N values assigned to class i by the distribution law, and is given by the following equation:

$$Vi = N\int_{x+1}^{x} F(x)\ dx = N[F(x) - F(x_{i+1})] \qquad \text{II.7}$$

The probability density function F(x) corresponds to the theoretical distribution.

Pearson defined the random variable, whose distribution was studied, with the following expression.

$$X^2 = \frac{(ni - vi)^2}{ni} \qquad \text{II.8}$$

We calculate χ^2, and then calculate the degrees of freedom:

$$\gamma = k\text{-}1\text{-}m \qquad \text{II.9}$$

We determine the theoretical χ^2 from Pearson's table.

With:

- m: Number of parameters of the distribution law on which the distribution depends (m=2).

The distribution is adequate for a significance level $\alpha = 0.05$ if and only if:

χ^2 calculated < χ^2 theoretical.

For the calculations, we used the HYFRAN software:

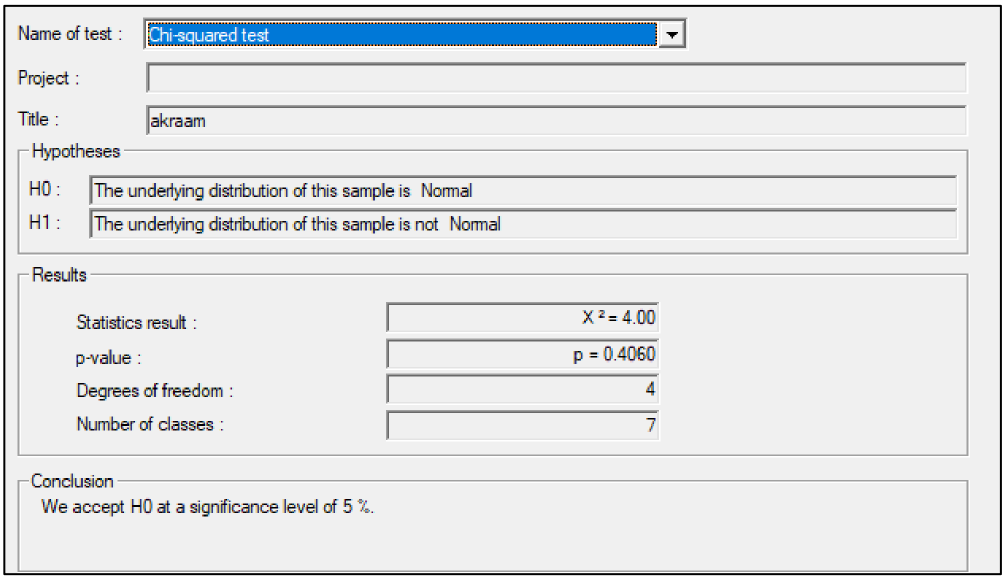

Figure III.2: Chi-squared test obtained using the HYFRAN software.

According to the HYFRAN Software:

- Significance level = 5%.
- Degree of freedom = 4.

Table II.10. Pearson's Chi squared Table

A\Ÿ	0,9	0,5	0,3	0,2	0,1	0,05	0,02	0,01	0,001
1	0,016	0,455	1,074	1,642	2,705	3,841	5,412	6,635	10,827
7	0,211	1,386	2,408	3,219	4,605	5,991	7,824	9,210	13,815
3	0,584	2,366	3,665	4,642	6,251	7,815	9,837	11,345	16,266
4	1,064	3,357	4,878	5,989	7,779	9,488	11,668	13,277	18,467
5	1,610	4,351	6,064	7,289	9,236	11,070	13,388	15,086	20,515
6	2,204	5,348	7,231	8,558	10,645	12,592	15,033	16,812	22,457
7	2,833	6,346	8,383	9,83	12,017	14,067	16,622	18,475	24,322
8	3,490	7,344	9,524	11,030	13,362	15,507	18,168	20,090	26,125
9	4,168	8,343	10,656	12,242	14,684	16,919	19,679	21,666	27,877

With:

- **Ÿ:** significance level.
- **A:** Degree of freedom.

According to the HYFRAN software, the following results were obtained:

Calculated chi-square (X^2) = 4.00

Referring to Pearson's chi-square table, we have:

Theoretical chi-square (X^2) = 9.488

In which:

Calculated chi-square (X^2) = 4.00 < Theoretical chi-square (X^2) = 9.488.

Therefore, the Gauss's Law Adjustment is considered acceptable.

III. 3. 4. Determination the Calculation Year:

Since the normal distribution is deemed the most suitable for fitting the rainfall distribution, it is selected to estimate the representative average annual rainfall for the region at an 80% frequency.

Table II.11 results of the adjustment

T	q	Xt	Confidence Interval
5.0	0.8000	413	373-452
2.0	0.5000	332	299-366

- $P_{theo\ (80\%)}$ = 413mm
- $P_{theo\ (50\%)}$ = 332mm

The formula for the average annual rainfall for the region at an 80% frequency is:

$$P_{80\%} = P_{avg} \times \frac{P_{theo\,(80\%)}}{P_{theo\,(50\%)}} \qquad \text{II.10}$$

Table II.12 Calculation of Monthly Rainfalls for (frequency = 80%)

Month	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Pavg (mm)	14,23	34,06	55,44	41,89	51,35	46,17	38,16	26,28	20,21	3,70	0,51	3,81
P80% (mm)	17,70	42,37	68,96	52,11	63,87	57,43	47,47	32,69	25,14	4,60	0,63	4,74

IV. Conclusion:

In conclusion, the field study indicates that the soil has a silty clay texture, similar reserves of total and active $CaCO_3$ minerals depending on the horizons. The absorbent complex is primarily composed of Ca^{++}.

The soil solution has a medium pH and low electrical conductivity. These characteristics may have implications for soil use in agriculture or land management, particularly regarding fertility management and erosion prevention.

According to the analysis of water resources, the waters from the Zouia Dam, which supply our area, have a SAR of 2.17 meq/l and EC = 1.34 mmhos/cm, therefore they are classified as C3-S1 analysis of water resources, with low alkalinity and some risk of salinity.

After reviewing the adjustments, it is evident that the normal distribution accurately fits the series of annual rainfall data from the Maghnia station.

Chapter III:

Crop Water Needs

I. Introduction:

The purpose of this chapter is to quantify the water needs of crops based on the previously defined calculations to compensate for the water deficit in the active soil layer.

The water provided to plants is released through leaf transpiration, while the remainder evaporates from the soil. The combination of these two processes is known as evapotranspiration, which we use to determine the water requirements of the crops.

II. Water Requirements of the Area:

Crop water requirements can be defined as the amount of water needed to maintain optimal soil moisture levels to ensure maximum plant yield. Assessing the water needs of the area involves determining the specific requirements of each crop listed in the agronomic calendar.

II. 1. Calculation of water needs:

Water requirements are defined as the additional amount of water needed through irrigation to supplement the contribution from precipitation. Before assessing the specific water needs of crops, it is essential to consider various plant-related parameters, as well as the climatic and soil data of the area in question.

$$\mathbf{B_i = ETM_i - (Peff + RFU_{i-1})} \qquad \text{III.1}$$

With:

- $\mathbf{B_i}$**:** irrigation needs.
- $\mathbf{ETM_i}$: is the value of maximum evapotranspiration in mm, it is equal to:

$$\mathbf{ETM = ET0 * Kc} \qquad \text{III.2}$$

- **Kc**: The crop coefficient of the considered crop.
- **Peff:** Effective rainfall.
- $\mathbf{RFU_{i-1}}$: readily available water.

II. 2. Calculation of Potential reference Evapotranspiration (ET_0):

Reference potential evapotranspiration (ETo) is a theoretical measure of the evaporation and transpiration from an ideal vegetated surface under standardized atmospheric conditions. It serves as the basis for estimating the water needs of actual crops in a given region.

There are several methods for calculating reference evapotranspiration, which can be divided into two categories:

II. 2. 1. Direct Methods:

- **Lysimetric Tank Evapotranspiration:** This method uses a lysimeter, a container with soil and plants, to measure water loss through evapotranspiration by monitoring the difference between water input and drainage.

- **Evaporation Pan:** This method uses a pan filled with water to measure the rate of evaporation. The data is then used to estimate the evapotranspiration of nearby crops by applying a coefficient.

II. 2. 2. Indirect Methods:

These methods calculate ET0 using formulas based on climatic parameters. The main calculation formulas include:

Prinstley-Taylor, Makkink, Turc, Hargreaves, Blaney-Criddle, Thornthwaite, Penman, and modified Penman-Monteith.

In our context, we're employing the Modified Penman-Monteith formula.

II. 2. 2. 1. Modified Penman-Monteith Formula:

In 1948, Penman and Monteith collaborated to develop an energy balance using a mass transfer method. Using climatological data such as sunshine, temperature,humidity, and wind speed, they devised an equation to calculate the evapotranspiration of a free water surface. Since then, the modified Penman-Monteith formula has become the predominant approach for estimating evapotranspiration and is strongly recommended by the FAO.The formula is detailed as follows:

$$ET_0 = \frac{0.408 \times \Delta \times (R_n - G) + \gamma \times \frac{900}{T + 273} \times U_2 \times (e_\delta - e_\alpha)}{\Delta + \gamma \times (1 + 0.34 \times U_2)} \qquad \text{III.3}$$

Where:

- ET0 : Reference evapotranspiration (mm/day).
- Rn: Net radiation at the crop surface (MJ/m²/day).
- G: Soil heat flux density (MJ/m²/day).
- T: Mean daily air temperature at 2 meters height (°C).
- U2: Wind speed at 2 meters height (m/s).
- e_s : Saturation vapor pressure (kPa).
- e_a : Actual vapor pressure (kPa).
- Δ: Slope of the saturation vapor pressure curve (kPa/°C).
- γ: Psychrometric constant (kPa/°C).

We utilized the CROPWAT software (FAO, 2008) to compute reference evapotranspiration employing the Penman-Monteith approach. Monthly input data included:

- **Temperature:** Minimum and maximum temperatures per month.
- **Air humidity:** Relative air humidity represented as a percentage (%).
- **Daily sunshine duration:** Hours of sunlight per day.
- **Wind speed:** Wind speed measured in meters per second (m/s).

The resulting reference evapotranspiration data (ET0), obtained from the CROPWAT software, are presented in the table provided below:

Table III.1: Calculated Reference Evapotranspiration (ET0)

Country: Algeria | Station: Maghnia
Altitude: 426 m. | Latitude: 34.82 °N | Longitude: 1.78 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	m/s	hours	MJ/m²/day	mm/month
January	9.7	12.7	78	2.3	6.5	10.6	43.22
February	8.8	14.3	78	2.6	7.1	13.5	51.14
March	12.9	14.7	75	2.6	7.8	17.3	79.23
April	14.7	18.1	73	2.7	8.9	21.4	104.97
May	17.6	21.2	67	2.7	8.8	22.7	135.38
June	20.4	25.3	63	2.6	10.7	25.9	162.75
July	24.8	28.4	59	2.7	10.8	25.7	190.91
August	26.7	29.3	62	2.7	10.3	23.8	185.34
September	22.7	24.9	70	2.5	8.9	19.5	128.65
October	19.3	21.9	73	2.5	7.6	14.8	94.23
November	13.1	17.8	75	2.2	6.6	11.2	57.80
December	10.4	14.5	77	2.5	5.9	9.4	45.05
Average	**16.8**	**20.3**	**71**	**2.6**	**8.3**	**18.0**	**1278.68**

III. Calculation of Effective Rainfall (P_{eff}):

The efficiency of rainfall can be defined as the proportion of rainfall that is truly beneficial for meeting the needs of crops, once losses due to surface runoff, deep percolation, and other similar factors are taken into account. There are several methods for calculating this rainfall efficiency, but in this context, we favor the detailed percentage method, which is described as follows:

$$\text{Effective rainfall} = A \times \text{Total rainfall} \qquad \text{III.4}$$

Where: "A" is represented by a coefficient estimated at 0.8.

IV. Soil water reserve calculation:

The amount of water present in the soil layer accessed by plant roots, ranging from the drainage point to the wilting point, constitutes the soil water content. However, as soil moisture nears the wilting point, plants find it increasingly difficult to absorb water. The readily available water (RAW) can be determined using the following formula:

$$RFU = (HCC - HPF) \times Da \times Z \times Y \qquad \text{III.5}$$

In our case, the soil water reserve of the previous month (month i-1) can be calculated as follows, using the following parameters:

- HCC: Field capacity moisture (Hcc) (27%).
- HPF: Wilting point moisture (HPF) (13%).

- Z: Root depth (mm).
- Y: Degree of drying,
  - Y = 2/3 for general crops.
  - Y = 1/3 for sensitive crops (Watermelon).
  - Y = 1/2 for cereal crops.
- Da: Soil bulk density (1,3).

The soil water reserve of the previous month (month i-1) is given by the following formula:

$$RFU_{i-1} = k \times RU \qquad \text{III.6}$$

Where:

k: is a coefficient = 1, or 1/2, 1/3, or 0 depending on the water reserve.

V. Crop Choice:

The selection of crops should consider the region's agro-climatic characteristics and the demands of the local or regional market to ensure the economic viability of the agricultural enterprise. The crop selection must balance the following criteria:

- The climatic conditions of the studied region;
- The quality and availability of irrigation water;
- The soil's suitability for cultivation based on pedological studies;
- The availability of production resources;
- The commercial demand reflecting the farmers' profiles.

For our area, the crop selection is outlined in the following table:

Table III.2: Land Occupation Based on Crops.

The Crops	Occupied Surface (%)	Occupied Surface (ha)
Arboriculture: Olive trees Peaches Prunes	24.73	42.05
Cereals: Wheat Barley	51.14	86.95
vegetables: Potatoes Carrots Peas Pepper	24.61	41.85
Total	100	170

Note: This Perimeter is 200ha, but due to constructions and the presence of the river and the wild vegetation, the irrigated area is 170 ha.

VI. The vegetative cycle:

The vegetative cycle of the proposed crops is detailed in Table III.3.

Table III.3: Vegetative Cycle of Proposed Crops.

Crop Coefficient (Kc)												
Month	J	F	M	A	M	J	Jl	A	S	O	N	D
wheat	→	→	→	→	→	→					←	←
Barley	→	→	→	→	→	→					←	←
Olive trees	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
Peaches	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
Prunes	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
Potatoes								↔	↔	↔	↔	↔
Carrots									↔	↔	↔	↔
Peas	→	→	→	→								←
Pepper				↔	↔	↔	↔					

VI. Estimation of Crop Water Requirements:

VI. 1. Irrigation:

Calculation of irrigation water requirements for crops:

$$B_i = ETM - \left(P_{eff} + RFU_{i-1}\right) \quad \text{III.1a}$$

With:

- B_i: Irrigation water needs (mm).
- ETM: Evapotranspiration (mm/month).
- P_{eff}: Effective rainfall.
- RFU: This is the readily available water for crops. In this approach, it represents the soil moisture from the previous month accessible to crops.

VI. 1. 1. Estimation of Water Requirements for Cereals:

Table III.4: Calculation of Water Requirements for Wheat.

Cereal									
Month	P 80%	peff (mm)	ET0 (mm/month)	Kc	ETM (mm/month)	Z(m)	RFU (mm)	RFU$_{real}$ (mm)	B$_i$ (mm)
Sept	17,70	14,20	128,65		0		0	0	0
Oct	42,37	33,90	94,23		0		0	0	0
Nov	68,96	55,20	57,8	0,2	11,56	0,3	27,3	27,3	0
Dec	52,11	41,70	45,05	0,4	18,02	0,5	45,5	22,75	0
Jan	63,87	51,10	43,22	0,4	17,29	0,5	45,5	22,75	0
Feb	57,43	45,90	51,14	0,6	30,68	0,6	54,6	0	0
Mars	47,47	38,00	79,23	0,8	63,38	0,6	54,6	0	41,31
April	32,69	26,20	104,97	1,15	120,72	0,6	54,6	0	104,39
May	25,14	20,10	135,38	1,15	155,69	0,6	54,6	0	142,14
Jun	4,60	3,68	162,75	0,4	65,1	0,6	54,6	0	59,38
Jul	0,63	0,5	190,91		0		0	0	0
Aug	4,74	3,79	185,34		0		0	0	0

Table III.5: Calculation of Water Requirements for Barley.

Barley									
Month	P 80%	peff (mm)	ET0 (mm/month)	Kc	ETM (mm/month)	Z(m)	RFU (mm)	RFU$_{real}$ (mm)	B$_i$ (mm)
Sept	19.16	14,20	128,6		0		0	0	0
Oct	22.39	33,90	94,23		0		0	0	0
Nov	63.03	55,20	57,8	0,2	11,56	0,3	27,3	27,3	0
Dec	33.38	41,70	45,05	0,4	18,02	0,5	45,5	22,75	0
Jan	28.61	51,10	43,22	0,4	17,29	0,5	45,5	22,75	0
Feb	18.16	45,90	51,14	0,6	30,68	0,6	54,6	0	0
Mars	9.95	38,00	79,23	0,8	63,38	0,6	54,6	0	41,31
April	21.77	26,20	104,9	1,15	120,72	0,6	54,6	0	104,39
May	21.98	20,10	135,3	1,15	155,69	0,6	54,6	0	142,14
Jun	1.73	3,68	162,7	0,4	65,1	0,6	54,6	0	59,38
Jul	0.11	0,5	190,9		0		0	0	0
Aug	0.73	3,79	185,3		0		0	0	0

VI. 1. 2. Estimation of Water Requirements for vegetables:

Table III.6: Calculation of Water Requirements for potatoes.

Potatoes									
Month	P 80%	peff (mm)	ET0 (mm/month)	Kc	ETM (mm/month)	Z(m)	RFU (mm)	RFU_{real} (mm)	B_i (mm)
Sept	19.16	14,20	128,6	0,7	90,06	0,4	48,56	0	75,82
Oct	22.39	33,90	94,23	0,9	84,81	0,5	60,7	0	63,13
Nov	63.03	55,20	57,8	0,9	52,02	0,5	60,7	0	16,74
Dec	33.38	41,70	45,05	0,8	36,04	0,5	60,7	0	6,67
Jan	28.61	51,10	43,22		0		0	0	0
Feb	18.16	45,90	51,14		0		0	0	0
Mars	9.95	38,00	79,23		0		0	0	0
April	21.77	26,20	104,9		0		0	0	0
May	21.98	20,10	135,3		0		0	0	0
Jun	1.73	3,68	162,7		0		0	0	0
Jul	0.11	0,5	190,9		0		0	0	0
Aug	0.73	3,79	185,3	0,5	92,67	0,2	24,28	0	85,61

Table III.7: Calculation of Water Requirements for Carrots.

Carrots									
Month	P 80%	peff (mm)	ET0 (mm/month)	Kc	ETM (mm/month)	Z(m)	RFU (mm)	RFU_{real} (mm)	B_i (mm)
Sept	19.16	14,20	128,65	0,42	54,03	0,3	36,42	0	39,79
Oct	22.39	33,90	94,23	0,7	65,96	0,4	48,56	0	44,28
Nov	63.03	55,20	57,8	0,85	49,13	0,5	60,7	0	13,85
Dec	33.38	41,70	45,05	0,7	31,54	0,6	72,84	0	2,17
Janv	28.61	51,10	43,22		0		0	0	0
Feb	18.16	45,90	51,14		0		0	0	0
Mars	9.95	38,00	79,23		0		0	0	0
April	21.77	26,20	104,9		0		0	0	0
May	21.98	20,10	135,3		0		0	0	0
Jan	1.73	3,68	162,7		0		0	0	0
Jul	0.11	0,5	190,9		0		0	0	0
Aug	0.73	3,79	185,3		0		0	0	0

Table III.8: Calculation of Water Requirements for Peas.

Peas									
Month	**P 80%**	**peff (mm)**	**ET0 (mm/month)**	**Kc**	**ETM (mm/month)**	**Z(m)**	**RFU (mm)**	**RFU_{real} (mm)**	**B_i (mm)**
Sept	19.16	14,20	128,65		0		0	0	0
Oct	22.39	33,90	94,23		0		0	0	0
Nov	63.03	55,20	57,8		0		0	0	0
Dec	33.38	41,70	45,05	0,5	22,53	0,4	48,56	24,28	0
Jan	28.61	51,10	43,22	0,8	34,58	0,7	84,98	0	0
Feb	18.16	45,90	51,14	1	51,14	0,7	84,98	0	24,79
Mars	9.95	38,00	79,23	0,95	75,27	0,7	84,98	0	53,2
April	21.77	26,20	104,9	0,5	52,49	0,7	84,98	0	36,16
May	21.98	20,10	135,3		0		0	0	0
Jun	1.73	3,68	162,7		0		0	0	0
Jul	0.11	0,5	190,9		0		0	0	0
Aug	0.73	3,79	185,3		0		0	0	0

Table III.9: Calculation of Water Requirements for Pepper.

Pepper									
Month	**P 80%**	**peff (mm)**	**ET0 (mm/month)**	**Kc**	**ETM (mm/month)**	**Z(m)**	**RFU (mm)**	**RFU_{real} (mm)**	**B_i (mm)**
Sept	19.16	14,20	128,6		0		0	0	0
Oct	22.39	33,90	94,23		0		0	0	0
Nov	63.03	55,20	57,8		0		0	0	0
Dec	33.38	41,70	45,05		0		0	0	0
Janv	28.61	51,10	43,22		0		0	0	0
Feb	18.16	45,90	51,14		0		0	0	0
Mars	9.95	38,00	79,23		0		0	0	0
April	21.77	26,20	104,9	0,7	73,48	0,7	84,98	0	57,15
May	21.98	20,10	135,3	0,9	121,84	1,1	133,53	0	108,2
Jun	1.73	3,68	162,7	0,9	146,48	1,1	133,53	0	140,7
Jul	0.11	0,5	190,9	0,7	133,64	1,1	133,53	0	127,8
Aug	0.73	3,79	185,3		0		0	0	0

VI. 1. 3. Estimation of Water Requirements for Arboriculture:

Table III.10: Calculation of Water Requirements for Olive trees.

Olive trees									
Month	**P 80%**	**peff (mm)**	**ET0 (mm/month)**	**Kc**	**ETM (mm/month)**	**Z(m)**	**RFU (mm)**	**RFU_{real} (mm)**	**B_i (mm)**
Sept	19.16	14,20	128,65	0,9	115,79	1,5	182,09	0	101,55
Oct	22.39	33,90	94,23	0,6	56,54	1,5	182,09	0	34,86
Nov	63.03	55,20	57,8		0		0	0	0
Dec	33.38	41,70	45,05		0		0	0	0
Jan	28.61	51,10	43,22		0		0	0	0
Feb	18.16	45,90	51,14		0		0	0	0
Mars	9.95	38,00	79,23		0		0	0	0
April	21.77	26,20	104,9	0,6	62,98	1,5	182,09	0	46,65
May	21.98	20,10	135,3	0,6	81,23	1,5	182,09	0	67,68
Jun	1.73	3,68	162,7	0,6	97,65	1,5	182,09	0	91,93
Jul	0.11	0,5	190,9	0,8	152,73	1,5	182,09	0	146,9
Aug	0.73	3,79	185,3	0,8	148,27	1,5	182,09	0	141,2

Table III.11: Calculation of Water Requirements for peaches.

Peaches									
Month	**P 80%**	**peff (mm)**	**ET0 (mm/month)**	**Kc**	**ETM (mm/month)**	**Z(m)**	**RFU (mm)**	**RFU_{real} (mm)**	**B_i (mm)**
Sept	19.16	14,20	128,65	0,65	83,62	1,5	182,09	0	69,38
Oct	22.39	33,90	94,23		0		0	0	0
Nov	63.03	55,20	57,8		0		0	0	0
Dec	33.38	41,70	45,05		0		0	0	0
Jan	28.61	51,10	43,22		0		0	0	0
Feb	18.16	45,90	51,14		0		0	0	0
Mars	9.95	38,00	79,23		0		0	0	0
April	21.77	26,20	104,9	0,5	52,49	1,5	182,09	0	36,16
May	21.98	20,10	135,3	0,9	121,84	1,5	182,09	0	108,2
Jun	1.73	3,68	162,7	0,9	146,48	1,5	182,09	0	140,7
Jul	0.11	0,5	190,9	0,65	124,09	1,5	182,09	0	118,3
Aug	0.73	3,79	185,3	0,65	120,47	1,5	182,09	0	113,4

Table III.12: Calculation of Water Requirements for prunes.

Prunes									
Month	P 80%	peff (mm)	ET0 (mm/month)	Kc	ETM (mm/month)	Z(m)	RFU (mm)	RFU_{real} (mm)	B_i (mm)
Sept	19.16	14,20	128,65	0,65	83,62	1,5	182,09	0	69,38
Oct	22.39	33,90	94,23		0		0	0	0
Nov	63.03	55,20	57,8		0		0	0	0
Dec	33.38	41,70	45,05		0		0	0	0
Jan	28.61	51,10	43,22		0		0	0	0
Feb	18.16	45,90	51,14		0		0	0	0
Mars	9.95	38,00	79,23		0		0	0	0
April	21.77	26,20	104,9	0,5	52,49	1,5	182,09	0	36,16
May	21.98	20,10	135,3	0,9	121,84	1,5	182,09	0	108,2
Jun	1.73	3,68	162,7	0,9	146,48	1,5	182,09	0	140,7
Jul	0.11	0,5	190,9	0,65	124,09	1,5	182,09	0	118,3
Aug	0.73	3,79	185,3	0,65	120,47	1,5	182,09	0	113,4

VI. 1. 4. Calculation of the total water needed for irrigation:

Table III.13: Net Requirements Results (mm)

Month	Weat	Barley	Potatoes	Carrots	Peas	Pepper	Olive Trees	Peaches	Prunes	Total (Per month)
Sept	0	0	75,82	39,79	0	0	101,55	69,38	69,38	**355,92**
Oct	0	0	63,13	44,28	0	0	34,86	0	0	**142,27**
Nov	0	0	16,74	13,85	0	0	0	0	0	**30,59**
Dec	0	0	6,67	2,17	0	0	0	0	0	**8,84**
Jan	0	0	0	0	0	0	0	0	0	**0**
Feb	0	0	0	0	24,79	0	0	0	0	**24,79**
Mars	41,31	41,31	0	0	53,2	0	0	0	0	**135,8**
April	104,39	104,39	0	0	36,16	57,15	46,65	36,16	36,16	**421,0**
May	142,14	142,14	0	0	0	108,29	67,68	108,29	108,29	**676,8**
Jan	59,38	59,38	0	0	0	140,76	91,93	140,76	140,76	**632,9**
Jul	0	0	0	0	0	127,86	146,95	118,32	118,32	**511,4**
Aug	0	0	85,61	0	0	0	141,21	113,41	113,41	**453,6**
Total (Per crop)	**347.22**	**347.22**	**247.97**	**100.09**	**114.15**	**434.06**	**630.83**	**586.32**	**586.32**	**3394.18**

VI. 2. Leaching:

Leaching is an agricultural technique involving the application of additional water to crops, exceeding their basic water needs. This method aims to move dissolved salts deeper into the soil, away from the plant root zone.

Leaching is essential for maintaining soil salinity at an optimal level. However, it is important to note that leaching often needs to be complemented by a drainage system, especially when a groundwater table is present, to ensure its effectiveness.

In irrigated crops, leaching aims to remove salts accumulated in the soil's root zone. These salts can either be naturally present or introduced through irrigation water. The leaching process requires:

- Adequate internal drainage conditions to ensure the removal of excess salts from the root zone or, at the very least, to keep them at a depth where they do not affect the crop.
- Knowledge of the additional amount of water needed to reduce salinity to an acceptable level.

VI. 2. 1. Calculation of Maintenance Leaching:

In this approach, the leaching dose is applied in fractions simultaneously with irrigation doses. This prevents the accumulation of salts in the soil, eliminating them gradually. The existing irrigation system is utilized to apply the leaching doses along with the irrigation doses. In 1972, M. Rhodes introduced a formula for a more rational evaluation of the maintenance leaching fraction.

$$LR = \frac{C_{eiw}}{5C_{ees} - C_{eiw}} \qquad \text{III.7}$$

With:

- **LR:** the minimal needs of leaching necessary to reduce salinity with ordinary techniques.
  surface irrigation, assuming the LR leaching fraction is fully effective and slowly percolates through the ground.
- **CEiw:** electrical conductivity of irrigation water.
- **CEes:** salinity of the saturated paste (the maximum salinity allowed for a drop in yield equal to 10%, we do maintenance leaching to keep the salinity from going above these levels).

Application:

$$LR = \frac{1.34}{5 \times 2.51 - 1.34} = 12\%\, ETM$$

In practice, the heterogeneity of the soil causes water to infiltrate rapidly in certain areas through preferential pathways, such as soil-root boundaries and cracks, without performing a leaching action. Therefore, we need to consider a leaching efficiency (Le), which depends on the soil's texture and structure.

$$LR_{eff} = \frac{LR}{Le} = new\ leachig\ requirement \quad \text{III.8}$$

The leaching efficiency:

- Le = 30% for cracked soils.
- Le = 50% / 60% for medium-textured soils.
- Le = 90% / 100% for sandy soils.

$$LR_{eff} = \frac{12}{0.6} = 20\%$$

The volume of leaching water (leaching dose) is given by the following formula:

$$DW = \frac{LR_{eff}}{1 - LR_{eff}} \times ETM = 0.25 \times ETM \quad \text{III.9}$$

The total volume of water needed to ensure proper irrigation and leaching is:

$$V_T = \frac{ETM}{1 - LR_{eff}} = 1.25 \times ETM \quad \text{III.10}$$

The calculated results of the leaching volume for each crop are summarized in the following table:

Table III.14: Leaching dose (Dw) for each crop (mm).

Month	Weat	Barley	Potatoes	Carrots	Peas	Pepper	Olive Trees	Peaches	Prunes	**Total (per month)**
Sept	0	0	18,96	9,95	0	0	25,39	17,35	17,35	**88,98**
Oct	0	0	15,78	11,07	0	0	8,72	0	0	**35,57**
Nov	0	0	4,19	3,46	0	0	0	0	0	**7,65**
Dec	0	0	1,67	0,54	0	0	0	0	0	**2,21**
Janv	0	0	0	0	0	0	0	0	0	**0**
Feb	0	0	0	0	6,20	0	0	0	0	**6,20**
Mars	10,33	10,33	0	0	13,30	0	0	0	0	**33,96**
April	26,10	26,10	0	0	9,04	14,29	11,66	9,04	9,04	**105,27**
May	35,54	35,54	0	0	0	27,07	16,92	27,07	27,07	**169,21**
Jan	14,85	14,85	0	0	0	35,19	22,98	35,19	35,19	**158,24**
Jul	0	0	0	0	0	31,97	36,74	29,58	29,58	**127,86**
Aug	0	0	21,40	0	0	0	35,30	28,35	28,35	**113,41**
Total (per crop)	86.81	86.81	61.99	25.02	28.54	108.52	157.71	146.58	146.58	**848..5**

VI. 3. Estimation of the total water requirement volume:

We calculate the entire requirements of water for our field to figure out whether our resources are sufficient in supplying us with the required water.

$1m^3/ha = 10$ mm,

$$\text{Total needs} = (\text{Bbrute} + \text{Dw}) \times S \qquad \text{III.11}$$

Table III.15: Total water requirement

	Weat	Barley	Potatoes	Carrots	Peas	Pepper	Olive Trees	Peaches	Prunes	**Total**
S (ha)	46,9	40	17,85	8	6	10	18,05	14	10	**170**
Bnet (m3/ha)	3472.2	3472.2	2479.7	1000.9	1141.5	4340.6	6308.3	5863.2	5863.2	**33941.8**
Bbrute (m3/ha)	4629.6	4629.6	3306.3	1334.5	1522	5787.5	8411.1	7817.6	7817.6	**45260**
leaching dose (m3/ha)	868.1	868.1	619.9	250.2	285.4	1085.2	1577.1	1465.8	1465.8	**8485.5**
Total needs (m3)	257840	219906	70083	12678	10844	68726	180286	129968	92834	**1043165**

From what we calculated the total water required for irrigation and leaching is 1.04 hm^3, this volume can be drawn from the Zouia dam, as the regulated volume is 2.3 hm^3.

VII. Conclusion:

In this chapter, we outlined the water supply requirements for our agricultural area, carefully selecting crops based on soil properties and local climatic conditions.

Once the crop selection was determined, we used the Penman method to estimate the water needs of each crop. This method enabled us to quantify the amount of water evaporated from the soil and transpired by the plants, considering various climatic parameters.

We then calculated the volumes of water required for irrigation during the growing period, adding a calculated percentage for leaching needs. Our goal was to ensure a sufficient and consistent water supply to promote optimal plant development and maintain proper soil salinity balance.

These water needs estimates and irrigation volumes, along with the leaching requirement (LR), are crucial for our water management. They allow us to proactively plan our water resources, accurately determine the amount of water needed, and ensure that our crops receive the necessary water for optimal growth, in our case the dam water is sufficient for our project's needs.

Chapter IV:

Drainage and Agricultural Sanitation

I. Introduction:

Sanitation refers to the collective actions aimed at eliminating surface water and harmful waters within rural areas at the watershed level. While Drainage, while similar in nature, operates on a smaller scale, focusing on individual plots of land or farming properties.

According to Willem Vlotamn, Gravity serves as the primary force behind drainage. When a material is sufficiently moist, the forces of capillarity are weaker than those of gravity, allowing water to flow downward, provided there are no obstacles.

II. The aim of drainage:

The primary aim of draining an agricultural area is to remove excess water and salts from the soil through an artificial drainage system. The following cases can be distinguished:

- **Temporary Flood Prevention:**

  These floods are caused by heavy rainfall, they occur due to low soil permeability or surface runoff toward a depression in the terrain. These floods are irregular and typically occur during the winter season.

  In Algeria, such conditions are generally found in the northern region.

- **Drying:**

  Reclaiming uncultivated lands that are permanently or frequently submerged. The aim of drainage is to lower the water table to a level suitable for cultivation.

- **Salinity Prevention or Soil Desalination:**

  In irrigated perimeters in arid and semi-arid regions, soil salinity is a major issue, the drainage network in this case is designed to remove leaching water containing accumulated salts in the soil.

III. The objectives and Advantages of drainage:

- Lower the water table to a level suitable for crops.
- Remove excess water from agricultural lands located in flat areas.
- Address insufficient natural drainage due to very low slopes or low permeability.
- Eliminate leaching water containing salts that have accumulated in the soil.
- Prevent plant asphyxiation by avoiding root submersion in water.
- Restore the soil to its original state (removing secondary salinization).

IV. Benefits of drainage :

Water is essential for crop development, but an excess in the soil can negatively affect both crops and the soil's physico-chemical properties.

- **Helps with poor soil aeration:**

In waterlogged soils, root respiration is hindered because excessive water blocks air circulation in the pores, leading to plant asphyxiation. Additionally, microbial and chemical processes in the soil slow down or stop entirely.

Plant responses to anaerobic conditions vary depending on the species, variety, and developmental stage. Some plants may adapt by developing shorter, thicker, less hairy roots, leading to superficial rooting in many crops. Some plants, like maize, barley, and beans, may develop air pockets in their root tissues. The most aquatic plant is rice. Sensitive plants display symptoms similar to nitrogen deficiency, such as yellowing leaves, elongated stems and leaves, and browning roots.

Drainage helps improve soil conditions by removing excess water, thereby reactivating the chemical and physiological processes. For example, water excess during the tillering (tallage) of cereals reduces the development of main and coronal roots and decreases the number of spikes, the presence of a drainage system can help with issue.

The resistance of a crop to flooding is a key factor in designing a drainage system; more resistant crops require less intensive drainage.

- **Warming of the soil:**

The water in the soil has a high thermal capacity (higher specific heat), which inhibits soil warming and keeps the soil cool, especially in spring. This can delay plant growth and result in lower yields.

If spring begins with dry conditions, delayed growth can leave the plant weak and unable to access water from deeper soil layers.

Implementing a drainage system would remove this water from the soil, which in turn limits the cooling of the soil in colder seasons.

- **Avoiding disruptions of agricultural practices resulting from excess water:**

Soil preparation for planting cannot occur when the soil is too wet:

- The energy required to operate a tractor is significantly higher, with fuel consumption increasing by 25-30% compared to working in normally moist soil.
- Plowing in wet conditions causes significant soil compaction, reducing its physical fertility.
- Lower permeability creates a mechanical barrier to root penetration.
- Prolonged wetness prevents the efficient use of machinery.

The depth at which the water table can rise without hindering the passage of machinery varies depending on soil type and machine weight (typically 40-80 cm below the soil surface), a drainage system would keep the water tables below these levels.

V. Drainage Techniques:

Drainage techniques facilitate the removal of a specific volume of water from a defined soil area over a given period.

V. 1. Open air ditch drainage:

Open ditch drainage involves digging trenches at regular intervals, which can reach depths of 3 meters or more and widths between 0.3 and 0.5 meters. This technique is used to remove surface water that has not been able to infiltrate the soil.

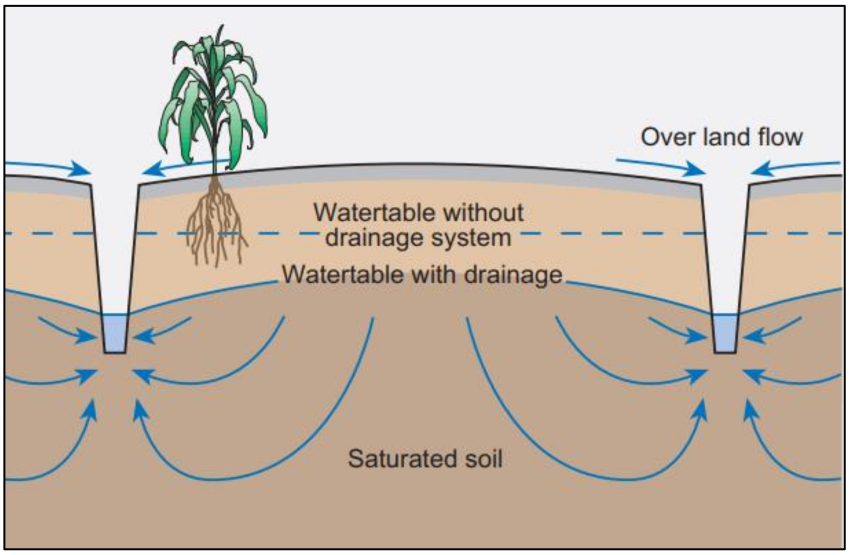

Figure IV.1: Illustration of an open-air ditch drain.

Role of Open Ditch Drainage:

- **I**ntercept Surface Runoff: Captures and removes excess surface water.
- Create Hydraulic Gradient: Establishes a gradient that facilitates underground flow from the soil to the ditch.

Advantages:

- Simple to Implement: The technique is straightforward and easy to set up.
- High Capacity: The dimensions of the ditches allow for the maximum flow rate to be managed.
- Easy Maintenance: Routine upkeep is relatively simple.

Disadvantages:

- Loss of Cultivated Land: Reduces the area available for farming.
- Accessibility Issues: Can be challenging to access for maintenance and operation.
- High Maintenance Costs: Ongoing maintenance can be expensive.

– Risk of Waterborne Diseases: Potential to create conditions that promote the spread of waterborne diseases.

V. 2. Subsurface pipe drainage:

Subsurface drainage involves managing groundwater levels by installing a network of perforated pipes below the soil surface. This technique controls the free surface level of the groundwater table, ensuring effective moisture management for agricultural lands.

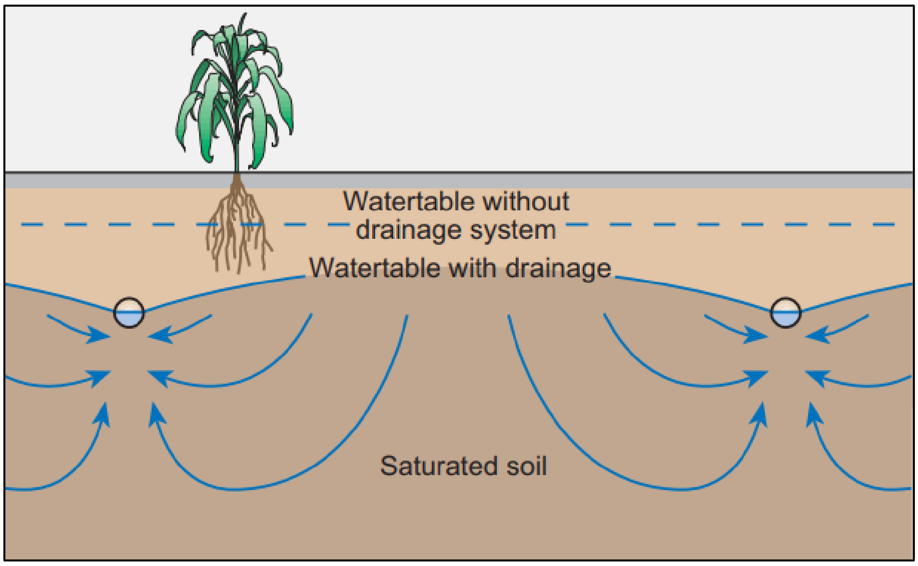

Figure IV.2: Illustration of a subsurface pipe drain.

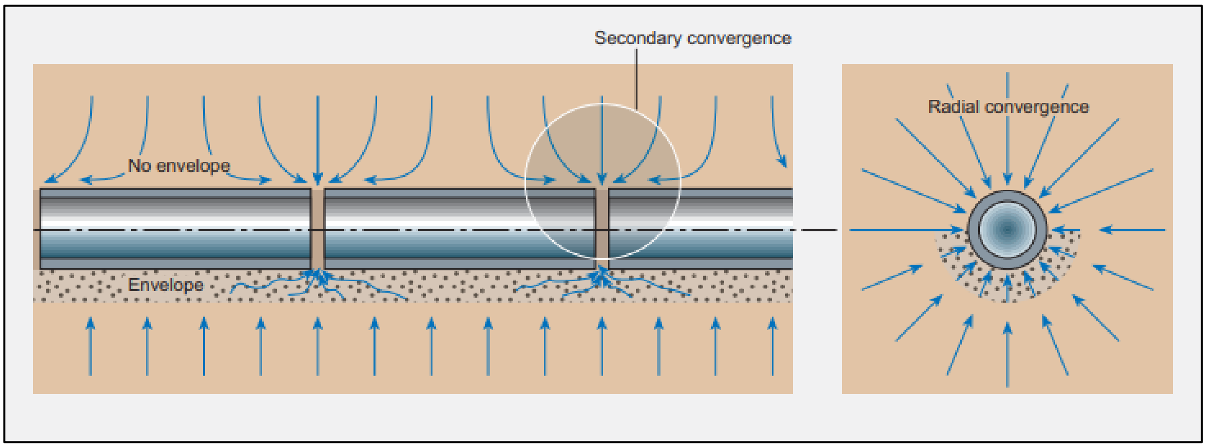

Figure IV.3: Illustration showing the function of a perforated drainpipe.

Installation:

A network of perforated pipes, typically 4 to 16 cm in diameter, is laid beneath the soil. These pipes are connected to a network of collectors that channel the water to a discharge point (emissary).

Types of pipes for subsurface drainage:

- Perforated plastic (PVC or HDPE).
- Concrete.

Plastic drain pipes (either PVC or HDPE) are currently the most common and the easiest and most secure types of pipes for machine installation. The plastic material is inert and is not affected by soil chemicals. The production of plastic pipes is a specialized process requiring high-cost equipment.

Concrete pipes can be used if plastic pipes are unavailable or if only small quantities of pipes are required. They can be made relatively simply, onsite. The installation of drains with concrete pipes is more cumbersome and much more susceptible to misalignment than the installation of plastic pipes. Under unstable soil conditions it is almost impossible to properly install concrete pipes. Some soil chemicals attack concrete pipes.

Operation:

The drains collect groundwater and channel it into the collectors. The collectors also often gather surface runoff through inspection chambers covered with grilles. If the natural slope is insufficient for gravity drainage, a pumping station is used to lift the water to the discharge point. Inspection chambers are placed at critical points, such as junctions, changes in direction, and slopes.

Advantages:

- Ease of Installation: The system is straightforward to set up.
- Durability: Pipes are resistant to crushing and wear.
- Reduced Operational Constraints: Provides easy access and maintenance.
- Preserves Cultivable Area: Does not reduce the land available for cultivation.

Disadvantages:

- Risk of Clogging: Pipes can become blocked by silt or debris, reducing effectiveness.
- High Maintenance C**osts:** Regular maintenance can be expensive.

V. 3. Installation equipment:

A complete set of equipment is necessary for the installation of drainage systems. The constitution of the set largely depends on the characteristics of the drainage systems and drainage material to be used.

Most of the equipment is support equipment that can also be used for other purposes like: tractors, trailers, hydraulic excavators, front loaders etc. and is not specific to drainage.

Equipment specific to subsurface drainage installation is confined to: drainage machines and to a lesser extent the gravel trailers and backfill equipment.

V. 3. 1. Required characteristics of drainage machines:

A drainage machine must be capable of installing a drain pipe at the desired depth and slope with minimal deviations under the prevailing soil conditions. Allowable deviations are plus or minus 25% of the drain diameter.

In practice the drainage machines have to install the pipe at the required depth either and slope:

- In a trench (usually dug by an excavator) that is later backfilled.
- Or at the desired location by pulling the pipe in a gallery formed by a knife-like device (trenchless machine).

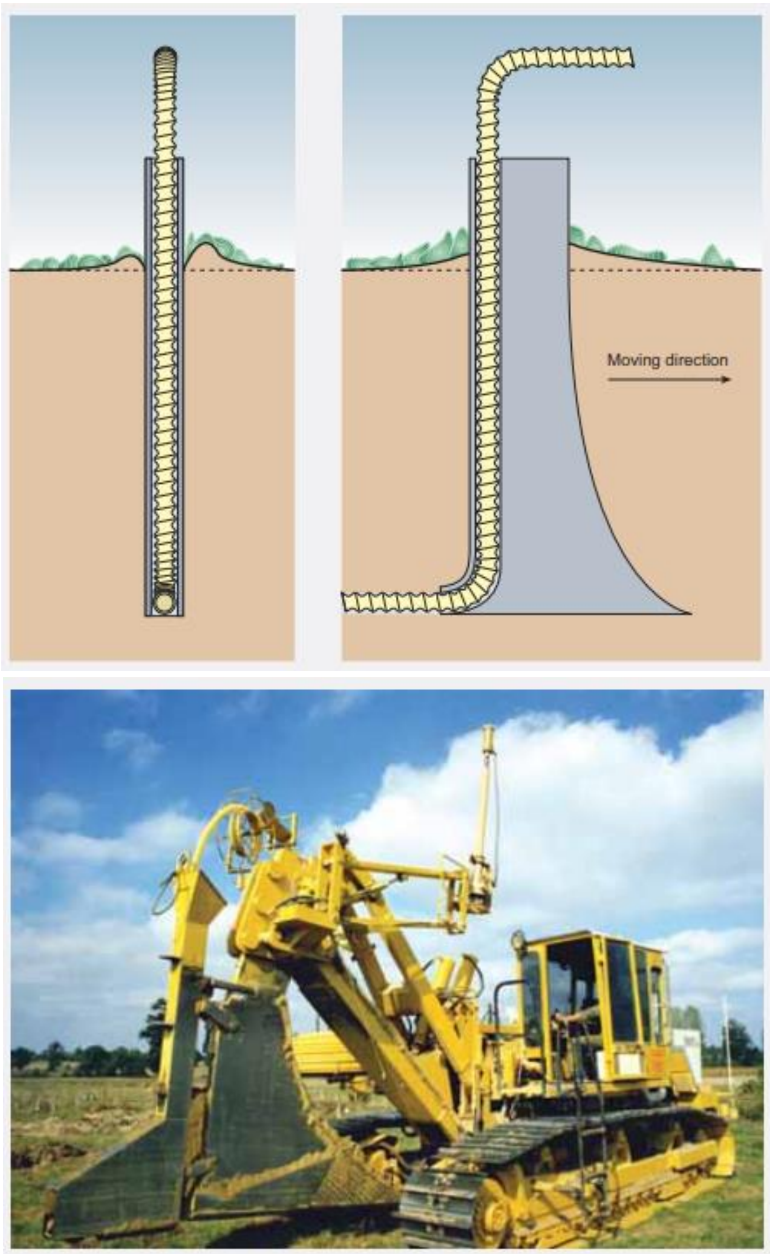

Figure IV.4: Trenchless drainage machine : subsoiler type.

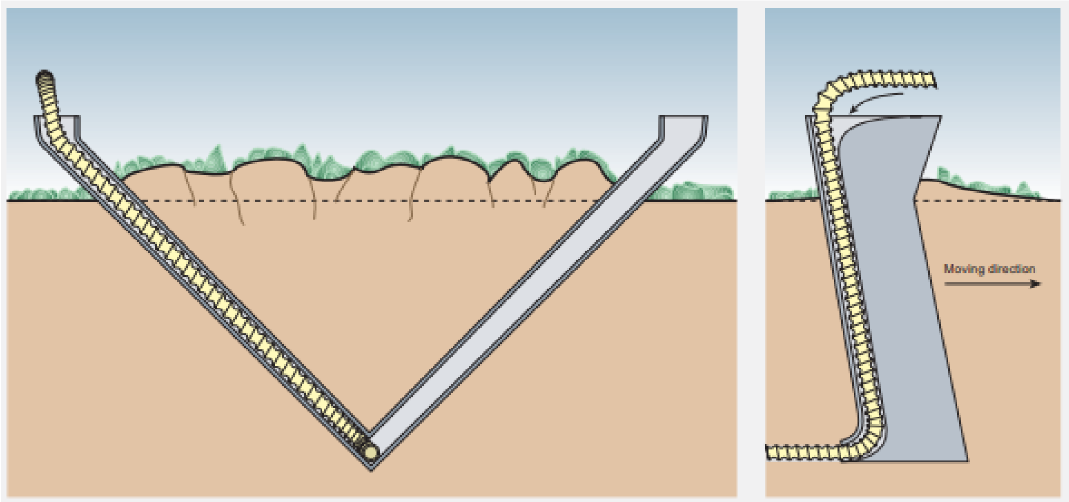

Figure IV.5: Trenchless drainage machine: V-plough type.

Figure IV.6: Hydraulic excavator digging a drain trench.

V. 4. Choice of the drainage technique:

We chose the subsurface drainage system over the open-air ditch system because:

The subsurface drainage system is:

- Easier to install**:** Subsurface drains are simpler to install, as they are installed using trenchless machines that are operated hydraulically to regulate the depth and slope of the installation as opposed to the use of regular excavators for digging the ditches.
- More cost Efficient: It offers economic benefits in terms of cultivable land and materials.

The open-air system:

- Loss of Cultivable Land: Open ditches reduce the area available for farming.
- Interference with Agricultural Practices: They obstruct soil preparation, plowing, and other machinery operations.
- Steep Slopes: The system is less effective in areas with significant slopes.

VI. Conclusion:

The choice of subsurface drainage allows us to remove ground water and control the water table level, while being easier to install, more durable and less expensive to maintain.

A technico-economic study is unnecessary since the open-air drainage system has been ruled out due to topographical and socio-economic reasons.

Chapter V:

Sizing of the Drainage Network

I. introduction:

The primary purpose of draining an agricultural area is to remove excess water and salts from the soil through an artificial evacuation system.

Excess water in an agricultural area can mainly originate from:

- Rainfall;
- Irrigation (losses through percolation and leaching dose);
- Lateral inputs or transfers.

II. Calculation of the characteristic flow rate “qc”:

The characteristic flow rate (denoted as qc) of a drainage network is the flow per area unit, required to efficiently evacuate excess water. The calculation of this flow rate depends on the drainage regime considered and whether storage capacity is factored in.

II. 1. In case the excess comes from rainfall:

Critical rainfall is the maximum amount of rain that falls within a fixed period and with a specified recurrence time (the interval of time in which a precipitation event is expected to occur once, on average).

The drainage network must be capable of evacuating **critical rainfall**. It is determined by its **duration**, **intensity** during that duration, and **frequency** (recurrence time).

The methods for calculating a drainage network vary depending on the climate and soil, there are two main drainage models based on the **flow regime**:

- **Permanent Regime:**
  - The permanent regime applies to heavy and **impermeable soils** that do not allow for temporary storage and have low infiltration rates.
  - Rainfall is **long**, frequent, and leaves only **short intervals** between rainfalls, preventing the soil from drying out. It maintains water levels below the maximum levels.
  - This is applied when the drainage flow is in equilibrium with the recharge of the aquifer (infiltration). There are two cases: **with storage** and **without storage**. Storage primarily results from a combination of high rainfall intensity and low permeability.

- **Variable Regime:**
  - The variable regime applies to more **permeable soils** that allow for temporary water table rise and relatively rapid drainage.
  - Rainfall is **short** with very **high intensity** and leaves sufficiently **long intervals** between rainfalls. The goal with the drainage network is to achieve a drawdown to the desired level within a well-defined time frame after the rain ends.

– Models applicable in a variable regime will lower the water table by a certain height over a more or less extended period. The variable regime describes the drawdown of the water table after precipitation ceases.

In Algeria, the most dominant rainfall regime in the Sahel is the permanent regime. In contrast, the variable regime predominates in the Saharan high plateaus, therefor I am going to be using the permanent regime models.

II. 1. 1. Frequency analysis of the rainfall series:

In drainage, it is not the total annual or monthly rainfall that poses the main issues, but rather the short-duration, high-intensity rainfall events. These can exceed the natural drainage capacity and potentially lead to the formation and/or rise of a water table close to the soil surface.

We have a daily rainfall series from the period (1992–2018) from Maghnia station. The first step is to classify and statistically process the existing rainfall data. The goal of this classification and processing is to highlight the maximum rainfall for short durations (1, 2, 3, 4, 5, 6 days) and their frequencies of occurrence.

This analysis can be done annually, but for greater accuracy, it is recommended to perform it quarterly to account for the period during which critical rainfall occurs in relation to the sensitive stages of different crops.

II. 1. 2. Fitting using the Gumbel distribution:

After recording the maximum rainfall for 1, 2, 3, 4, 5, and 6 days over several years of observations, these values are arranged in ascending order, and each value is assigned a non-exceedance frequency F(x):

$$F(x) = \frac{r - 0.5}{n} \qquad \text{IV.1}$$

- **r**: the rank of the observation.
- **n**: the total number of observation years.
- **Gumbel distribution**: F(x) is the cumulative distribution function.
- **x_0** and: adjustment coefficients.

By performing a variable transformation, we obtain:

$$y = \alpha(x - x_0) \qquad \text{IV.2}$$

$$F(y) = e^{-e^{-y}} \quad \text{IV.3}$$

- **y**: Gumbel reduced variable.
- **F(y)**: non-exceedance frequency of the variable y.

❖ **Results of the fitting:**

The Gumbel distribution fitting is performed using the HYFRAN software. The results of the fitting are presented in the following tables:

Table V.1: Fitting results for the first quarter (September, October, November)

Durée/fréquence	2ans	3ans	5ans	10ans
1J	1.22	1.83	2.52	3.39
2J	4.83	6.76	8.90	11.6
3J	5.96	8.89	12.1	16.2
4J	8.96	13.5	18.5	24.8
5J	11.3	18	25.6	35
6J	15.8	25.3	36	49.4

Table V.2: Fitting results for the second quarter (December, January, February)

Durée/fréquence	2ans	3ans	5ans	10ans
1J	1.26	1.94	2.71	3.66
2J	6.63	9.04	11.7	15.1
3J	8.01	12.2	16.9	22.8
4J	8.3	12.6	17.4	23.4
5J	8.65	14.5	21	29.2
6J	8.08	13.9	20.4	28.6

Table V.3: Fitting results for the third quarter (March, April, May)

Durée/fréquence	2ans	3ans	5ans	10ans
1J	1.12	1.66	2.26	3.01
2J	4.13	5.88	7.82	10.3
3J	5.49	8.54	11.9	16.2
4J	11.6	17.2	23.4	31.2
5J	16.7	25.6	35.4	47.8
6J	11.4	18.5	26.5	36.5

Subsequently, we can plot the rainfall-duration-frequency graphs:

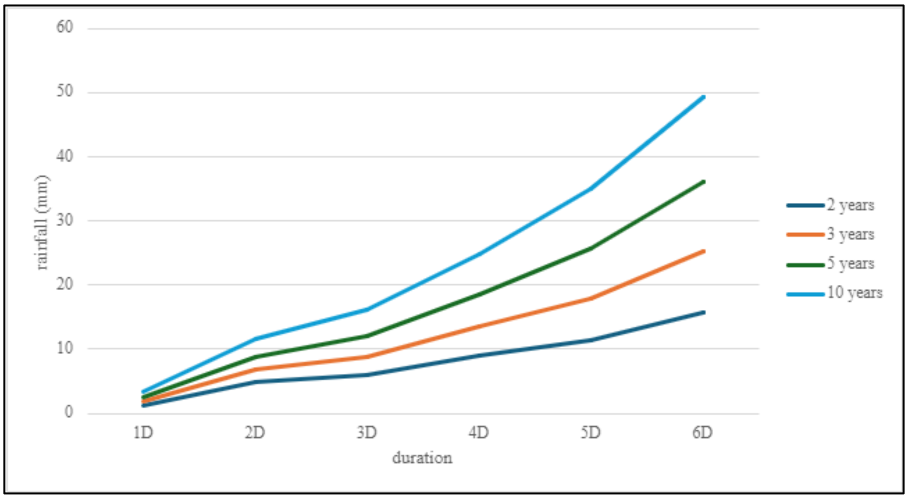

Figure V.1: the rainfall-duration-frequency graphs for the first quarter

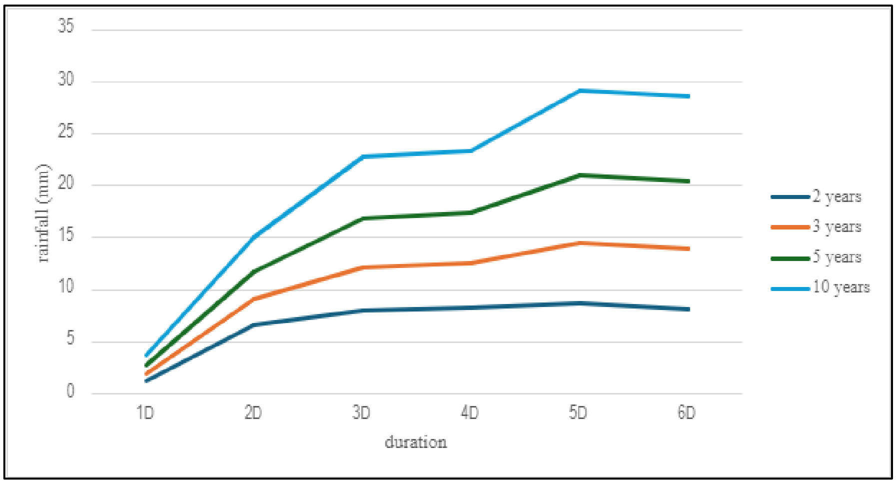

Figure V.2: the rainfall-duration-frequency graphs for the second quarter

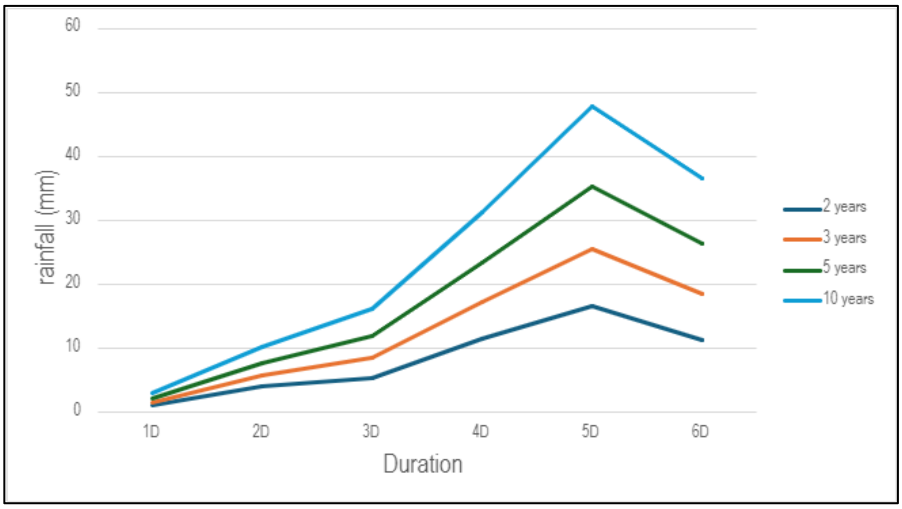

Figure V.3: the rainfall-duration-frequency graphs for the third quarter

The graphs allow for a quick determination of the probable maximum rainfall for a given return period and duration.

❖ **Critical rainfall:**

We use different frequencies to measure the critical rainfall for each type of culture:

Table V.4: frequency used to measure the critical rainfall for each type of culture.

Type of crop	Frequency
Vegetables	2 - 3 years
Cereals and Forage crops	3 – 5 years
Trees	5 – 10 years

II. 1. 3. Permanent rainfall regime taking storage in consideration:

The characteristic flow rate qc is calculated, taking into account **temporary storage S**, using the following expression:

$$qc = \frac{P - E - S}{\theta} \quad \text{IV.4}$$

While:

$$S = hc \times \mu \quad \text{IV.5}$$

- **qc**: characteristic flow rate (mm/day).
- **P**: critical rainfall (mm).
- **E**: evapotranspiration (mm).
- **S:** Storage capacity (mm)
- **θ**: allowable submersion duration (days).
- **µ**: drainage porosity (%) for a known drain depth.
- **hc:** critical height = drain depth – water table level.

In winter and during rainfall, evapotranspiration **E** is equal to 0, therefor the expression for qc becomes:

$$qc = \frac{P - S}{\theta} \times \frac{1}{8.64} (l/s/h\,a) \quad \text{IV.6}$$

❖ **Drainage porosity "μ":**

According to Taylor (1960), the equivalent drainage porosity μ is the unit volume of water released by the soil profile when the water table is lowered from one position to another.

The type of soil plays an important role in determining the drainage porosity.

Table V.5: Drainage porosity depending on soil texture.

Texture	μ (%)
Clay soil	1-2
Clay loam soil	4-8
Fine sand	10-20
Coarse sand	25-30

For our area, we have a clay-loamy soil, which means we have a drainage porosity of **μ = 0.06.**

❖ **Critical Height "hc":**

The placement of drains must be done carefully. After a critical rainfall (in the case of a permanent regime), at least part of the plant's roots should remain dry. The water table must therefore be at a minimum depth

$$hc = p - hop \qquad \text{IV.7}$$

- p: being the drain depth, generally between 1-1.2 meters.
- hop: being the optimal admissible height (dry zone of the root system).

Table V.6: Critical water height for each type of culture.

Type of crop	hop (mm)	hc (mm)
Vegetables	500 - 600	400-500
Cereals and Forage crops	600	400
Trees	800 -1200	200
Pastures	200 - 300	700

❖ **Allowable submersion duration "θ":**

The admissible duration of submersion for crops "θ" is the period during which plants can survive with their roots in water when the soil is saturated. Beyond this period, the plant dies from root asphyxiation.

Table V.7: Allowable submersion duration according to plant type.

Type of crop	**Θ (days)**
Vegetables	1 to 2
Cereals and Forage crops	3
Trees	5
Pastures	7

Table V.8: Results of calculation of “qc” for excess rainfall considering storage.

Crop	θ (days)	hc (mm)	µ (%)	S (mm)	P (mm)	qc (l/s/ha)
Vegetables	2	400	0.06	24	6.63	0
Cereals	3	400		24	12.2	0
Trees	5	200		12	35.4	0.52

The characteristic flow coming from excess rainfall in a permanent regime model while taking storage in consideration is:

qc = 0.52 (l/s/ha)

II. 1. 4. Permanent rainfall regime without taking storage in consideration:

Taking the intensity of the critical rainfall (ip), the amount of rain that falls over a given duration, it is assumed that the fraction of this rain to be drained by the network is the sum of direct runoff and infiltration:

$$i + r = 1 - e \qquad \text{IV.8}$$

The characteristic flow rate to be evacuated per unit area is:

$$qc = (1 - e) \times ip \qquad \text{IV.9}$$

With:

- i: Infiltration coefficient $i = \frac{I}{P}$
- e: Evaporation coefficient $e = \frac{E}{P}$
- r: Runoff coefficient $r = \frac{R}{P}$
- ip**:** Intensity of the critical rainfall. $ip = \frac{P}{\theta}$

Table V.9: (1-e) according to plant type.

Type of crop	**1 – e**
Vegetables	0.8 - 0.9
Cereals and Forage crops	0.6 - 0.8
Trees	0.5
Pastures	0.5 - 0.6

Table V.10: Results of calculation of "qc" for excess rainfall without considering storage.

Crop	θ (days)	P (mm)	ip (mm/day)	1-e	qc (l/s/ha)
Vegetables	2	6.63	3.32	0.8	0.31
Cereals	3	12.2	4.07	0.6	0.28
Trees	5	35.4	7.08	0.5	0.41

The characteristic flow coming from excess rainfall in a permanent regime model without taking storage in consideration is:

qc = 0.41 (l/s/ha)

II. 2. In case the excess comes from irrigation:

We will calculate the characteristic flow rate of the excess that could result from irrigation, as each irrigation system has its efficiency, leading to percolation losses that recharge the water table.

In our area, the irrigation system to be implemented will have an efficiency of 70%, resulting in a **percolation loss of 20%**, with the remaining 10% lost through evapotranspiration.

We have:

- RFU = 54.6mm
- Bnet = 142.14mm
- Number of irrigations = Bnet/RFU = 2.6 (3 times).
- Frequency of irrigation = 30/3= once every 10 days.
- The Volume of percolated irrigation water to drain: $\frac{RFU}{Ef} \times 0.2 = \frac{54.6}{0.7} \times 0.2 = 15.6mm$
- We need to drain 15.6mm in 10 days.

Therefor:

$$qc = \frac{15.6}{10} = 1.56\, mm/j = 0.18\, l/s/ha$$

The characteristic flow coming from percolated irrigation water is:

qc= 0.18 l/s/ha

II. 3. In case the excess comes from leaching:

The leaching dose is applied in fractions alongside the irrigation doses, meaning that salts are not allowed to accumulate in the soil but are gradually leached out.

The irrigation system in place is thus used to apply the leaching doses together with the irrigation doses.

In the 3rd chapter, we calculated the leaching fraction **LR:**

$$LR_{eff} = 20\%$$

and the leaching dose:

$$DW = \frac{LR_{eff}}{1 - LR_{eff}} \times ETM = 0.25 \times ETM \qquad \text{III.9a}$$

We take:

ETM = 142.14 mm/month

Which gives us:

Dw = qc = 35.54 mm/month

Or:

$$qc = \frac{10 \times 35.54 \times 1000}{3600 \times 24 \times 30} = 0.137\ (l/s/ha)$$

The characteristic flow coming from leaching is:

qc= 0.137 l/s/ha

II. 4. Choice of the characteristic flow rate:

Table V.11: choice of characteristic flow "qc".

Type of excess water	qc (l/s/ha)
Rainfall with storage	0.52
Rainfall without storage	0.41
Percolation from irrigation	0.18
leaching	0.137

For the design of the drainage network, we must take the highest value among the characteristic flow rates calculated for rainfall, irrigation, and leaching. Therefore, the characteristic flow rate used for drainage design is **qc = 0.52 l/s/ha.**

III. Dimensioning of the spacing between drains (E):

Since the rainfall in the Zouia region is considered to be of a permanent regime, we're going to be using the Hooghoudt equation to calculate the spacing between the drains.

III. 1. Hooghoudt's equation:

The procedure for determining the spacing of buried drains **E** using Hooghoudt's formula includes the following steps:

1. **Calculation of basic design criteria:** Determine the characteristic flow rate and the optimal height (**qc** and **hop**).
2. **Establishment of the field drainage base:** Define the drainage base W and the available fall height **hc = P − hop**.
3. **Establishment of soil parameters:** Identify soil permeability K (or permeability below and above the drain, K1 and K2) and the distance between the drains and the impermeable layer D.
4. **Selection of drain type:** Choose between a pipe or ditch drain and determine the drainage porosity µ.
5. **Determination of drain spacing:** Solve Hooghoudt's equation to find the spacing E or L using an iterative process:
   - Assume a value for **E** and determine **d** using the vlotman Table.
   - Solve Hooghoudt's formula for the spacing **E** and compare this value with the assumed value.
   - Adjust the value of **E** and repeat the process until the calculated and assumed values are equal

$$E^2 = \frac{4k_1h^2}{qc} + \frac{8k_2dhc}{qc} \qquad \text{IV.10}$$

With:

- hc: critical height (hc =0.4m).
- P: depth of drain installation, P = 1 m.
- hop: optimal height (hop = 0.6m)
- d: equivalent depth (measured using the Vlotman table).
- k: soil permeability k = 7 mm/h = 0.168 m/day.
- Depth of impermeable layer: D =12 m
- qc: Characteristic flow = 0.52 l/s/ha = 4.5 mm/day

Therefore, after using the iterative process using Vlotman's table we get:

- d = 1.55m:

$$E^2 = \frac{4 \times 0.168 \times 0.4^2}{4.5 \times 10^{-3}} + \frac{8 \times 0.168 \times 0.4 \times 1.55}{4.5 \times 10^{-3}} = 208.8$$

$$E \approx 15m$$

IV. Dimensioning of drains:

The main parameters for drain dimensioning are:

- Installation slope (i).
- Drain length (L).
- Drain diameter (ϕ).

In a permanent regime, the calculation is based on project characteristics, such as:

- The spacing between drains.
- Drain length and number of drains.
- Characteristic flow rate (qc) in a permanent regime.
- Flow within the drains.
- Plot layout, topography, hydrography, and technical constraints.

IV. 1. The installation slope:

The choice of slope directly influences the flow velocity. If the flow is sufficiently high when the drain operates at full capacity, sedimentation of particles is avoided, thus preventing any blockage of the drains. Here are some guidelines for easier installation, based on multiple trials:

Absolute minimum slope, noted as i_{min}, is fixed at 0.05%. However, this minimum should be increased for smaller diameters:

- $i = 0.1\%$ for $\phi < 150$ mm
- $i = 0.08\%$ for $200 \text{ mm} < \phi < 250$ mm
- $i = 0.05\%$ for $\phi > 250$ mm

The flow velocity in the drain should be between 1 m/s and 1.25 m/s to reduce the risk of clogging and prevent the suction effect at the joints and perforations of the drains.

The diameter (ϕ) of the drains is inversely proportional to the slope (i). This means that as the slope increases, the drain diameter can be reduced. However, it is advisable to avoid having a slope that is too steep, generally above 1%.

In practice, the most commonly used slopes range from 0.1% to 1%. The choice of slope should be based on factors such as the terrain's topography, the location of collectors, the position of outlets, and the total length of the drainage system.

IV. 2. Drains length:

The Drains lengths “L” are chosen based on the dimensions of the plot. The maximum acceptable length “Lmax” is: Lmax = 1000 m, which is the limit imposed by the diameter ϕ_{max}. The most common lengths range between 150 m and 400 m.

IV. 3. Water flow to be evacuated by the drains:

$$Q_d = q \times S \quad \text{IV.11a}$$

$$Q_d = q \times L \times E \quad \text{IV.11b}$$

With:

- S: the surface drained by the drain,
- q: the flow rate of the drain (4.5 mm/day or 4.5×10^{-3}m/day);
- L: the length of the drain (m);
- E: the spacing between the drains (E=15m).

IV. 4. The Technical characteristics of the drains:

In flow channels, it is essential to account for roughness, which depends on the material, such as ceramic drains, smooth drains, or corrugated drains.

We use the roughness from the Manning-Strickler formula (η), the roughness of the drains is:

- **Plastic (PVC, smooth PE with perforations)**: η = 0.0054
- **Concrete**: η = 0.011 to 0.015 (depending on quality)

For corrugated drains, roughness η varies with the drain's internal diameter:

- ϕ = 44 mm: η = 0.0222
- ϕ = 60 mm: η = 0.0167
- ϕ = 72 mm: η = 0.0143

Average value η = 0.0141

For dimensioning, in case of a non-uniform flow and for perforated corrugated drains, we use the Chezy-Manning equation:

$$Q_{drains} = 38 \times d^{2.67} \times i^{0.5} \quad \text{IV.12a}$$

$$d_{drains} = \sqrt[2.67]{\frac{Q_{drains}}{38 \times i^{0.5}}} \quad \text{IV.12b}$$

The agricultural drains will be corrugated perforated PVC pipes, with nominal diameters of 44, 58, 72, and 91 mm. The nominal diameter corresponds to the outer diameters of the drains minus the grooves, the outer diameters are 50, 65, 80, and 100 mm, respectively.

V. Dimensioning of the collectors:

In cases where the installation slope is around 0.1%, the collector receives water from all the connected drains. A reduction of 25% in its capacity should be anticipated, primarily due to particles carried by the water from the drains.

$$Q_{collector} = \sum q_{drains} \tag{IV.13}$$

$$Q_{collector} = \frac{50 \times d^{2.71} \times i^{0.57}}{0.75} \tag{IV.14a}$$

$$d_{collector} = \sqrt[2.71]{\frac{Q_{collector} \times 0.75}{50 \times i^{0.57}}} \tag{IV.14b}$$

It is also necessary to ensure velocities of V < 1 - 1.5 m/s to avoid suction effects at the joints and perforations of the drains, and V > 0.5 m/s to prevent the sedimentation of infiltrated particles.

$$V = \frac{Q}{S} \tag{IV.15}$$

$$S = \pi \times \frac{D^2}{4} \tag{IV.16}$$

The results of calculations for the diameters of the drains and collectors are summarized in the following table:

Table V.12: Sizing of the drains and collectors.

Collectors	Drains/Collectors	L (m)	Q (m^3/day)	Q (m^3/s)	ϕ calculated (mm)	ϕ normalised (mm)
Collector D	drain 1	166,2	11,22	0,00013	32,69	44
	drain 2	178,5	12,05	0,000139	33,58	44
	drain 3	191,3	12,91	0,000149	34,46	44
	drain 4	199,5	13,47	0,000156	35,01	44
	drain 5	192,2	12,97	0,00015	34,52	44
	drain 6	190,3	12,85	0,000149	34,4	44
	drain 7	188,9	12,75	0,000148	34,3	44
	drain 8	203,2	13,72	0,000159	35,25	44
	drain 9	222,7	15,03	0,000174	36,48	44
	drain 10	229,5	15,49	0,000179	36,89	44
	drain 11	228,3	15,41	0,000178	36,82	44
	drain 12	228,8	15,44	0,000179	36,85	44
	drain 13	226,8	15,31	0,000177	36,73	44
	drain 14	228,6	15,43	0,000179	36,84	44
	drain 15	238,6	16,11	0,000186	37,44	44
	drain 16	244	16,47	0,000191	37,75	44
	drain 17	250,2	16,89	0,000195	38,11	44
	drain 18	174,9	11,81	0,000137	33,32	44

	drain 19	172,2	11,62	0,000135	33,13	44
	drain 20	164,3	11,09	0,000128	32,55	44
	drain 21	151,3	10,21	0,000118	31,56	44
	drain 22	350	23,63	0,000273	43,21	44
	drain 23	340	22,95	0,000266	42,75	44
	drain 24	329	22,21	0,000257	42,22	44
	drain 25	320	21,6	0,00025	41,79	44
	drain 26	313	21,13	0,000245	41,44	44
	drain 27	396	26,73	0,000309	45,26	58
	drain 28	283	19,1	0,000221	39,91	44
	drain 29	284	19,17	0,000222	39,96	44
	drain 30	285	19,24	0,000223	40,01	44
	drain 31	285	19,24	0,000223	40,01	44
	drain 32	288	19,44	0,000225	40,17	44
	drain 33	283	19,1	0,000221	39,91	44
	drain 34	261	17,62	0,000204	38,72	44
	drain 35	237	16	0,000185	37,34	44
	drain 36	215	14,51	0,000168	36	44
	drain 37	365	24,64	0,000285	43,9	44
	drain 38	422	28,49	0,00033	46,35	58
	drain 39	412	27,81	0,000322	45,93	58
	drain 40	414	27,95	0,000323	46,02	58
	drain 41	409	27,61	0,00032	45,81	58
	drain 42	417	28,15	0,000326	46,14	58
	drain 43	415	28,01	0,000324	46,06	58
	drain 44	412	27,81	0,000322	45,93	58
	drain 45	418	28,22	0,000327	46,18	58
	drain 46	419	28,28	0,000327	46,22	58
	drain 47	420	28,35	0,000328	46,27	58
	drain 48	420	28,35	0,000328	46,27	58
	drain 49	421	28,42	0,000329	46,31	58
	drain 50	422	28,49	0,00033	46,35	58
	drain 51	423	28,55	0,00033	46,39	58
	drain 52	399	26,93	0,000312	45,39	58
	drain 53	382	25,79	0,000298	44,65	58
	drain 54	272	18,36	0,000213	39,32	44
	drain 55	231	15,59	0,00018	36,98	44
	drain 56	283	19,1	0,000221	39,91	44
	drain 57	294	19,85	0,00023	40,48	44
	drain 58	304	20,52	0,000238	40,99	44
	drain 59	315	21,26	0,000246	41,54	44
	drain 60	314	21,2	0,000245	41,49	44
	drain 61	325	21,94	0,000254	42,03	44
	drain 62	332	22,41	0,000259	42,37	44
	drain 63	336	22,68	0,000263	42,56	44
	drain 64	340	22,95	0,000266	42,75	44
	drain 65	345	23,29	0,00027	42,98	44
	drain 66	349	23,56	0,000273	43,17	44
	drain 67	354	23,9	0,000277	43,4	44
	drain 68	358	24,17	0,00028	43,58	44
	drain 69	368	24,84	0,000288	44,03	58
	drain 70	387	26,12	0,000302	44,87	58
	drain 71	407	27,47	0,000318	45,72	58
	drain 72	117	7,9	0,000091	28,67	44
	drain 73	150	10,13	0,000117	31,46	44
	drain 74	187	12,62	0,000146	34,17	44

	drain 75	212	14,31	0,000166	35,81	44
	drain 76	245	16,54	0,000191	37,81	44
	drain 77	287	19,37	0,000224	40,12	44
	drain 78	316	21,33	0,000247	41,59	44
	drain 79	345	23,29	0,00027	42,98	44
	drain 80	359	24,23	0,00028	43,63	44
	drain 81	376	25,38	0,000294	44,39	58
	Total for Collector D	**1617**	**1636,02**	**0,02**	**195,38**	**200**
Collector C	drain 1	130	8,78	0,000202	29,82	44
	drain 2	164	11,07	0,000228	32,53	44
	drain 3	177	11,95	0,000238	33,47	44
	drain 4	281	18,97	0,00032	39,8	44
	drain 5	320	21,6	0,00035	41,79	44
	drain 6	343	23,15	0,000368	42,89	44
	drain 7	360	24,3	0,000381	43,67	44
	drain 8	380	25,65	0,000397	44,56	58
	drain 9	390	26,33	0,000405	45	58
	drain 10	387	26,12	0,000402	44,87	58
	drain 11	413	27,88	0,000423	45,98	58
	drain 12	412	27,81	0,000422	45,93	58
	drain 13	430	29,03	0,000436	46,68	58
	Total for Collector C	**198**	**282,62**	**0,005228**	**109.21**	**110**
Collector B	drain 1	425	28,69	0,000332	46,47	58
	drain 2	438	29,57	0,000342	47	58
	drain 3	432	29,16	0,000338	46,76	58
	drain 4	426	28,76	0,000333	46,51	58
	drain 5	420	28,35	0,000328	46,27	58
	drain 6	412	27,81	0,000322	45,93	58
	drain 7	401	27,07	0,000313	45,47	58
	drain 8	390	26,33	0,000305	45	58
	drain 9	366	24,71	0,000286	43,94	44
	drain 10	337	22,75	0,000263	42,6	44
	drain 11	312	21,06	0,000244	41,39	44
	drain 12	287	19,37	0,000224	40,12	44
	drain 13	260	17,55	0,000203	38,66	44
	drain 14	236	15,93	0,000184	37,28	44
	drain 15	208	14,04	0,000163	35,56	44
	drain 16	181	12,22	0,000141	33,76	44
	drain 17	147	9,92	0,000115	31,23	44
	drain 18	187	12,62	0,000146	34,17	44
	drain 19	186	12,56	0,000145	34,1	44
	drain 20	190	12,83	0,000148	34,37	44
	drain 21	201	13,57	0,000157	35,11	44
	drain 22	60	4,05	0,000047	22,32	44
	drain 23	84	5,67	0,000066	25,32	44
	drain 24	109	7,36	0,000085	27,92	44
	drain 25	132	8,91	0,000103	29,99	44
	drain 26	156	10,53	0,000122	31,93	44
	drain 27	182	12,29	0,000142	33,83	44
	drain 28	207	13,97	0,000162	35,5	44
	drain 29	232	15,66	0,000181	37,04	44
	drain 30	264	17,82	0,000206	38,88	44
	drain 31	297	20,05	0,000232	40,63	44
	drain 32	338	22,82	0,000264	42,65	44
	drain 33	374	25,25	0,000292	44,3	58
	drain 34	411	27,74	0,000321	45,89	58

	drain 35	483	32,6	0,000377	48,75	58
	drain 36	513	34,63	0,000401	49,87	58
	drain 37	653	44,0775	0,000510	54,58	58
	drain 38	150	10,125	0,000117	31,46	58
	drain 39	156	10,53	0,000122	31,93	58
	drain 40	160	10,8	0,000125	32,23	58
	drain 41	172	11,61	0,000134	33,12	58
	drain 42	184	12,42	0,000144	33,96	58
	drain 43	199	13,4325	0,000155	34,98	58
	Collector D		1636,02	0,018935	211,30	
	Collector C		282,62	0,05228	109,47	
	Total for Collector B	**1503**	**2725,855**	**0,0315**	**235,88**	**250**
Collector A	drain 1	416	28,08	0,000325	46,1	58
	drain 2	415	28,01	0,000324	46,06	58
	drain 3	413	27,88	0,000323	45,98	58
	drain 4	412	27,81	0,000322	45,93	58
	drain 5	411	27,74	0,000321	45,89	58
	drain 6	412	27,81	0,000322	45,93	58
	drain 7	412	27,81	0,000322	45,93	58
	drain 8	409	27,61	0,00032	45,81	58
	drain 9	405	27,34	0,000316	45,64	58
	drain 10	401	27,07	0,000313	45,47	58
	drain 11	397	26,8	0,00031	45,3	58
	drain 12	393	26,53	0,000307	45,13	58
	drain 13	389	26,26	0,000304	44,96	58
	drain 14	386	26,06	0,000302	44,83	58
	drain 15	387	26,12	0,000302	44,87	58
	drain 16	386	26,06	0,000302	44,83	58
	drain 17	385	25,99	0,000301	44,78	58
	drain 18	383	25,85	0,000299	44,7	58
	drain 19	382	25,79	0,000298	44,65	58
	drain 20	381	25,72	0,000298	44,61	58
	drain 21	379	25,58	0,000296	44,52	58
	drain 22	377	25,45	0,000295	44,43	58
	drain 23	672	45,36	0,000525	55,17	58
	drain 24	535	36,11	0,000418	50,66	58
	drain 25	532	35,91	0,000416	50,55	58
	drain 26	507	34,22	0,000396	49,65	58
	drain 27	511	34,49	0,000399	49,79	58
	drain 28	515	34,76	0,000402	49,94	58
	drain 29	520	35,1	0,000406	50,12	58
	drain 30	524	35,37	0,000409	50,26	58
	drain 31	528	35,64	0,000413	50,41	58
	drain 32	532	35,91	0,000416	50,55	58
	drain 33	535	36,11	0,000418	50,66	58
	drain 34	542	36,59	0,000423	50,9	58
	drain 35	548	36,99	0,000428	51,11	58
	drain 36	553	37,33	0,000432	51,29	58
	drain 37	561	37,87	0,000438	51,56	58
	drain 38	573	38,68	0,000448	51,97	58
	drain 39	585	39,49	0,000457	52,38	58
	drain 40	596	40,23	0,000466	52,75	58
	drain 41	608	41,04	0,000475	53,14	58
	drain 42	620	41,85	0,000484	53,53	58
	drain 43	631	42,59	0,000493	53,89	58
	drain 44	641	43,27	0,000501	54,2	58

	drain 45	651	43,94	0,000509	54,52	58
	drain 46	660	44,55	0,000516	54,8	58
	drain 47	667	45,02	0,000521	55,02	58
	drain 48	672	45,36	0,000525	55,17	58
	drain 49	676	45,63	0,000528	55,29	58
	drain 50	676	45,63	0,000528	55,29	58
	drain 51	676	45,63	0,000528	55,29	58
	drain 52	672	45,36	0,000525	55,17	58
	drain 53	519	35,03	0,000405	50,08	58
	drain 54	667	45,02	0,000521	55,02	58
	drain 55	650	43,88	0,000508	54,49	58
	drain 56	611	41,24	0,000477	53,24	58
	drain 57	577	38,95	0,000451	52,11	58
	drain 58	558	37,67	0,000436	51,46	58
	drain 59	547	36,92	0,000427	51,08	58
	drain 60	533	35,98	0,000416	50,58	58
	drain 61	519	35,03	0,000405	50,08	58
	drain 62	505	34,09	0,000395	49,57	58
	drain 63	496	33,48	0,000388	49,24	58
	drain 64	488	32,94	0,000381	48,94	58
	drain 65	484	32,67	0,000378	48,79	58
	drain 66	485	32,74	0,000379	48,83	58
	drain 67	480	32,4	0,000375	48,64	58
	drain 68	490	33,08	0,000383	49,02	58
	drain 69	485	32,74	0,000379	48,83	58
	drain 70	481	32,47	0,000376	48,68	58
	drain 71	477	32,2	0,000373	48,52	58
	drain 72	480	32,4	0,000375	48,64	58
	drain 73	484	32,67	0,000378	48,79	58
	drain 74	488	32,94	0,000381	48,94	58
	drain 75	487	32,87	0,00038	48,9	58
	drain 76	485	32,74	0,000379	48,83	58
	drain 77	487	32,87	0,00038	48,9	58
	drain 78	491	33,14	0,000384	49,05	58
	drain 79	500	33,75	0,000391	49,39	58
	drain 80	506	34,16	0,000395	49,61	58
	drain 81	512	34,56	0,0004	49,83	58
	drain 82	511	34,49	0,000399	49,79	58
	drain 83	436	29,43	0,000341	46,92	58
	drain 84	394	26,6	0,000308	45,17	58
	drain 85	354	23,9	0,000277	43,4	44
	drain 86	326	22,01	0,000255	42,08	44
	drain 87	298	20,12	0,000233	40,69	44
	drain 88	275	18,56	0,000215	39,48	44
	drain 89	328	22,14	0,000256	42,17	44
	drain 90	328	22,14	0,000256	42,17	44
	drain 91	334	22,55	0,000261	42,46	44
	drain 92	335	22,61	0,000262	42,51	44
	drain 93	335	22,61	0,000262	42,51	44
	drain 94	336	22,68	0,000263	42,56	44
	drain 95	318	21,47	0,000248	41,69	44
	drain 96	268	18,09	0,000209	39,1	44
	drain 97	211	14,24	0,000165	35,75	44
	drain 98	253	17,08	0,000198	38,27	44
	drain 99	323	21,8	0,000252	41,93	44
	drain 100	331	22,34	0,000259	42,32	44

	drain 101	336	22,68	0,000263	42,56	44
	drain 102	342	23,09	0,000267	42,84	44
	drain 103	350	23,63	0,000273	43,21	44
	drain 104	359	24,23	0,00028	43,63	44
	drain 105	367	24,77	0,000287	43,99	44
	drain 106	371	25,04	0,00029	44,17	58
	drain 107	372	25,11	0,000291	44,21	58
	drain 108	374	25,25	0,000292	44,3	58
	drain 109	376	25,38	0,000294	44,39	58
	drain 110	371	25,04	0,00029	44,17	58
	drain 111	354	23,9	0,000277	43,4	44
	drain 112	330	22,28	0,000258	42,27	44
	drain 113	321	21,67	0,000251	41,84	44
	drain 114	319	21,53	0,000249	41,74	44
	drain 115	354	23,9	0,000277	43,4	44
	drain 116	352	23,76	0,000275	43,3	44
	drain 117	348	23,49	0,000272	43,12	44
	drain 118	344	23,22	0,000269	42,93	44
	drain 119	339	22,88	0,000265	42,7	44
	drain 120	334	22,55	0,000261	42,46	44
	Collector B		2725,855	0,031547		
	Total for Collector A	**2312**	**6420,145**	**0,07430**	**323,58**	**400**

The Layout of the drainage network was done respecting the topographical and morphological characteristics of the area and the natural slope, which is more cost efficient.

The Table V.13 organizes the collector Pipes, the drains that discharge into said pipes, it displays also the length of the pipes, the flow of water and the finally the calculated diameter.

However, some groups of drains discharge directly into the tributary rivers. This decision was made because the flow from these drains would be insufficient to maintain a water velocity above 0.5 m/s in the collectors. Over time, this would hinder the collectors' function and increase their maintenance needs. The dimensions of these drains are illustrated in the following table, Chaaba A and B are the two tributary rivers:

Table V.13: Dimensioning of the drains that discharge in the river.

Discharge River	Drains	L (m)	Q (m^3/day)	Q (m^3/s)	ϕ Calculated (mm)	ϕ Normalized (mm)
Chaaba A	drain 1	195	13,16	0,000152	34,71	44
	drain 2	140	9,45	0,000109	30,66	44
	drain 3	168	11,34	0,000131	32,83	44
	drain 4	195	13,16	0,000152	34,71	44
	drain 5	222	14,99	0,000173	36,44	44
	drain 6	250	16,88	0,000195	38,1	44
	drain 7	278	18,77	0,000217	39,64	44
	drain 8	307	20,72	0,00024	41,14	44
	drain 9	335	22,61	0,000262	42,51	44
	drain 10	362	24,44	0,000283	43,76	44
	drain 11	390	26,33	0,000305	45	58
	drain 12	415	28,01	0,000324	46,06	58
	drain 13	492	33,21	0,000384	49,09	58
Chaaba B	drain 14	359	24,23	0,00028	43,63	44
	drain 15	291	19,64	0,000227	40,33	44
	drain 16	231	15,59	0,00018	36,98	44

	drain 17	190	12,83	0,000148	34,37	44
	drain 18	197	13,30	0,000154	34,84	44
	drain 19	346	23,36	0,000270	43,03	44
	drain 20	456	30,78	0,000356	47,71	58
	drain 21	319	21,53	0,000249	41,74	44
	drain 22	271	18,29	0,000212	39,26	44
	drain 23	246	16,61	0,000192	37,87	44
	drain 24	210	14,18	0,000164	35,69	44
	drain 25	193	13,03	0,000151	34,58	44
	drain 26	174	11,75	0,000136	33,26	44
Main river	drain 27	174	11,75	0,000136	33,26	44
	drain 28	198	13,37	0,000155	34,91	44
	drain 29	251	16,94	0,000196	38,15	44
	drain 30	287	19,37	0,000224	40,12	44
	drain 31	343	23,15	0,000268	42,89	44
	drain 32	134	9,05	0,000105	30,16	44
	drain 33	163	11,00	0,000127	32,46	44
	drain 34	196	13,23	0,000153	34,78	44
	drain 35	204	13,77	0,000159	35,30	44
	drain 36	178	12,02	0,000139	33,55	44
	drain 37	301	20,32	0,000235	40,84	44
	drain 38	318	21,47	0,000248	41,69	44
	drain 39	335	22,61	0,000262	42,51	44
	drain 40	329	22,21	0,000257	42,22	44
	drain 41	195	13,16	0,000152	34,71	44
	drain 42	284	19,17	0,000222	39,96	44
	drain 43	332	22,41	0,000259	42,37	44
	drain 44	830	56,03	0,000648	59,71	72
	drain 45	990	66,83	0,000773	63,79	72
	drain 46	862	58,19	0,000673	60,56	72
	drain 47	877	59,20	0,000685	60,96	72
	drain 48	891	60,14	0,000696	61,32	72
	drain 49	907	61,22	0,000709	61,73	72
	drain 50	927	62,57	0,000724	62,24	72
	drain 51	798	53,87	0,000623	58,84	72

The table below shows the calculated velocities inside the collectors:

Table V.14: water Velocity inside the collectors.

Collector	Q (m3/s)	Diameters (mm)	V (m/s)
Collector D	0,02	200	0,63
Collector C	0,005228	110	0,54
Collector B	0,0315	250	0,64
Collector A	0,07430	400	0,59

The calculated Diameters are valid as $0.5<V<1.5$ m/s, there is no risk of suction or sedimentation in the collectors.

The following table summarizes the total length of all the pipes involved in this project:

Table V.15: Total length of the drains and collectors.

Function	Diameter (mm)	Total Length (m)
Drains	44	39889
	58	71329
	72	7082
Collectors	110	198
	200	1617
	250	1503
	400	2312

VI. Junctions of the collectors:

VI. 1. Junctions with drains:

The junction should be made at an angle greater than 30° and less than 60° to prevent clogging.

The depth of the drains varies between 0.5 and 1.5 meters and can go up to 1.8 meters. The junction between the drain and the collector must be greater than or equal to D-d.

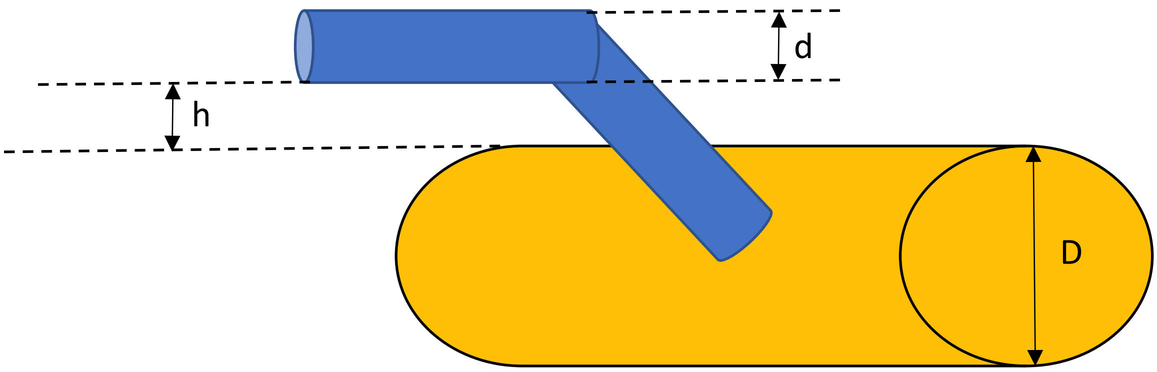

Figure V.4: Illustration of a junction between drain and collector

- D = diameter of the collector.
- d = diameter of the drain.
- h = the difference in installation levels between the collector and the drain ($h \geq D - d$).

VI. 2. Junctions' collector/collector:

The junction between the collectors is ensured by inspection chambers. The inspection chambers installed in the network serve to correct the slope, change diameters and direction, as well as to allow sedimentation of particles infiltrated into the drain. There are 40 inspection chambers in our drainage network.

VI. 3. Junction collector/outlet:

The collectors must discharge into an outlet at least 0.2 meters above their bottom, and 0.1 meters above the average water level.

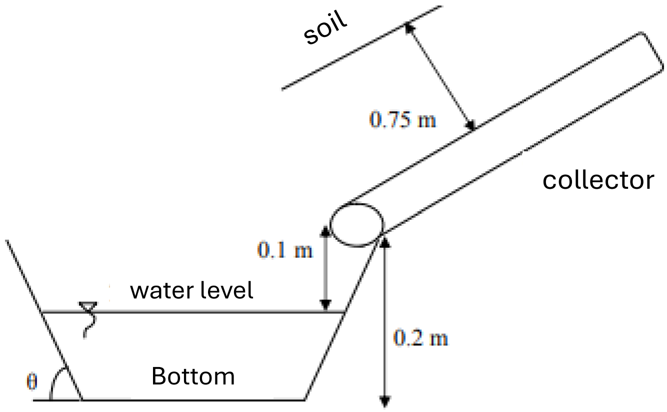

Figure V.5: Illustration of a junction between a collector and the outlet.

VII. Conclusion:

In this chapter, we were led to design the drainage network using subsurface pipe drains, which proved to be the most suitable for our study area due to its minimal land footprint.

The network consists of 308 drains distributed across the area at a depth of 1m below the surface, and a slope of 0.5%. These drains have diameters of 44, 58 and 72 mm, with lengths of 39889, 71329, 7082 m respectively.

Out of these drains, 257 are connected to four collectors, while 51 discharge directly into the river. The collectors have diameters ranging from 110 mm to 400 mm.

Chapter VI:

Maintenance of the Drainage Network

I. introduction:

A well-executed drainage system should, in principle, function for many years without the need for maintenance work. However, obstructions can prevent the system from operating effectively. To ensure our drainage network is efficient in the long term and has minimal environmental impact, it must be properly managed, regularly inspected, and maintained.

II. causes of drainage network malfunction:

There are several possible causes that can reduce or block the functioning of a drainage system. These include:

- **Obstructions due to poor execution:** Issues arising from flaws during the study or execution of the work, such as improper installation, inadequate slopes, or poorly connected pipes.
- **Natural causes:** Natural factors, such as sediment accumulation, root infiltration, or organic matter buildup, can obstruct the drainage system and hinder its effectiveness.

II. 1. Obstruction due to technical reasons:

II. 1. 1. Insufficient drain slope:

Slope irregularities during drainage installation can stem from two main sources: the drainage equipment and the operator.

- **Equipment Issues:** If the drainage machine is not properly calibrated or suited for the terrain, it can cause inconsistent slopes.
- **Operator Errors:** The operator's skills and attention to detail are critical. Human errors, such as improper adjustments or mismanagement of the machine, often lead to slope irregularities. Even with advanced tools like laser guidance, these issues can persist if the system isn’t closely monitored.

When the slope is insufficient, the water flow rate drops below the minimum acceptable level, leading to the accumulation of sand or clay deposits in the drains. Such issues should not arise if the drainage parameters are correctly calculated, and the work is executed with precision.

II. 1. 2. Poor pipe quality:

Today, nearly all drainage projects are constructed using pipes made of polyethylene (PE) or polyvinyl chloride (PVC).

PE and PVC pipes are generally of high quality, but each material has its own considerations:

- **PVC Pipes:** While PVC is durable and widely used, it is sensitive to ultraviolet (UV) rays. Prolonged exposure to UV light can degrade the material, compromising its stability and strength. Additionally, PVC pipes can deform when exposed to high temperatures, typically around 80°C or higher.

- **PE Pipes:** Polyethylene is less affected by UV exposure and performs well in various environmental conditions. However, it is still important to ensure that PE pipes are installed and maintained correctly to maximize their lifespan and effectiveness.

II. 2. Obstructions due to natural reasons:

II. 2. 1. Clogging caused by Deposition of minerals:

Sedimentation or Silting is commonly observed in unstable soils, such as sandy or clayey types, particularly when drainage work is carried out in water-saturated conditions. This issue typically arises soon after the pipe installation and may continue to some extent.

Figure VI.1: Clogging due to mineral deposit

To address this, the drain should be protected with a filter or a cover material. In sandy soils, it is especially crucial to ensure that the pipe is fully protected with a filter.

Drain envelopes (or filters) can be made of mineral (granular), organic or synthetic materials as shown in Figure VI.2. Envelopes can be made of wrapped polypropylene fibres (a, f & g), polystyrene granules (b) and coconut fibres (c), non-woven nylon (d) and woven typar (e).

Figure VI.2: Drain envelopes (filters).

II. 2. 2. Clogging caused by chemical reactions:

Sedimentation effects are often caused by the presence of iron, iron sulfide, and manganese in the soil. When ferrous iron Fe^{++} in the soil comes into contact with oxygen, it oxidizes to form ferric iron Fe^{3+}, leading to the formation of deposits. While this issue may sometimes resolve itself after a few years of operation, in severe cases, it can persist.

Preventive measures can be challenging to implement, but a solution involves reducing aeration in the system by using a special fitting at the drain outlet.

III. Maintenance:

III. 1. Clearing:

Clearing is performed using a cleaning machine designed to pump water into the drain through a hose equipped with a jet. This process dissolves the deposits and expels them with the injected water.

There are two main types of evacuation systems: high-pressure and low-pressure.

- **High-pressure systems** operate at 80-120 atmospheres of pressure, effectively handling more stubborn deposits and ensuring thorough cleaning.
- **Low-pressure systems** work at about 20-30 atmospheres, suitable for less challenging cleaning tasks.

Both systems are capable of servicing drains up to 400 meters in length. Even difficult and silty deposits, resulting from sedimentation, can be effectively removed using these clearing methods.

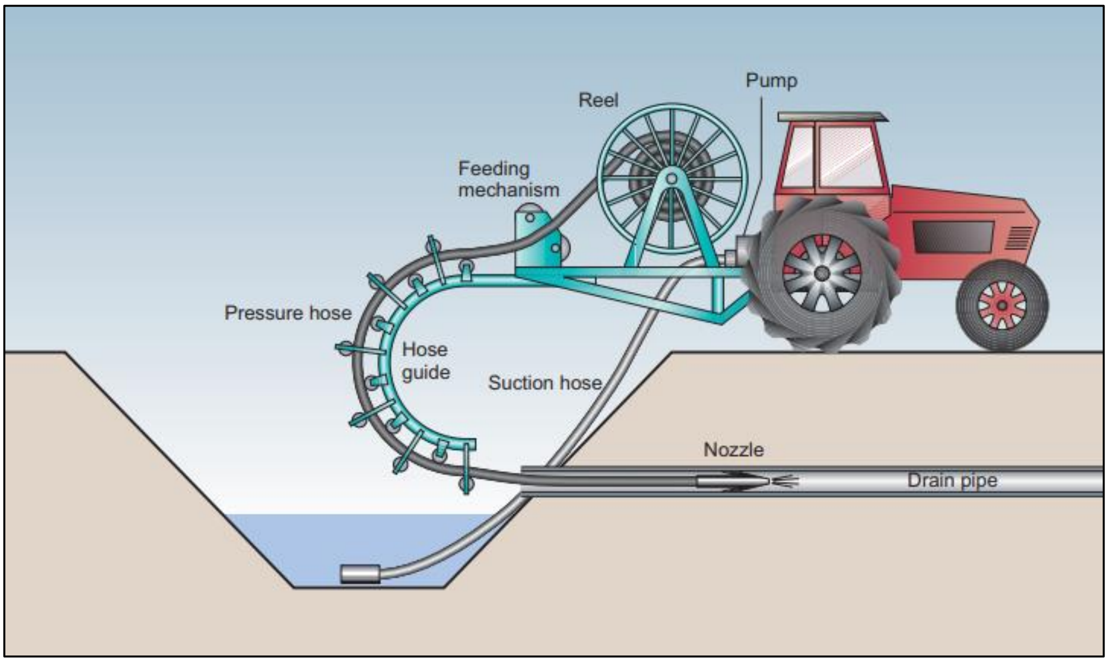

Figure VI.3: Evacuation system.

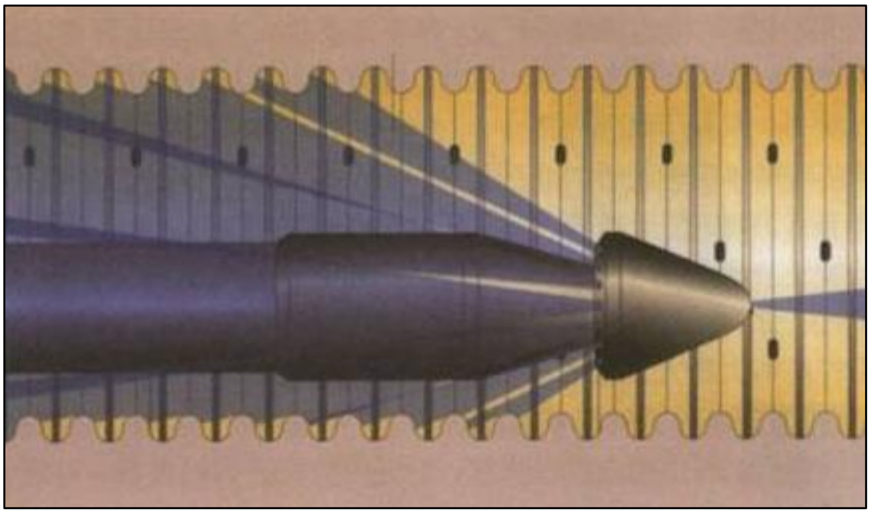

Figure VI.4: high pressure evacuation nozzle.

III. 2. Maintenance of underground networks:

Regular inspections of underground drainage networks are crucial, especially at key points such as discharge outlets. Inspection chambers, typically located at junctions or where pipe diameters change, should also be checked.

When necessary, pressure cleaning of buried drains can be performed. However, this should not be a routine practice as it can destabilize the surrounding soil.

Avoid Soil Compaction, Soil compaction makes it difficult for water to penetrate and reach drainage pipes and can also damage the pipes. To avoid soil compaction:

- Wait until the drainage system has adequately removed excess water before working the soil.
- Avoid repeatedly crossing drainage pipes with heavy machinery.
- Rotate the location of feed distributors.

Additional Management Practices:

- **Conduct Regular Soil Analyses**: Periodically analyze soil to stay informed about its structure and nutrient content.
- **Maintain Soil Porosity**: Preserve soil porosity by practicing crop rotation.
- **Adopt Effective Agronomic Practices**: Be aware of soil management techniques that promote good water infiltration to drainage pipes.
- **Monitor Soil Depth Above Pipes**: Check the depth of soil above drainage pipes regularly, as organic soils may settle and reduce soil depth.
- **Consult with Drainage Experts**: Discuss soil types with your drainage contractor to ensure proper soil preparation for planting.

These practices help ensure the optimal performance and longevity of drainage systems.

III. 3. Maintenance of the outlet:

The best times for inspecting underground drainage systems are in the spring before planting and in the autumn after heavy rainfall.

Drainage Outlet (Discharge Points)

- Remove any debris or waste that may have accumulated around the drainage outlet.
- Check for signs of erosion around the drainage pipes and ensure that water is not flowing beneath the pipe.
- Ensure that the drainage outlet is not obstructed.
- Verify that the protective grate on the drainage outlet is in place and functioning properly.

IV. Conclusion:

Regular inspections of underground drainage systems are crucial, with a particular focus on critical areas like drainage outlets. Inspection wells should also be routinely checked, as they are typically positioned at key locations in the network, such as junctions or changes in pipe diameter. While pressure cleaning of buried drains may be necessary at times, it should not be performed routinely, as it can potentially disrupt the stability of the soil around the pipes.

Chapter VII:

Site Management

I. Introduction:

After completing the various phases of the study, a comprehensive analysis is necessary to estimate the total project cost, including construction, preparation, and expenses related to the required facilities for project execution.

II. Execution of Pipeline Installation Works

II. 1. 1. Excavation of Trenches

This process involves digging trenches to install pipelines, typically using a mechanical excavator. The trench dimensions vary depending on the pipeline's diameter in each section, and it is essential to excavate the trench with the appropriate dimensions to ensure stability and proper accommodation of the pipeline.

II. 1. 2. Sand Bed Installation:

A sand bed, placed at the bottom of the trench before the pipeline installation, serves to evenly distribute the load on the pipe's support area, helping to prevent potential damage. Prior to installation, the trench should be cleared of large stones, shaped according to the longitudinal profile, and leveled to provide a stable foundation for the pipeline.

II. 1. 3. Backfilling of Trenches:

Once the pipeline is correctly positioned on the sand bed, the previously excavated soil can be used as backfill. This operation consists of filling the trench to bury the pipeline and secure it in place.

II. 1. 4. Leveling and Compaction:

After backfilling, the soil must be evenly spread and leveled, especially if mounds have formed. Mechanical compaction follows to increase soil density. Compaction is critical to prevent soil settlement over time, which could damage the pipeline or lead to subsidence. These steps ensure the long-term stability and durability of the pipeline installation.

III. Excavation Volume:

III. 1. Trench Dimensions:

III. 1. 1. Trench Bottom Width:

The width of the trench will depend on the diameter of the pipe, applying the following formula:

The trench width (B) is calculated as follows:

$$B = D + 0.6 \quad \text{VII.1}$$

Where:

- B: represents the trench width in meters.
- D: represents the pipe diameter in meters.

III. 1. 2. Trench Depth

The depth of the pipe must be selected to allow proper installation of specific connections while avoiding any conflicts with other conduits. The trench depth is calculated using the following formula:

$$Htr = e + D + h \qquad \text{VII.2}$$

- Htr: represents the trench depth in meters.
- e: corresponds to the height of the bedding in meters.
- D : denotes the pipe diameter in meters.
- h : represents the height of the backfill above the pipe in meters.

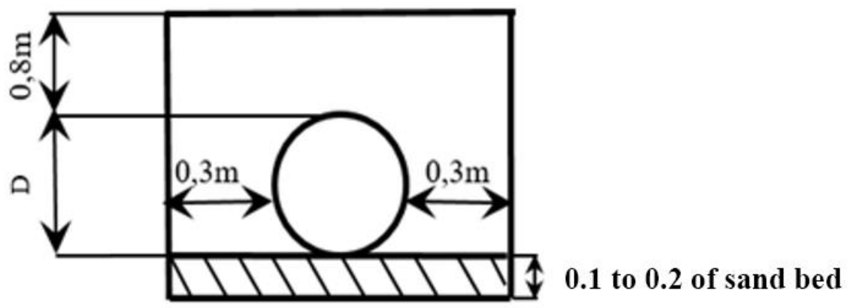

Figure VII.1: Trench Diagram

III. 1. 3. Trench Cross-Section

The dimensions of the trenches are defined as follows:

$$Str = Htr \times B \qquad \text{VII.3}$$

With the following parameters :

- Htr: represents the total depth of the trench in meters.
- B: denotes the bottom width of the trench in meters.

III. 1. 4. Trench Volume

The calculation of the trench volume is done using the following relation:

$$V\text{tr} = Str \times L \qquad \text{VII.4}$$

With :

- Vtr : represents the excavation volume in cubic meters.

- Str : is the cross-section of the trench in square meters.
- L : corresponds to the length of the trench in meters.

III. 2. Calculation of Excavation Volumes

III. 2. 1. Excavation Volume

The excavation of a trench corresponds to the materials extracted from the ground to allow the installation of the pipes, and its calculation is done as follows:

$$\text{Vexcavation} = V\text{tr} = B \times H\text{tr} \times L \qquad \text{VII.5}$$

With:

- B: trench width (m).
- Htr: trench depth (m).
- L: trench length (m).

III. 2. 2. Sand Bedding Volume

The sand bedding is a horizontal layer composed of sand that serves to establish a solid base, and its calculation is done using the following relation:

$$Vls = e \times B \times L \qquad \text{VII.6}$$

Using the following parameters :

- Vls : the volume of the sand bedding in cubic meters.
- e : the thickness of the sand bedding layer in meters.
- B : the width of the trench in meters.
- L : the length of the trench in meters.

III. 2. 3. Volume Occupied by the Pipe

It is determined using the following formula:

$$\text{Vcon} = \text{Scon} \times L = \frac{\pi \times D^2 \times L}{4} \qquad \text{VII.7}$$

- Vcon : The volume occupied by the pipe (in cubic meters).
- Scon : The cross-section of the pipe (in square meters).
- L : The length of the trench (in meters).
- D: The outer diameter of the pipe (in meters).

III. 2. 4. Backfill Volume

The backfill corresponds to the amount of soil required to fill a trench and return it to its original level. This volume is determined using the following formula:

$$\text{Vbac} = \text{Vexc} - (Vls + \text{Vcon}) \quad \text{VII.8}$$

- Vbac : the backfill volume (in cubic meters).
- Vexc : the excavation volume (in cubic meters).
- Vls : the sand bedding volume (in cubic meters).
- Vcon : the volume occupied by the pipe (in cubic meters).

The calculation of excavation, sand, and backfill volumes for the distribution network is presented in Table:

Table VII.1: Calculation of Various Volumes for the collectors

Collectors	**Diameter (mm)**	**Length** (m)	**Width B** (m)	**Height** (m)	**Excavation volume** (m3)	**Sand volume** (m3)	**Pipe volume** (m3)	**Backfill volume** (m3)
Collector C	110	198	0,71	1,01	141,99	14,06	1,88	126,05
Collector D	200	1617	0,8	1,1	1422,96	129,36	50,77	1242,83
Collector B	250	1503	0,85	1,15	1469,18	127,76	73,74	1267,69
Collector A	400	2312	1	1,3	3005,60	231,20	290,39	2484,01
				Sum	6039,73	502,37	416,78	5120,57

Table VII.2: Calculation of Various Volumes for the collectors

Drain Diameters (mm)	**Length (m)**	**Width B (m)**	**Height (m)**	**Excavation volume (m3)**	**Sand volume (m3)**	**Pipe volume (m3)**	**Backfill volume (m3)**
110	39889	0,644	0,944	24249,96	2568,85	60,62	21620,49
200	71329	0,658	0,958	44963,23	4693,45	188,36	40081,42
250	7082	0,6	0,9	3824,28	424,92	0,00	3399,36
			Sum	73037,47	7687,22	248,98	65101,27

IV. Project Cost Calculation

- The cost per cubic meter of excavation is 450 Algerian Dinars (DA).
- The rate per cubic meter of backfill is 300 Algerian Dinars (DA).
- The price per cubic meter of sand is 1200 Algerian Dinars (DA).

Table VII.3: Estimation of Excavation Works Cost for collectors

Type of Work	Unit of Measurement	Quantities (m^3)	Unit Price (DA)	Amount (DA)
Excavation	m^3	6039,73	450	2717878,5
Backfill	m^3	5120,57	300	1536171
Sand	m^3	502,37	1200	602844
			Total Price (Excl. Tax)	**4,856,893.50**
			Total Price (Incl. Tax 19%)	**5,779,703.26**

Table VII.4: Estimation of Excavation Works Cost for Drains

Type of Work	Unit of Measurement	Quantities (m^3)	Unit Price (DA)	Amount (DA)
Excavation	m^3	73037,47	450	32866861,5
Backfill	m^3	65101,27	300	19530381
Sand	m^3	7687,22	1200	9224664
			Total Price (Excl. Tax)	**61,621,906.5**
			Total Price (Incl. Tax 19%)	**73,330,068.74**

IV. 1. Drainage Network Cost

Table VII.5: Estimation of the drainage network

Description of works	Diameter (mm)	Quantity	Unit price	Prix total (DA)
Drains	44	39889 m	195 DA/m	7778355
	58	71329 m	230 DA/m	16405670
	72	7082 m	285 DA/m	2018370
Collectors	110	198 m	800 DA/m	158400
	200	1617 m	2400 DA/m	3880800
	250	1503 m	4000 DA/m	6012000
	400	2312 m	12000 DA/m	27744000
			Total	**64,343,595**
			Total TTC	**76,568,878.05**

IV. 2. Total Project Cost

This is the sum of various prices calculated earlier.

Table VII.6: Project Total Cost Estimation

Works	**Amount (DA)**
Drainage network	76,568,878.05
Excavation, Sand, Backfill for drains	73,330,068.74
Excavation, Sand, Backfill for Collectors	5,779,703.26
Total Amount (including tax)	**155,678,650.10**

The project amount is One hundred fifty-five million, six-hundred seventy-eight thousand, six hundred fifty Algerian Dinars

V. The Use of Personal Protective Equipment is Essential for ensuring better safety on a construction site

The use of personal protective equipment (PPE) is crucial to enhance safety on a construction site. These devices, such as helmets, gloves, safety shoes, protective glasses, and masks, are of utmost importance to prevent potential hazards. Here are some key points regarding these safety equipments:

- **Helmets**: They are now more comfortable, even in hot weather, which facilitates their mandatory use. It is crucial to ensure that helmets are in good condition, comply with current standards, and have not exceeded their recommended usage date. When working at heights, securing the helmet's chin strap is imperative to prevent it from falling.
- **Safety Shoes**: There is currently a wide range of safety shoes offering protection against impacts and aggressive agents such as fire or chemicals. It is recommended to choose shoes with non-slip soles and antibacterial treated interiors.
- **Gloves**: Hands are the body parts most exposed to injuries during work accidents. It is essential to choose gloves that fit the user's hand size and are suitable for the type of work and risks encountered (cuts, punctures, vibrations, allergies, chemicals). Gloves should comply with current standards and be properly maintained.
- **Protective Glasses**: Eye accidents represent 3% of work accidents and could easily be avoided by wearing appropriate protective glasses.
- **Protective Masks**: Solid particles, aerosols, liquids, vapors, and gases can be particularly harmful. Using appropriate respiratory protective equipment, such as cartridge masks, prevents the inhalation of these substances. For hot work, cartridge filter masks are recommended, while for cold work, disposable half-filter masks can be used.

It is imperative to use this personal protective equipment correctly and regularly to ensure the safety of workers on the construction site.

VI. Conclusion

This chapter focused on evaluating the costs of each component used in our study. We began by estimating the costs for the volumes of sand, excavation, and backfill. Next, we accounted for the costs of all the pipes used.

By following this method, we obtained both quantitative and financial estimates, ultimately calculating the total project cost, which amounts to 155,678,650.10 DZD.

General Conclusion:

At the end of this work, we have found that:

- The region is characterized by a semi-arid climate, requiring irrigation during the dry season and leaching to maintain an acceptable salinity level of C=2.51mmhos/cm in the soil.
- The water from the Zouia dam (2.3 hm^3) supplying our area satisfies our total water needs (1.04 hm^3).
- The most suitable drainage option for our area is subsurface drainage, considering the topography of the terrain.
- The drainage network is designed using the critical flow of excess rainfall water, in permanent regime, where the critical flow rate is 4.5 mm/day.
- The outer diameter of the drains ranges from 50 to 80 mm, as for the collectors, it ranges between 110 to 400 mm, with a total discharge of 89 l/s, 74,5 l/s through collector A and 14.5 l/s discharged directly into the river.
- The project management analysis revealed that implementing our project will require an estimated cost of 155,678,650.10 DA.

In conclusion, agricultural drainage has a significant impact on agronomic activity. It not only saves cultivable fields but also treats saline soils and revives abandoned lands.

Finally, we hope that this work has contributed to the improvement of this area, increasing its profitability, and ultimately fostering a durable and productive agriculture that positively impacts the country’s economy.

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Abbreviation List:

ONM: National Meteorology Office

ANRH: National Water Resources Agency

ONID: National Office of Irrigation and Drainage

USSL: United States Salinity Laboratory.

Appendix:

Appendix 1: Equivalent depth “d” for commonly used pipe drains (Vlotman W F, 2020).

TABLE 7.1 *Equivalent depth 'd' for commonly used pipe drains* (r_o = 4–10 cm; u ≃ 0·3 m)

D(m)	L (m)→ 5	7·5	10	15	20	25	30	35	40	45	50	75	80	85	90	100	150	200	250
0·50	0·45	0·50	0·50	0·50	0·50	0·50	0·50												
0·75	0·60	0·65	0·70	0·70	0·75	0·75	0·75	0·75	0·75	0·75	0·75								
1·00	0·65	0·75	0·80	0·85	0·90	0·90	0·95	0·95	0·95	0·95	0·95	0·95	0·95	0·95	1·00	1·00	1·00	1·00	1·00
1·25	0·70	0·80	0·90	1·00	1·05	1·10	1·10	1·15	1·15	1·15	1·15								
1·50		0·90	0·95	1·10	1.20	1·25	1·30	1·30	1·35	1·35	1·35								
1·75		0·90	1·00	1·20	1·30	1·40	1·45	1·50	1·50	1·55	1·55								
2·00			1·10	1·30	1·40	1·50	1·55	1·60	1·65	1·70	1·70	1·80	1·80	1·80	1·85	1·85	1·90	1·90	1·95
2·25			1·15	1·35	1·50	1·70	1·70	1·75	1·80	1·85	1·85								
2·50				1·40	1·55	1·70	1·80	1·85	1·95	2·00	2·00								
2·75				1·40	1·65	1·75	1·90	2·00	2·05	2·10	2·20								
3·00				1·45	1·65	1·85	1·95	2·10	2·15	2·25	2·30	2·50	2·50	2·55	2·55	2·60	2·70	2·80	2·85
3·25				1·50	1·70	1·90	2·05	2·15	2·25	2·35	2·40								
3·50				1·50	1·75	1·95	2·10	2·25	2·35	2·45	2·55								
3·75				1·50	1·80	1·95	2·15	2·30	2·45	2·55	2·65								
4·00					1·80	2·00	2·20	2·35	2·50	2·60	2·70	3·05	3·10	3·10	3·15	3·25	3·45	3·60	3·65
4·50					1·85	2·10	2·30	2·50	2·65	2·75	2·85								
5·00					1·90	2·15	2·40	2·60	2·75	2·90	3·00	3·50	3·55	3·60	3·65	3·80	4·10	4·30	4·45
5·50						2·20	2·45	2·65	2·85	3·00	3·15								
6·00							2·50	2·70	2·90	3·10	3·25	3·85	3·95	4·00	4·10	4·25	4·70	4·95	5·15
7·00							2·55	2·80	3·05	3·25	3·45	4·15	4·25	4·35	4·40	4·60	5·20	5·55	5·80
8·00							2·55	2·85	3·15	3·35	3·55	4·40	4·50	4·60	4·70	4·95	5·70	6·15	6·45
9·00								2·90	3·20	3·45	3·65	4·55	4·70	4·80	4·95	5·25	6·10	6·65	7·00
10·00									3·25	3·50	3·75	4·75	4·90	5·05	5·20	5·45	6·45	7·10	7·55
12·50												5·00	5·20	5·40	5·55	5·90	7·20	8·05	8·70
15·00												5·20	5·40	5·60	5·80	6·25	7·75	8·85	9·65
17·50												5·30	5·55	5·75	6·00	6·45	8·20	9·45	10·40
20·00													5·60	5·85	6·10	6·60	8·55	9·95	11·10
25·00													5·75	5·95	6·20	6·80	9·00	10·70	12·10
30·00																	9·25	11·30	12·90
35·00																	9·45	11·60	13·40
40·00																		11·80	13·80
45·00																		12·00	13·80
50·00																		12·10	14·30
60·00																			14·60
~	0·70	0·95	1·15	1·55	1·90	2·25	2·60	2·90	3·25	3·55	3·90	5·40	5·75	6·00	6·25	6·80	9·55	12·20	14·70

Roughly

d = constant for D > ¼L

Appendix 2: Normalized PVC pipes diameters.

***Pipes of rigid PVC UNI EN 1452 for pressure use** conforming to the sanitary rule of Ministry of Health (M.D. 174 of the 6 april 2004).*
Color: gray RAL 7011 - Useful lenght: 6 meters. Pipes are available with rubber gasket or plain ends only on request.

Diamentro esterno *Outside Diameter* mm	PN6 (SDR 33)		PN10 (SDR 21)		* PN12,5 (SDR 17)		PN16 (SDR 13,6)		* PN20 (SDR 11)		Guarnizioni *Gasket* prezzo netto *net price* € / cad.
	Spessore *Thickness* mm	€ / m.	Spessore *Thickness* mm	€ / m.	Spessore *Thickness* mm	€ / m.	Spessore *Thickness* mm	€ / m.	Spessore *Thickness* mm	€ / m.	
** 16	–	–	–	–	–	–	–	–	1,5	**0,51**	–
** 20	–	–	–	–	–	–	1,5	**0,65**	1,9	**0,80**	–
25	–	–	–	–	–	–	1,9	**1,03**	2,3	**1,22**	–
32	–	–	1,6	**0,80**	1,9	**0,94**	2,4	**1,14**	2,9	**1,34**	–
40	1,5	**0,89**	1,9	**1,09**	2,4	**1,36**	3,0	**1,63**	3,7	**2,06**	0,16
50	1,6	**1,18**	2,4	**1,71**	3,0	**2,11**	3,7	**2,51**	4,6	**3,19**	0,19
63	2,0	**1,83**	3,0	**2,65**	3,8	**3,31**	4,7	**4,00**	5,8	**5,05**	0,23
75	2,3	**2,53**	3,6	**3,80**	4,5	**4,69**	5,6	**5,67**	6,8	**7,06**	0,29
90	2,8	**3,46**	4,3	**5,03**	5,4	**6,24**	6,7	**7,50**	8,2	**9,27**	0,39
	PN6 (SDR 41)		PN10 (SDR 26)		PN12,5 (SDR 21)		PN16 (SDR 17)		* PN20 (SDR 13,6)		
110	2,7	**4,13**	4,2	**6,08**	5,3	**7,85**	6,6	**9,20**	8,1	**11,44**	0,57
125	3,1	**5,40**	4,8	**7,83**	6,0	**10,02**	7,4	**11,73**	9,2	**14,74**	0,68
140	3,5	**6,77**	5,4	**9,88**	6,7	**12,71**	8,3	**14,73**	10,3	**18,46**	0,82
160	4,0	**8,76**	6,2	**12,96**	7,7	**16,65**	9,5	**19,22**	11,8	**24,10**	1,05
180	4,4	**10,60**	6,9	**16,15**	8,6	**20,92**	10,7	**24,34**	13,3	**30,62**	1,38
200	4,9	**13,42**	7,7	**20,03**	9,6	**25,90**	11,9	**30,04**	14,7	**37,57**	1,48
225	5,5	**16,97**	8,6	**25,16**	10,8	**32,70**	13,4	**38,11**	16,6	**47,71**	2,34
250	6,2	**21,30**	9,6	**31,24**	11,9	**40,02**	14,8	**46,79**	18,4	**58,89**	2,58
280	6,9	**26,45**	10,7	**39,05**	13,4	**50,50**	16,6	**58,93**	20,6	**73,97**	3,75
315	7,7	**33,29**	12,1	**49,84**	15,0	**63,44**	18,7	**74,77**	23,2	**93,92**	4,62
355	8,7	**43,65**	13,6	**65,10**	16,9	**81,85**	21,1	**98,36**	26,1	**119,67**	6,31
400	9,8	**55,49**	15,3	**82,81**	19,1	**104,97**	23,7	**124,64**	29,4	**151,89**	7,70
450	11,0	**70,00**	17,2	**104,81**	21,5	**132,71**	26,7	**158,10**	33,1	**192,39**	–
500	12,3	**87,00**	19,1	**128,75**	23,9	**163,93**	29,7	**195,38**	36,8	**237,66**	–

* solo su richiesta / *only on request*
** tubo liscio senza bicchiere / *pipe straight without socket*

Appendix 3: Crops tolerance to salts (US Salinity laboratory Riverside).

TABLEAU 1

Tolérance des végétaux au sel et quantité d'eau de lessivage
Prévision de décroissance de la production en fonction des teneurs
d'après U.S. Salinity Laboratory Riverside

	0 %			10 %			25 %			50 %			Maximum
	EC_e	EC_w	LR	EC_e	EC_w	LR	EC_e	EC_w	LR	EC_e	EC_w	LR	EC_{dw}
Orge	8 000	5 300	12 %	12 000	8 000	18 %	16 000	10 700	24 %	18 000	12 000	27 %	44 000
betterave à sucre	6 700	4 500	11 %	10 000	6 700	16 %	13 000	8 700	21 %	16 000	10 700	26 %	42 000
coton	6 700	4 500	11 %	10 000	6 700	16 %	12 000	8 000	19 %	16 000	10 700	26 %	42 000
safran	5 300	3 500	12,5%	8 000	5 300	19 %	11 000	7 300	26 %	14 000	8 000	28,5%	28 000
blé	4 700	3 100	8 %	7 000	4 700	12 %	10 000	6 700	17 %	14 000	9 300	23 %	40 000
sorgho	4 000	2 700	7,5%	6 000	4 000	11 %	9 000	6 000	17 %	12 000	8 000	22 %	36 000
soja	3 700	2 500	10 %	5 500	3 700	14 %	7 000	4 700	18 %	9 000	6 000	23 %	26 000
riz (paddy)	3 300	2 200	9 %	5 000	3 300	14 %	6 000	4 000	16 %	8 000	5 300	22 %	24 000
maïs	3 300	2 200	12 %	5 000	3 300	18 %	6 000	4 000	22 %	7 000	4 700	26 %	18 000
lin	2 000	1 300	7 %	3 000	2 000	11 %	4 500	3 000	17 %	6 500	4 300	24 %	18 000
féverole	1 000	700	6 %	1 500	1 000	8 %	2 000	1 300	11 %	3 500	2 300	19 %	12 000
Betterave	5 300	3 500	11 %	8 000	5 300	17 %	10 000	6 700	21 %	12 000	8 000	25 %	32 000
épinard	3 700	2 500	12,5%	5 500	3 700	18,5%	7 000	4 700	23,5%	8 000	5 300	26,5%	20 000
tomate	2 700	1 800	8 %	4 000	2 700	12 %	6 500	4 300	19,5%	8 000	5 300	24 %	22 000
brocoli	2 700	1 800	7 %	4 000	2 700	10 %	6 000	4 000	15 %	8 000	5 300	20 %	26 000
chou	1 700	1 100	4 %	2 500	1 700	6,5%	4 000	2 700	10 %	7 000	4 700	18 %	26 000
pomme de terre	1 700	1 100	5,5%	2 500	1 700	8,5%	4 000	2 700	13,5%	6 000	4 000	20 %	20 000
maïs doux	1 700	1 100	5,5%	2 500	1 700	8,5%	4 000	2 700	13,5%	6 000	4 000	20 %	20 000
patate douce	1 700	1 100	5,5%	2 500	1 700	8,5%	3 500	2 300	11,5%	6 000	4 000	20 %	20 000
laitue	1 300	900	5 %	2 000	1 300	7 %	3 000	2 000	11 %	5 000	3 300	18 %	18 000
poivre	1 300	900	5 %	2 000	1 300	7 %	3 000	2 000	11 %	5 000	3 300	18 %	18 000
oignon	1 300	900	7,5%	2 000	1 300	11 %	3 500	2 300	19 %	4 000	2 700	22,5%	12 000
carotte	1 000	700	6 %	1 500	1 000	8 %	2 500	1 700	14 %	4 000	2 700	22,5%	12 000
haricot	1 000	700	7 %	1 500	1 000	10 %	2 000	1 300	13 %	3 500	2 300	23 %	10 000
cantaloup	2 300	1 500	8 %	3 500	2 300	12 %	*pas de données*			*pas de données*			-
pastèque	2 000	1 300	8 %	*pas de données*			"	"		"	"		-
Seigle batard	4 700	3 100	8 %	7 000	4 700	12 %	10 500	7 000	17,5%	14 500	9 700	24 %	40 000
seigle pérenne	5 300	3 500	10 %	8 000	5 300	15 %	10 000	6 700	19 %	13 000	8 700	24 %	36 000
lotier	4 000	2 700	10 %	6 000	4 000	14 %	8 000	5 300	19 %	10 000	6 700	24 %	28 000
luzerne	2 000	1 300	5 %	3 000	2 000	7 %	5 000	3 300	12 %	8 000	5 300	19 %	28 000
prairie	1 300	900	4 %	2 000	1 300	5 %	3 500	2 300	10 %	6 500	4 300	18 %	24 000
trèfle	1 300	900	6 %	2 000	1 300	9 %	2 500	1 700	12 %	4 000	2 700	19 %	14 000

	0 %			10 %			50 % (1)			
	EC_e	EC_w	LR	EC_e	EC_w	LR	EC_e	EC_w	LR	EC_{dw}
Palmier	5 300	3 500	7 %	8 000	5 300	11 %	16 000	10 000	21 %	48 000
figuier	2 700	1 800		4 000	2 700					
olivier	à	à	6 à10%	à	à	10 à 14%	9 000	6 000	21 %	28 000
grenadier	4 000	2 700		6 000	4 000					
raisin	2 700	1 800	7,5%	4 000	2 700	11 %	8 000	5 300	22 %	24 000
pamplemousse	1 700	1 100	7 %	2 500	1 700	11 %	5 000	3 300	33 %	16 000
oranger	"	"	"	"	"	"	"	"	"	"
citronnier	"	"	"	"	"	"	"	"	"	"
pommier	"	"	"	"	"	"	"	"	"	"
poirier	"	"	"	"	"	"	"	"	"	"
amandier	"	"	"	"	"	"	"	"	"	"
abricotier	"	"	"	"	"	"	"	"	"	"
pêcher	"	"	"	"	"	"	"	"	"	"
prunier (pruneaux)	"	"	"	"	"	"	"	"	"	"
noyer	"	"	"	"	"	"	"	"	"	"
murier	"	"	"	"	"	"	"	"	"	"
framboisier	1 000 à 1700	700 à 1 100	5 à 8%	1500 à 2500	1 000 à 1700	7 - 12 %	4 000	2 700	19 %	14 000
avocatier	1 300	900	7,5%	2 000	1 300	11 %	4 000	2 700	22,5%	12 000
fraisier	1 000	700	7 %	1 500	1 000	10 %	3 000	2 000	20 %	10 000

Appendix 4: Geological Description of soil layers in the Zouia region.

Prof (m)	Coupe	Etage	Description géologique
0 - 2			*Argile jaune et rouge*
2 - 6			*Calcaires et grés fins*
6 - 13			*Argiles jaunes, alternance d'argile jaune et beige avec grés très fins, argileux*
13 - 26			*Argile beige à jaune compacté*
26 - 27			*Grés jaunes, passage fin dolomitique*
27 - 45			*Marnes dures bleues foncées, parfois sont calcaire – dolomitique*
45 - 46			*Apparition de grés fins durs, ciment calcaire*
46 - 70			*Marnes dures bleu foncée*
70 - 84			*Grés gris clair très fins en plaquette micacés avec passage de marnes*
84 -91			*Calcaire dolomitiques et grés*
91 - 113			*Marnes dures parfois passage de lits de calcaire marneux, marnes grises à foncées ou bleues*
113 - 119			*Calcaires marneux bleus*
119 - 148			*Marne calcaire avec parfois passages de marnes bleu avec calcaire*
148 - 150			*Grés gris clair micacés peu marneux*
150 - 156			*Grés gris à ciment de calcaire passage de calcaire dolomitique*
156 - 190			*Marnes, grés, dolomies gris foncée noires dures*
190 -207			*Calcaire marneux gris foncée à bleu devient de plus en plus marneux veines de calcite blanche et rose*
207 - 209			*Marnes dures peu calcaires*
209 - 227			*Marnes bleues cassure chocolat et noir passage de calcaire dolomitiques*
227 - 230			*Marne bleues avec grés fins gris marneuse*
230 - 233			*Calcaires gris foncées peu marneux*
233 - 250			*Calcaires bleues avec dolomies friables blanc rose beiges calcites blanche*

Appendix 5: moisture and field capacity per soil texture (FAO Irrigation and Drainage Bulletin Reference).

Texture	Moisture at Field Capacity (HCC)	Moisture at Wilting Point (HPF)	Available Water Content (HCC - HPF)
Sandy	9% (6 to 12)	4% (2 to 6)	85% (70 to 100)
Silty Loam	14% (10 to 18)	8% (5 to 11)	6% (4 to 6)
Loam	22% (18 to 26)	10% (8 to 12)	12% (10 to 14)
Clay Loam	27% (25 to 31)	13% (11 to 15)	14% (12 to 16)
Silty clay	31% (27 to 35)	15% (13 to 17)	16% (14 to 18)
Clay	35% (31 to 39)	17% (15 to 19)	18% (16 to 20)