KASDI MERBAH UNIVERSITY

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Domain : Hydraulic

Field : Water drilling

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THEME :

Vulnerability of the aquifer of the terminal complex and wellhead protection area of water catchment in the valley of El Oued

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Dedications

With the help of God, I was able to carry out the work I dedicated:

To my dear parents in recognition of the various sacrifices, their precious advice, their moral support and their encouragement.

My sisters and all those who contributed to my success.

THANKS

I thank God Almighty for giving me the strength and courage to overcome this work.

I thank my parents from my heart for supporting me to success in my life.

I thank Miss TIDJANI.K for her efforts and her presence in carrying out this work.

I extend my sincere thanks to all those who have contributed to this humble work from everywhere.

**** Tidjani ****

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General Introduction

Since independence, population growth and agricultural and industrial development in this region have led to a considerable increase in the demand for water, leading to increased drilling to mobilize the water resources of deep aquifers. The majority of the extracted volume is discharged to the surface that infiltrates the aquifers, because of the absence of drainage systems, for the collection and disposal of wastewater.

The valley of Oued Souf (Southeast of Algeria) has a very important underground water, consisting of three underground aquifers: the water table, the aquifer of the Terminal Complex (TC) and the aquifer of the Continental Intercalary (CI). Groundwater has confronted the problem of rising water, which has adverse environmental and health consequences, this has led to the use of deep-water aquifers (TC and CI) to satisfy the needs of drinking water and irrigation.

In addition, the wastewater discharged directly into the aquifers not only contributes to the rise of the latter, but also constitutes a serious factor of chemical and bacteriological pollution.

This work contains six chapters: we tried to detail the characteristics of the city: the geographical situation to define the general framework of our region of study, hydroclimatology study, hydrological and hydrodynamic study. In the last chapter, we will try to estimate the vulnerability and calculate the isochrones of the fourteen wells in the study area.

Chapter I : Geographical situation

I.1 Geographical situation of El Oued:

The region of Oued Souf is located in the southeast of Algeria, it is located northeast of the northern Sahara, it is administratively limited by the following cities:

- Biskra, Khenchela and Tebessa at the North.
- Djelfa at the North West.
- Ouargla at the South and Southwest.
- Algeria-Tunisia boundary at the East.

Geographically it has limited by the following coordinates:

Table 01: Geographical coordinates of the municipality of El Oued:

Longitudes	**X_1 = 5° 30’**	**X_2 = 07°00' EAST**
Latitudes	**Y_1 = 35° 30’**	**Y_2 = 37°00' NORTH**

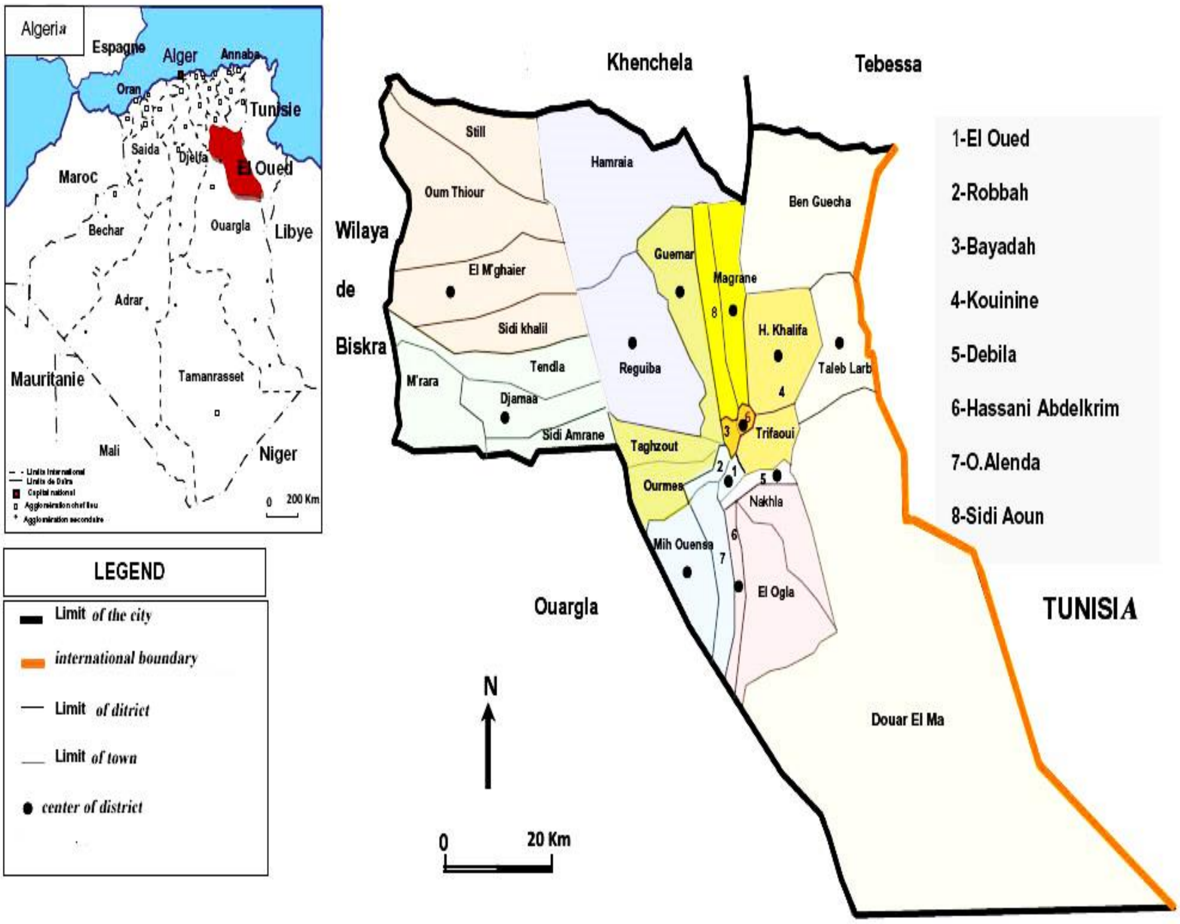


Figure 01: Geographical situation of the El Oued region (NAWR, 2011).

I.2 Overview of the city of El Oued:

Souf is a Berber word that has the same meaning in Arabic as the word Oued.

The expression "Oued Souf" therefore has the distinction of repeating the same term twice, but in two distinct dialects. These two significant expressions river in French...

The city has divided into three distinct zones, which are as follows:

The Valley of Souf.

The Valley Oued Rhig .

The border area (Taleb Larbi).

The city of El Oued occupies an area of 44585 km^2, divided into 30 communes with a population of 990,000 inhabitants and a density of 12 inhabitants per square kilometer, this population is distributed through 30 districts grouped in 12 boycotts.

I.3 Distribution demographic and administrative:

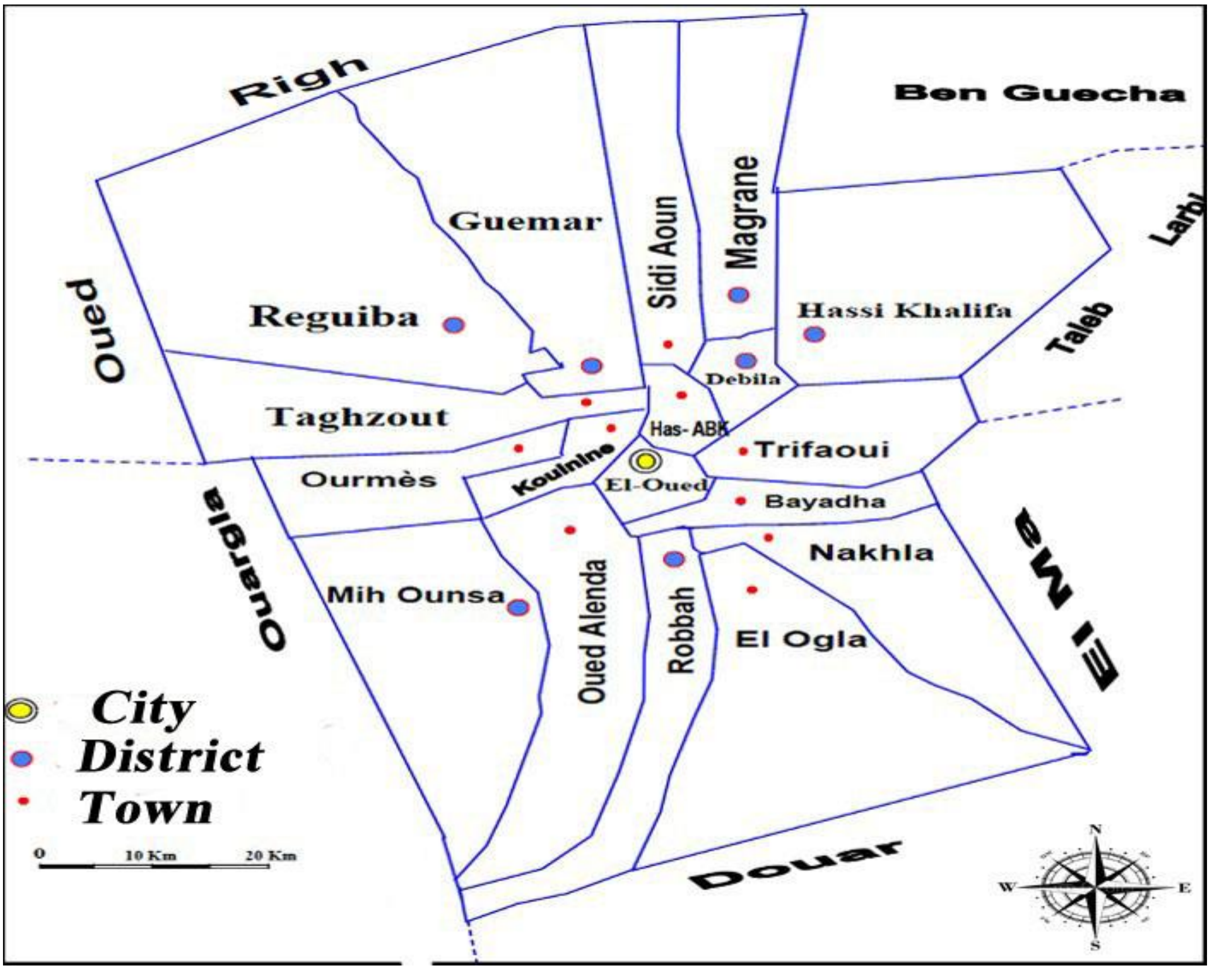
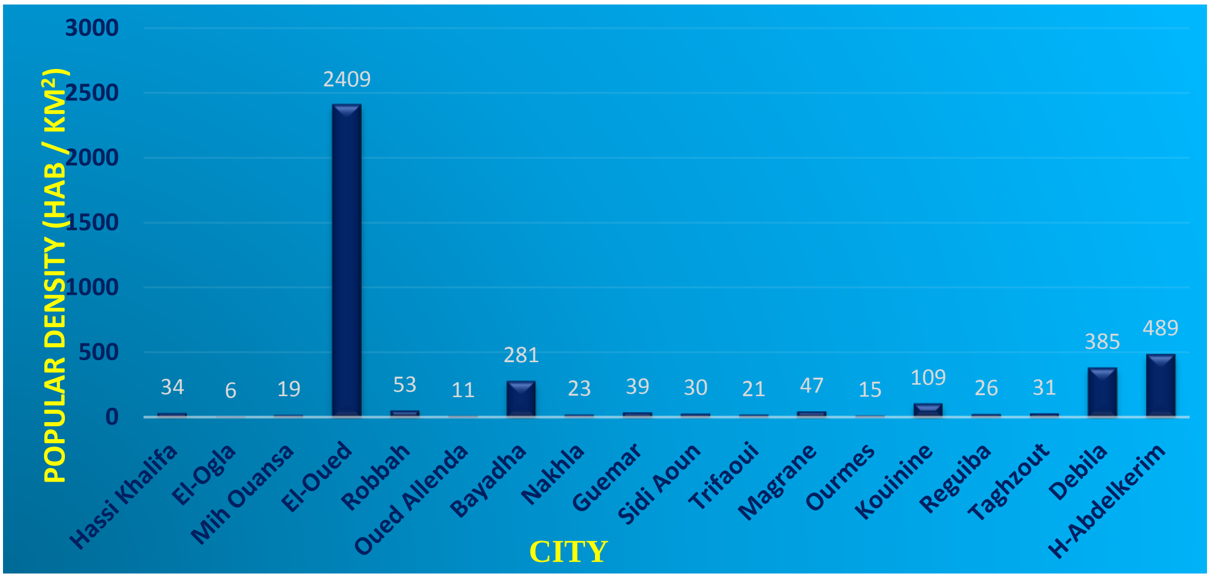


Figure 02: Administrative distribution of the dictricts of Oued Souf (El Oued DWR, 2013)

Figure 03: Histogram, The popular density of some districts of El Oued:



Source: (El Oued DWR, 2009)

• According to the histogram (03):

The most populated municipality is El-Oued with a density of about (2409 inhabitants / km^2) and the district of Hassani Abdelkrim is classified after El-oued with a density of (489 inhabitants / km^2) and the district of El-Ogla has low popular density equal to (6 inhabitants / km^2).

I.4 Economic situation:

The city of El Oued contains an agricultural area of 44586.8 km^2, and it is has a huge aquatic wealth, with easy access. It is characterized by a large and varied agricultural activity, relatively concentrated on the production of dates. Currently it is about 3788500 palm trees, and it is produced around 2474000 tons / year of dates (Ministry of Agriculture and Rural Development, 2015) and focuses on growing tobacco, peanuts and vegetable potatoes, the agricultural activities are often practiced in the hollow of the dunes (**Ghout**) and in circular agricultural zones called system of irrigation (**pivots)**.

Livestock is one of the most important incomes of the city (Sheep, goat and camel breeding).

Table 02: Livestock distribution in the study area (DAS, 2010):

Camels	Cattle	Ovine	Goat
27300 heads	4700 heads	500 000 heads	153 000 heads

In the industrial sector, the city of El Oued has characterized by the following activities: textiles, cosmetics, agro-food industry, production of table salt from chotts, sabkhat, and the manufacture of materials constructions and so on.

One of the most important economic aspects of the city is trade, inside and outside the city, also exporting and importing of various products and goods, and that is making the city an important center of commercial in the Southeast of Algeria.

I.5 Topography of El Oued:

The region of Oued Souf, also known as the Lower Sahara region, has characterized by a low altitude in the Southeast of the city, the altitude decreases from South to North and from West to East.

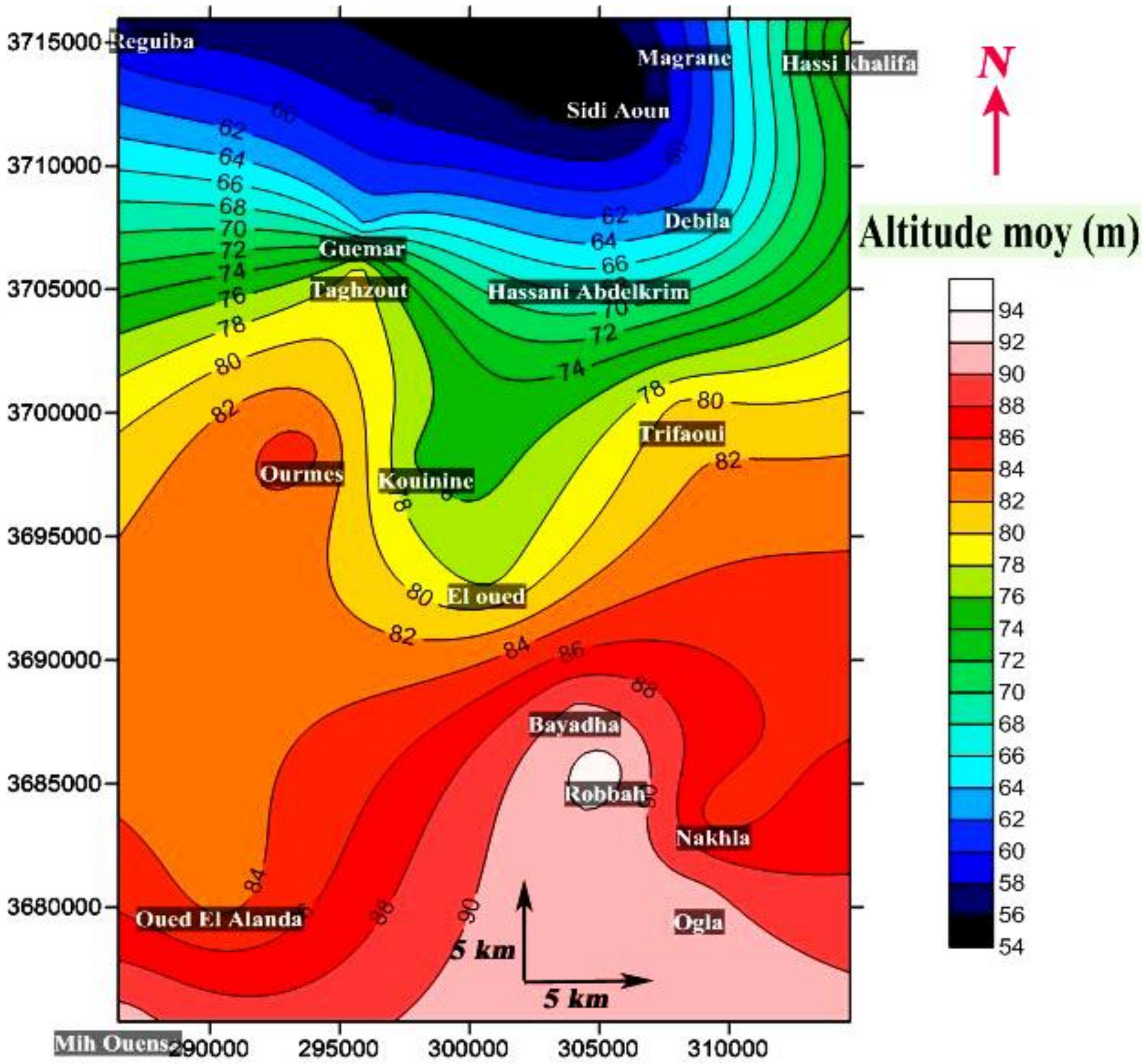


Figure 04: **Topographic map of the Valley of Souf (El Oued DWR, 2016).**

I.6 Conclusion:

The city of El Oued is located northeast of the northern Sahara, it occupies an area of 44 585 km^2, with a population of 990,000 inhabitants. It has divided at three areas: The Valley of Souf, Oued Rhig and border (Taleb Larbi).

It contains an important area of agriculture and an enormous aquatic richness and has characterized by an economic activity based on the trade and the culture of palms and the potato.

The hills of El Oued has characterized by the existence of three main forms: a sandy region, a rocky hill and a depression zone.

From a topography, the altitude decreases from South to North and from West to East to reach negative values in the chotts.

Chapter II : Geological Study

II.1 Introduction

Geology is a very useful way of investigation in hydrogeology, because it allows the determination of horizons probable to be aquifers.

The geology of Algerian desert has characterized by four major groups:

1- The shield of the Hoggar and the dorsal. 2- The desert platform domain.

3- The Paleozoic cover of the Rguiba basement. 4- The recent formations (Erg Hamada).

The study area is exactly in the northern part of the desert platform characterized by detrital formations particularly sandy. It appears in the form of dunes and anti-dunes, because the subsoil of the region being sandy and ensuring the infiltration of water and the underground circulation of water, it is mainly represented by sandy sandstone layers of Continental Intercalaire, and sandy accumulations fluvio-lacustrine of Tertiary continental, and the Mio-Pliocene formations are covered by a considerable thickness of Quaternary deposits presented in the form of dunes leading to the Appearance of an enormous erg which itself is part of the extension of the great Oriental Erg.

II.2 Geological setting of El Oued:

The geological map shows that only quaternary-age sites are visible at the outcrop, they have covered by considerable thicknesses of quaternary deposits.

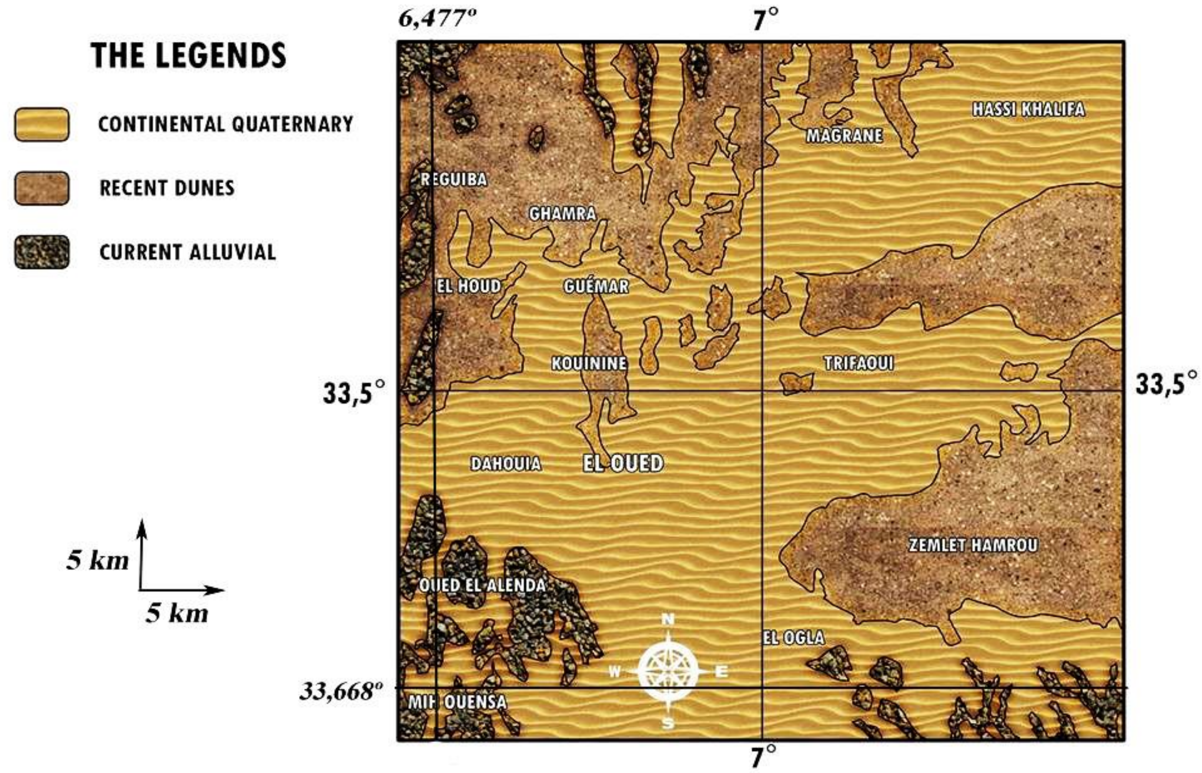


Figure (01): The geological map of El Oued *(CORNET, 1964) SCALE: 1/200.*

Drilling cut /Of El-Oued F3 The unit of depth is in **meter**	Geological description GPS coordinates of the site is : X=33.20.193 /Y=6.51.323 / Z= 150	Floors
	Alternation of sometimes sandy clay and heterogeneous sand with intercalation of gypsum	**Mio-pliocene**
	Alternation of cracked limestone and massive limestone	**Eocene**
	Alternation of gray-green marl and gray limestone, compact and hard. **Anhydrous beige dolomite alternation white and clay limestone**	**Senonian Carbonate**
	White anhydrite, massive hard with passage of dolomite light gray and intercalation of limestone	**Senonian lagunaire**
	Microcrystalline beige dolomite compact, hard, with little dolomitic limestone	**Turonian**
	Massive anhydrite and clayey limestone with marl passages	**Cenomanian**
	Anhydrite with passage of limestone, dolomite and marl	
	Anhydrite with passage of limestone, marl and dolomite with clay intercalation	
	Light gray clay limestone with dolomite passage compact, sometimes microcrystalline	**Vraconian**
	Gray Marne with gray-green clay passage, intercalation of flint, low passage limestone sandstone	**Albian**
	Dolomite, limestone, marm	**Aptian**
	Red brown clay with sandstone intercalations	**Barremien**
	Sandstone, dolomite, limestone and sand, interlay of flint	

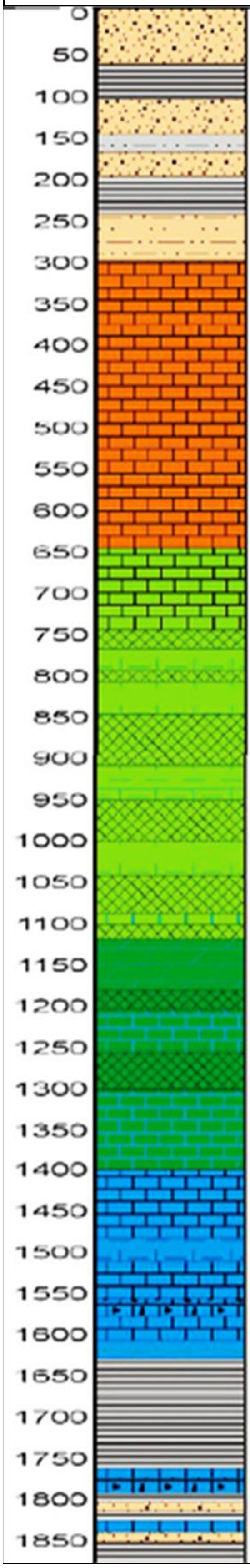


Figure (02): **F3Albian drilling log, cited 19 March El Oued** ***(cut according to DWR, 2011)***

The succession of lands and their lithologic description has made by using the log of water drilling (Figure 02).

II.3 Stratigraphic framework:

According to the stratigraphic logs and the drill cuts established from the boreholes, the Floor depths vary from region to another. On the basis of the drilling logs of the Albian made by ***DWR (2011)***, on the region of Oued Souf, we can mention the main layers found in this region, going from the oldest to the most recent:

II.3.1 Formation of the Secondary age:

II.3.1.1 The Barremian:

This stage has captured by all the inter-continental drill holes made in this region.

Presents a lithology of alternation of sandstone with passages of clays and sometimes intercalations of dolomitic limestone. We also encounter sands with presence of flint, the average thickness of this floor is from 200 to 230 meters.

II.3.1.2 The Aptian:

Like the Barremian, the latter consists mainly of dolomitic formations, marly and marl-limestone. According to the geological sections of the boreholes made in the region, the Aptian is the only floor whose thickness does not exceed 30 meters.

II.3.1.3 The Albian:

This floor consists of alternating marls, sandstone and limestone with flint and clay passages.

The roof of the helm constitutes the lower limit, while its limit superior has characterized by the appearance of facies carbonated clay. According to the cuts of boreholes Albian, the thickness of this floor varies from 100 to 150 meters, in others places it can reach 200 meters.

II.3.1.4 The Vraconien:

In fact, it is a transition zone between the sandy Albian and the Cenomanian carbonated clay.

This floor consists mainly of an irregular alternation of Dolomitic clay levels, we also show sandy clays and rare past cement sandstone limestone.

In the study area, the thickness of this stage varies between 250 and 300 meters. Because of the importance of its clay levels.

II.3.1.5 The Cenomanian:

All the drilling carried out in this region has shown that this layer has constituted by an alternation of dolomites, dolomitic limestones, dolomitic marls, clays and of anhydrite. This floor plays the role of an impermeable screen.

As for the limits of this floor, we can say that the lower limit has characterized by the appearance of evaporites and dolomites, which clearly distinguishes it. The upper limit characterized by the appearance of evaporites and limestones corresponding to the lower limit Turonian.

II.3.1.6 The Turonian:

This layer represents the base of the terminal complex. It is generally has constituted by dolomitic limestones and compact micro-crystalline dolomites withintercalations of Turonian limestones and sometimes marl. Drilling in the region clearly shows that its thickness varies from one place to another. It sometimes exceeds 650 meters.

II.3.1.7 The Senonian:

Most geological studies carried out across the Algerian Sahara show that the Senonian is made up of two very different sets from the facies point of view: the corresponding at the Senonian lagoon located at the base and the other Senonian carbonate at the top.

II.3.1.8 Senonian lagoon:

The limit of this sub-floor is well distinguished. The Lagoon Senonian is characterized by a evaporitic facies with clays where these are easily differentiated from those of Turonian.

It is also composed of anhydrites, dolomitic limestones of clay and especially the benches solid salt whose thickness is around 150 meters. The upper limit of this training coincides with the roof of the last anhydrid intercalation.

II.3.1.9 The carbonate Senonian:

This second sub-floor consists of dolomites, dolomitic limestones with intercellations marno clay and largely by fissured limestones. Its thickness sometimes exceeds 300 meters.

It should mentioned also the existence of lithological continuity between the Senonian carbonate and the Eocene, which have similar limestones with presence of nummulites.

II.3.2 Training of the Tertiary era:

II.3.2.1 The Eocene:

It is formed by sands and clays, sometimes we encounter gypsum and gravel. In this region, the Eocene is carbonated at its base; its upper part is defined by clays lagoon type. The thickness of this layer varies between 150 and 200 meters.

II.3.2.2 The Miopliocene:

It rests in discordance indifferently on the Primary on the one hand and on the lower Cretaceous. The Turonian, the Cenomanian and the Eocene are belongs to the whole called commonly Terminal Complex (TC).

Most survey cuts capturing this horizon , show that the Miopliocene is constituted by a stack of levels alternatively sandy, sandy clay with gypse intercalations and sandstone past.

Throughout the eastern Sahara, Scientists separate this horizon into 04 levels:

- **Clay level:**

It is thin and exists only in the central area of the Eastern Sahara. With the Eocene lagoon, the clays of the Miopliocene base constitute a poorly permeable barrier between the Senono-Eocene carbonate and the sandy Pontian aquifers.

- **Sandstone level:**

It is the most interesting on the hydrogeological, its thickness remains almost regular on the whole extent of the Eastern Sahara. At its base, gravel is sometimes found while the top is gradually loaded with clays. This is where the main aquifer horizon of the Terminal Complex.

- **Clay level:**

It is not very interesting; this level contains sandy lenses that can form the fourth (sandy) level of the Miopliocene.

- **Sandy level:**

This level constitutes the second aquifer horizon of the terminal complex, from the point of view hydrogeological, these sandy levels are of great interest because they correspond to as well as to the tablecloth of the sands of the Terminal Complex.

II.3.3 Quaternary Formations:

They are in the form of sand dunes whose deposit is still likely to continue today. Quaternary lands represent the superficial cover which is located mainly at the level of the depressions and cover the greatest extension at the level of the lower desert. They are formed of alluvial and eolian material from which one finds the formation of the sandy and clay alluvial deposits.

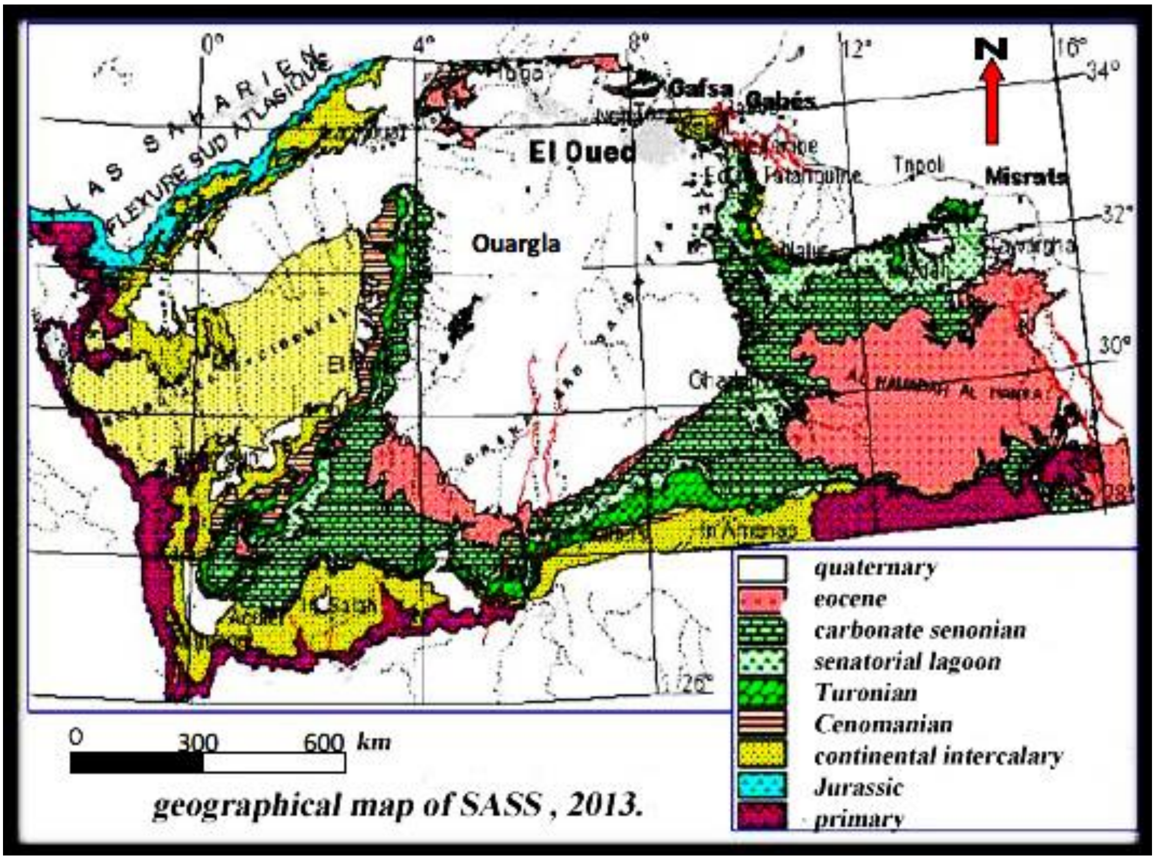


Figure (03): **Regional Geological Map (SASS, 2003).**

II.4 Interpretation of the cutting:

The purpose of the cutting establishment is to determine a lithological correlation of the subsoil, as well as to identify the geographical extension, the approximate thickness of the aquifer and the useful thickness of the layers.

- **The section n ° 1 :**

Cut N ° 1 directed NE-SW, going from Hassi khalifa towards Mihouensa.

The Miopliocene formations has characterized by a considerable thickness (more than 200m).

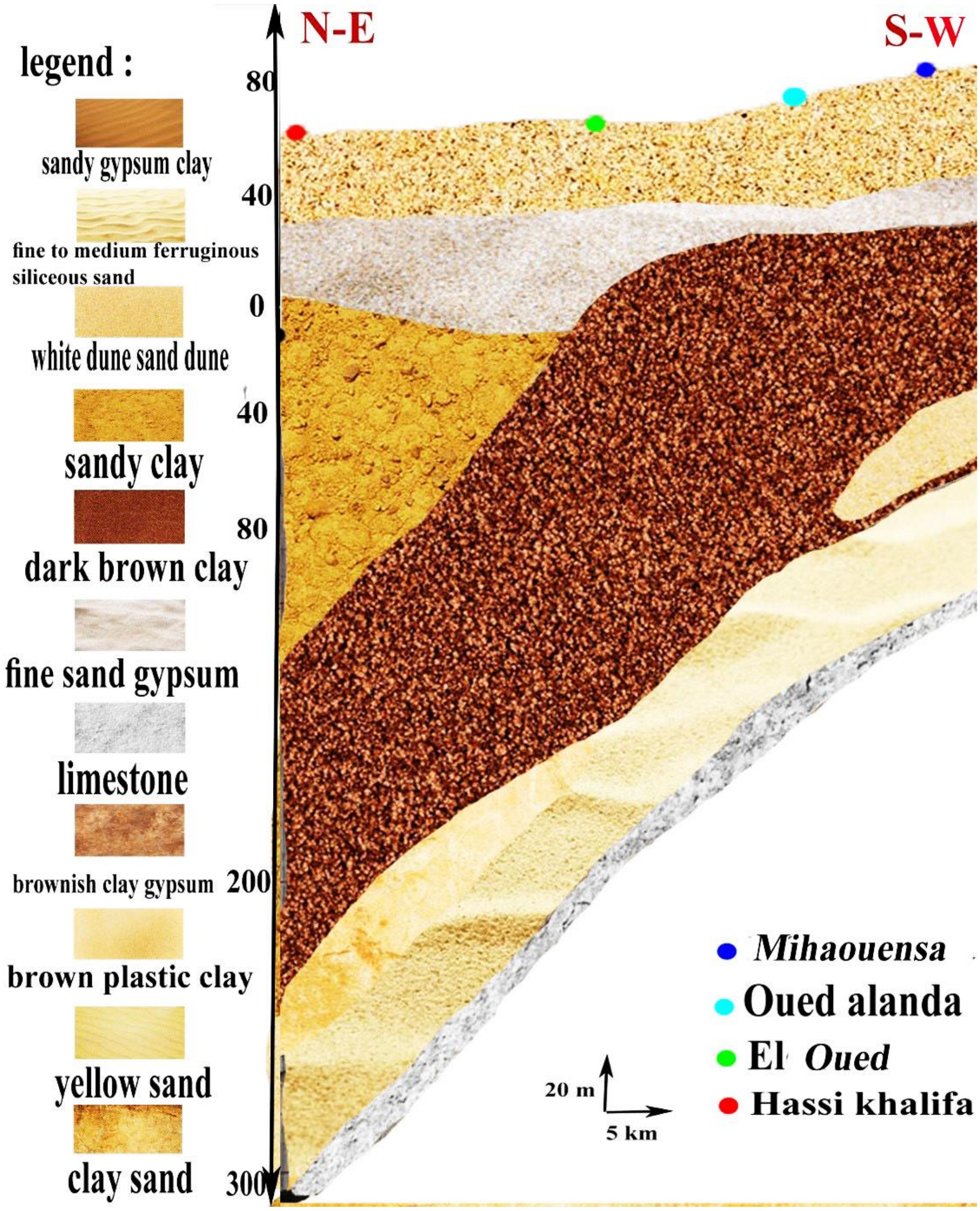


Figure (04): Geological section N °1, Extracted from the lithological logs of the boreholes,

(SAADINE and FOREMHYD company, 2019)

- **The section n ° 2:**

The N ° 2 section is oriented NW-SE, going from Rguiba to Rabbah. The Miopliocene formations are characterized by a considerable thickness. We note that the thickness of the Quaternary formations is more important in the Southeast than in the Northwest.

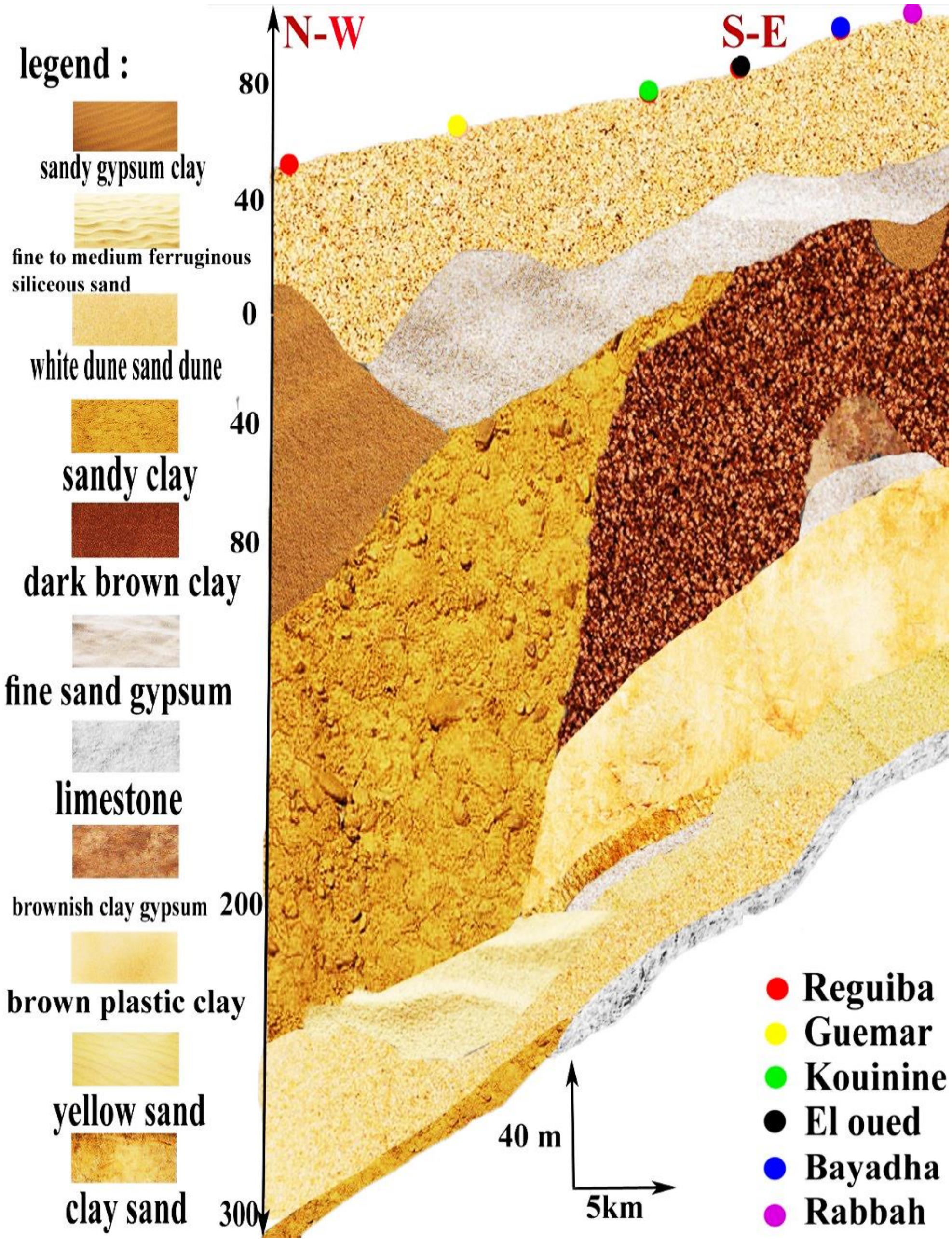


Figure (05): Geological section N °2, Extracted from the lithological logs of the boreholes,

(SAADINE and OUED RIGH company, 2019)

II.5 Geomorphology:

According to (Khachana, 2014):

The subsoil presents striking contrasts. In the South, 6 kilometers from El-Oued to El-Ogla 24 km further on, there is a total absence of "Tefza" (Calcareous stone), and while on another axis from El-Oued to Ghamra (by Tiksebt, Kouinine and Guemar) the "Tefza" occupies all the ground there.

Thus two bands of sedimentary terrains, of different formations, containing dissimilar rocks on which depends the quality of the aquifer, extend of share and others on the main axes of Souf.

A cut in the ground, allows us to distinguish:

- Tercha: Has fine crystals that give it a sandstone appearance; meets in plates continuous or in extremely hard benches, it is composed of iron crystals.
- Louss: The Louss is made of iron gypsum crystals of nested blades, it meets under forms of continuous, very hard layers of mixed sand networks, isolated columns that seem to be built around ancient gypsum roots.
- Salsala or Smida: Found in continuous slabs or extremely hard benches, it is composed of crystals iron like the Louss, but it's thinner and tighter.
- Tefza: It is a rather hard white sandstone, and constitutes the stone to be heated which will give the plaster. (Tercha, Louss, Salsala, Smida and Tefza are the local names, used for different geological layers).

II.6 hills:

The hills of El-Oued valley is characterized by the existence of three main forms:

A sandy region: which presents itself in two aspects; the Erg and the Sahara.

A form of rocky plateaus: which extends to the South with an alternation of dunes and rocky ridges.

An area of depression: characterized by the presence of a multitude of chotts which plunge to the East. It should be noted that the altitude decreases from south to north and from West to East to become negative at the level of chotts, *(Khachana, 2014).*

II.7 Tectonic:

According to Khachana, (2014):

The study area is part of the sedimentary basin of the northern Sahara of which the extension covers an area of 780 000 km^2. This basin constitutes a major topographic depression, which is subtended by a structural basin in the form of an asymmetrical syncline. The sedimentary series is marked, in the center of the hole, by important sub-vertical tectonic accidents.

The sedimentary curves seem to thicken from the north of El Oued to the center of this depression, which shows that deepening follows sedimentation closely. So if we wish to trace the paleogeographic event of the Souf, it should be noted that during of the immense depression at the beginning of the Quaternary and under the effect of the sedimentation, the center of this depression, moves towards the North while giving birth to new depressions corresponding currently to the zone of the chotts, where their establishment was made only at the end of the Quaternary.

These characteristics favored the formation in the Souf and throughout the lower Sahara of several aquifers with variable hydrodynamic behavior according to their facies.

The Quaternary Souf aquifer has an average thickness of 40 meters. Its substratum is structured in many depressions, domes and furrows. It is outcropping in the northwest of the Foulia region and is less than 10 meters deep at the northeastern ends of the study area. The lagoon sedimentary series covering the cretaceous platform forms a vast syncline whose bottom has a very large radius of curvature.

II.8 Conclusion:

The geology of El-Oued is masked by a thick layer of quaternary soils. Their description was resulted by the interpretation of the stratigraphic logs of the water wells.

It is represented by lands ranging from Cretaceous to Quaternary, we find that the region has a specific geological peculiarity, as well as tectonic and paleogeographic conditions have allowed the establishment of a sedimentary series with a varied lithology in time, regular and homogeneous in space.

The lithology of the formations is detritic and evaporitic for the Quaternary, detrital, evaporitic and carbonate for the Tertiary and Lower Cretaceous.

The dipping of the layers shows a lagoon sedimentation marked by the presence evaporates.

Chapter III : Hydroclimatology Study

III.1. Introduction:

The knowledge of the hydro-climatological characteristics is necessary for the hydrogeological study. It is essential to evaluate the supply of underground (water layer) by infiltration, and for the establishment of a water balance.

In this chapter, we will take a series of climatological data recorded over a period of 10 years (2005-2014); Provided by the National Office of Meteorology (NOM) in Guemar north of the city of Oued Souf.

III.2. Hydroclimatological parameters study:

Table 01: Geographic coordinates of the weather station in El Oued region:

Station	Code A.N.R.H	Altitude (m)	Longitude	Latitude
Guemar	13 04 09	64	06°47'E	33°30'N

III.2.1 Temperature:

The temperature sometimes reaches 46 ° C in summer, while it can reach between 5 ° and 21 ° C in winter. In the oases reigns a wet climate created by the density of the palm grove in the Ghout.

a) Mean monthly interannual temperatures:

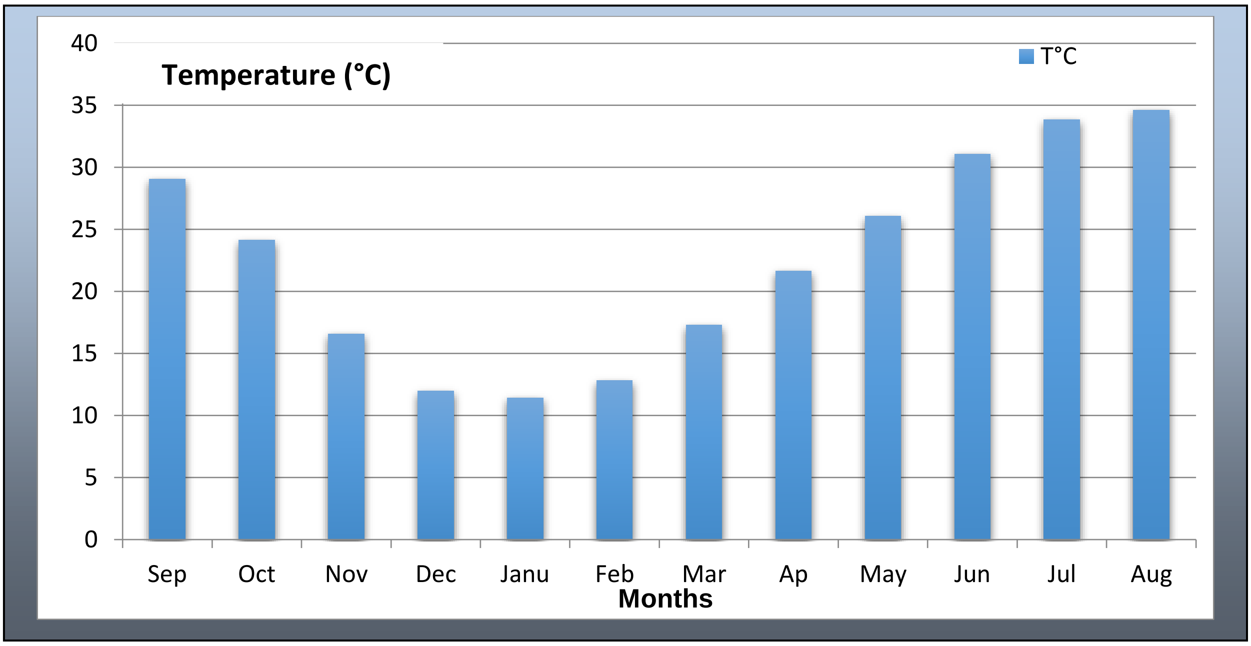


Figure 01: Histogram of Monthly Mean Temperatures (2005-2014).

According to the histogram (figure 01), we have the following results:

- The maximum of the monthly Mean Temperatures is recorded in August (34.62 ° C).

- The minimum is observed in January (11.42 ° C).

Two climatic periods are distinguished:

- A cold period from November to April with a minimum during the month of January 11.42 ° C
- A hot period from May to September with a maximum temperature recorded during the month of August 34.62 ° C.
- The annual average is of the order of 22.54 ° C

III.2.2 Precipitation:

a) Monthly average rainfall:

Table 02: Monthly average rainfall in the Oued Souf region (2005-2014):

months	Sep	Oct	Nov	Dec	Janu	Feb	Mar	Ap	May	Jun	July	Aug	∑p Annually
P (mm)	7,49	7,36	6,93	7,73	20,88	1,32	7,21	11,58	1,65	0,99	0,16	2,65	75,95

(NOM. El Oued Guemar, 2015)

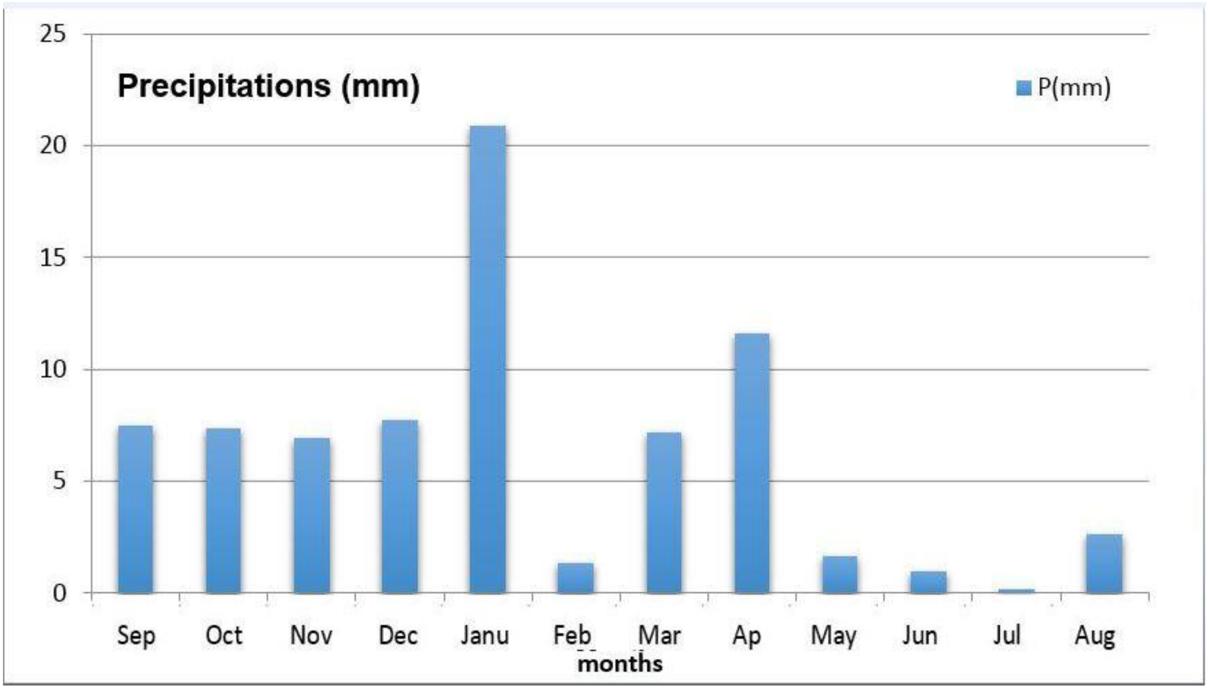


Figure 02: Histogram of Monthly Mean Precipitation (2005-2014).

The table (02) shows a variability of the precipitation over time we have:

- The maximum of the monthly interannual averages is recorded during the month of January with a value of 20.88 mm
- The minimum is recorded during the month of July with a value of 0.16 mm.
- The annual precipitation is the order of 75.38 mm.

b) Average annual rainfall:

Table 03: Distribution of annual average rainfall (2000-2016):

year	P (mm)	year	P (mm)
2000/2001	47.12	**2008/2009**	102.78
2001/2002	48.91	**2009/2010**	197
2002/2003	74.44	**2010/2011**	40.51
2003/2004	97,9	**2011/2012**	27.2
2004/2005	142.7	**2012/2013**	21.1
2005/2006	57.94	**2013/2014**	23.5
2006/2007	68.72	**2014/2015**	28.4
2007/2008	44.46	**2015/2016**	43.85
		Annual average	**75.38 mm**

(NOM. El Oued Guemar, 2016)

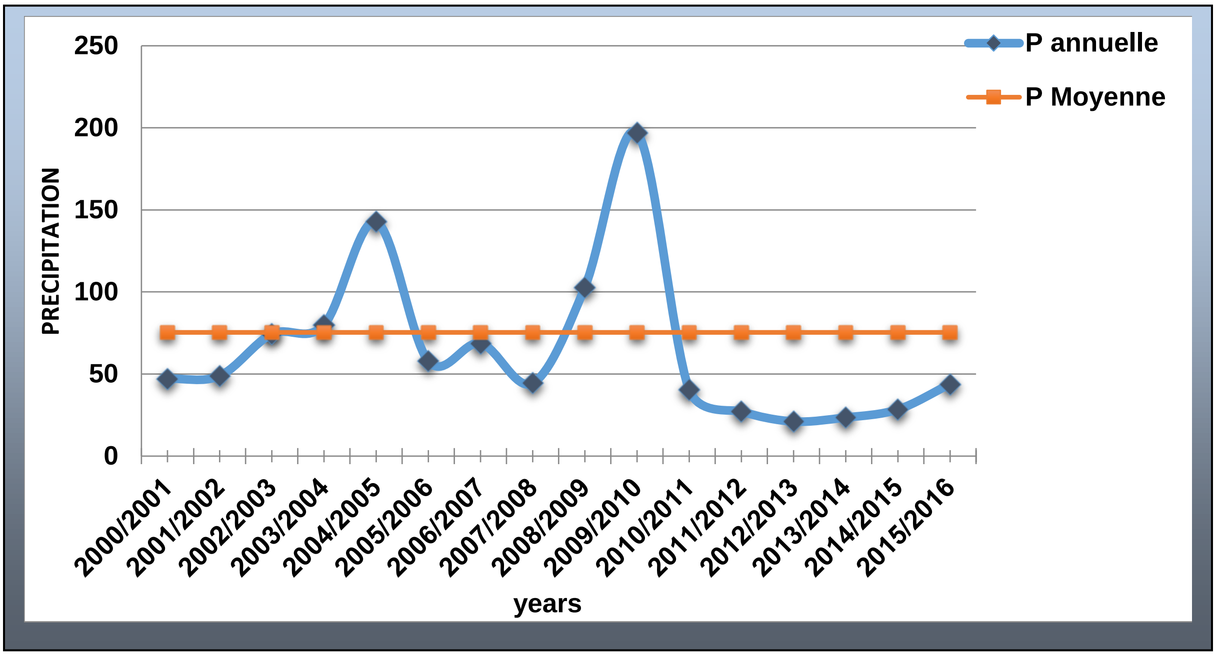


Figure 03: Distribution of annual rainfall averages (2000-2016).

c) Pluviothermal diagram:

Based on precipitation data and monthly temperatures over the same observation period, the rain curve can be established to determine the dry and wet periods.

A dry month is when the average total precipitation (mm) is less than or equal to twice the average temperature (° C) of the same month.

This relationship provides a pluviothermal diagram on which temperatures are plotted on a double scale of precipitation.

When temperatures rise above the precipitation curve, the corresponding period is water deficient; and when the precipitation curve passes above that of the temperatures, the corresponding period is wet.

Table 04: Temperature / Monthly Interannual Precipitation of El Oued Region (2005-2014):

month	sep	oct	nov	dec	jan	feb	mar	ap	may	june	july	aug
2T °C	58.1	48.26	33.18	23.96	22.84	25.62	34.7	43.3	52.14	62.12	67.7	69.24
P(mm)	7.49	7.36	6.93	7.73	20.88	1.32	7.21	11.59	1.65	0.99	0.16	2.65

(NOM, El Oued/Guemar, 2015)

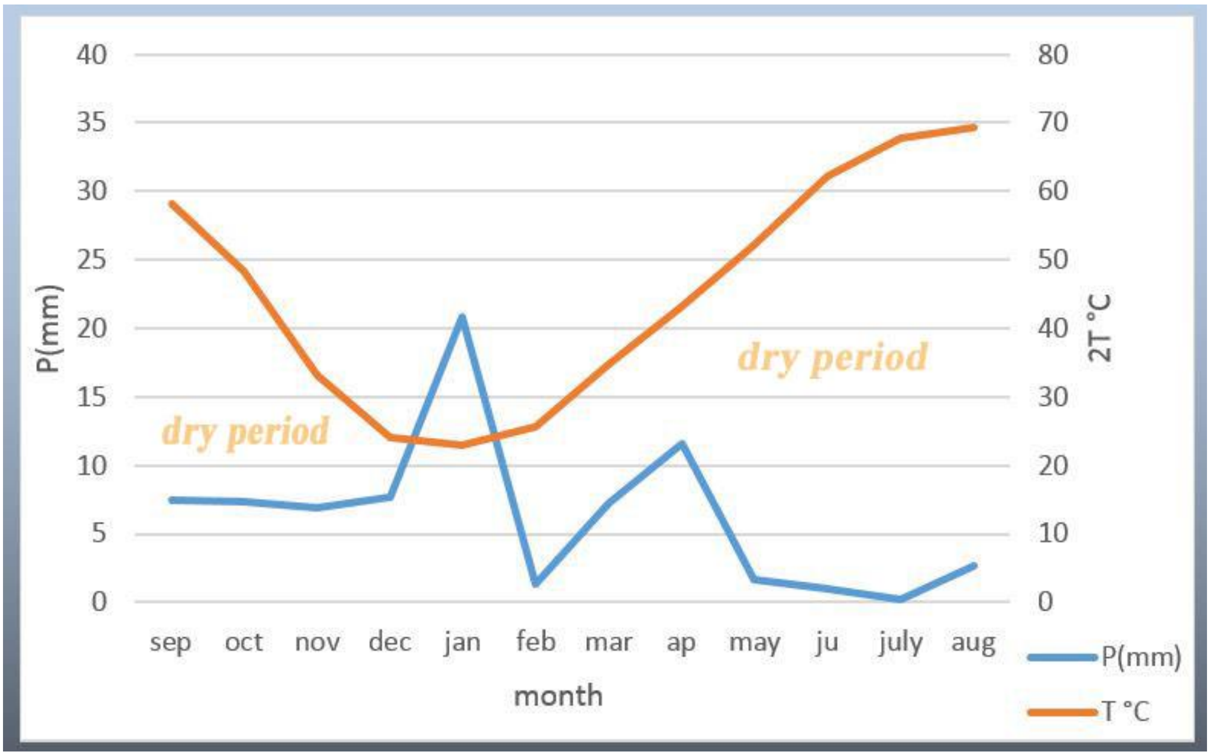


Figure 04: **Pluviothermal diagram of Guemar station during the period (2005-2014).**

From the diagram, we find that the drought (dry period) is permanent throughout the year except the month of January, because of the low rainfall and high temperatures and the complete absence of the wet period, except the month of January (wet period) has low temperature (11.42 ° C) and the highest precipitation (20, 88 mm).

III.2.3 Humidity:

Moisture is a state of climate that results in the percentage of water existing in the atmosphere. It has effects on chemical alterations such as oxidation.

Table 05: **Monthly average humidity of Oued Souf region (2005-2014):**

Months	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Ap	May	Jun	July	Aug	average
Humidity %	47,56	53,60	57,78	63,42	62,44	54,08	48,58	45,85	40,52	36,29	33,42	37,35	48,41

(NOM,El Oued Guemar, 2015).

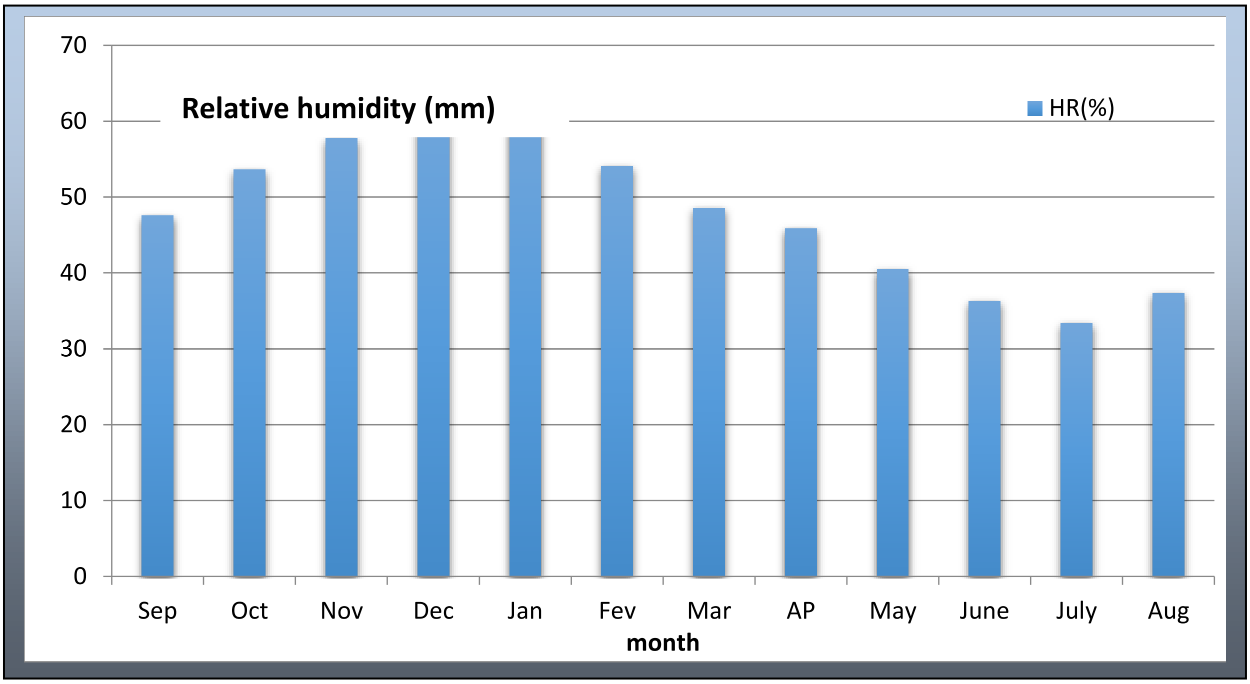


Figure 05: Histogram of the monthly average relative humidity (2005-2014).

The histogram (Figure 06) distinguishes dry months from relatively wet months.

We note that:

- The wet months are January, February, October, November, December
- Dry months are March, April, may, June, July, august, September.

According to the table (05), we note that:

- A minimum recorded during the month of July with a value of about 33.42% is the summer season.
- A maximum recorded during the month of December with a value of 63.42% is the winter season.
- Annual humidity of about 48.41%.

III.2.4 Wind:

The winds are frequent, the most violent ones are during the spring, and the dominant direction is northeast, with the exception of the winter months (its direction is southwest).

The sirocco (Chihili) presents the wind characterizing the summer season blows frequently in the region, taking a South-North direction and throwing currents of hot air sometimes bordering waves of sands.

We must also talk about the sand winds (between February and April, during the spring), but fortunately, real storms are very rare.

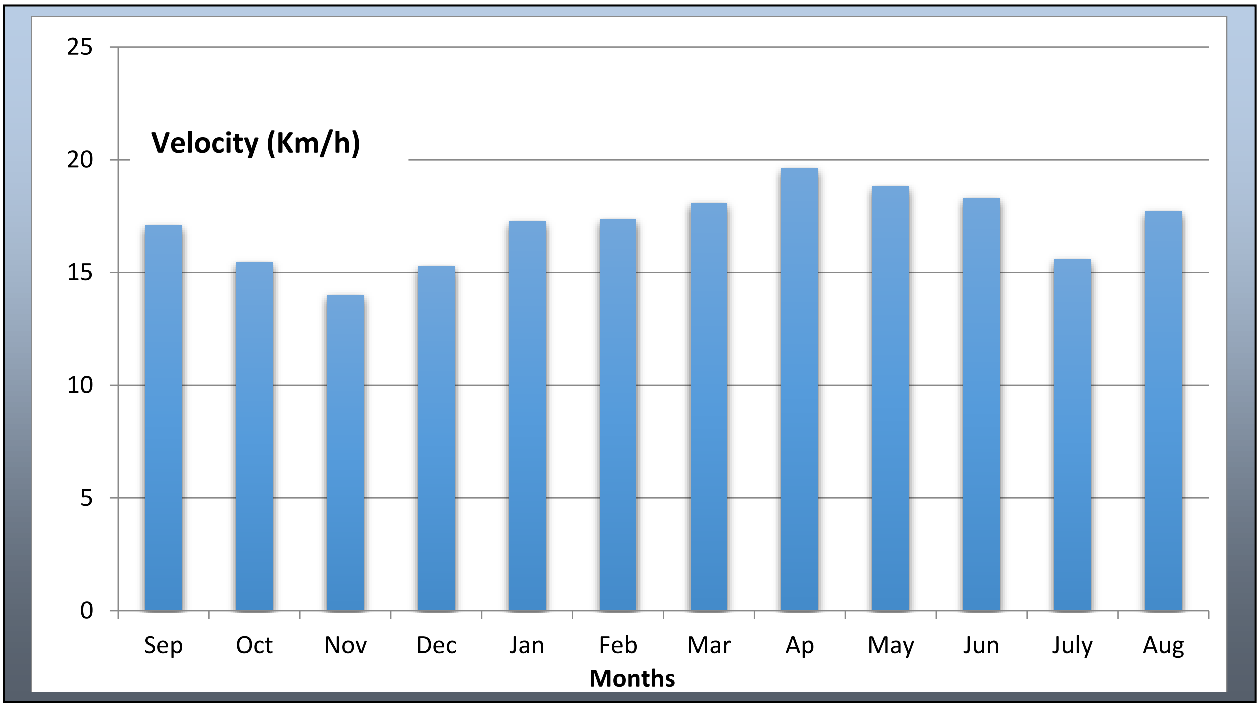


Figure 06: Histogram of average monthly wind speeds in Km / h (2005-2014).

(NOM, El Oued Guemar, 2015).

According to the histogram, it can be noted that the average wind speed varies between 15,27Km / h recorded during the month of December and 17, 73 m / s for the month of April.

The average annual wind speeds is 17, 05 m / s.

III.2.5 Evaporation:

The following table (06) shows the monthly average values of the evaporation period (2005-2014).

The highest evaporation occurs in June, July and August, and the lowest in January.

Table 06: Monthly average evaporation at Oued Souf in (2005-2014):

Months	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Ap	May	June	July	Aug	Average
EVAP (mm)	19.98	14.76	9.833	7.865	7,79	9.6	14 .72	20.62	25.57	29.92	33.39	30.79	22.485

(NOM, El Oued Guemar, 2015).

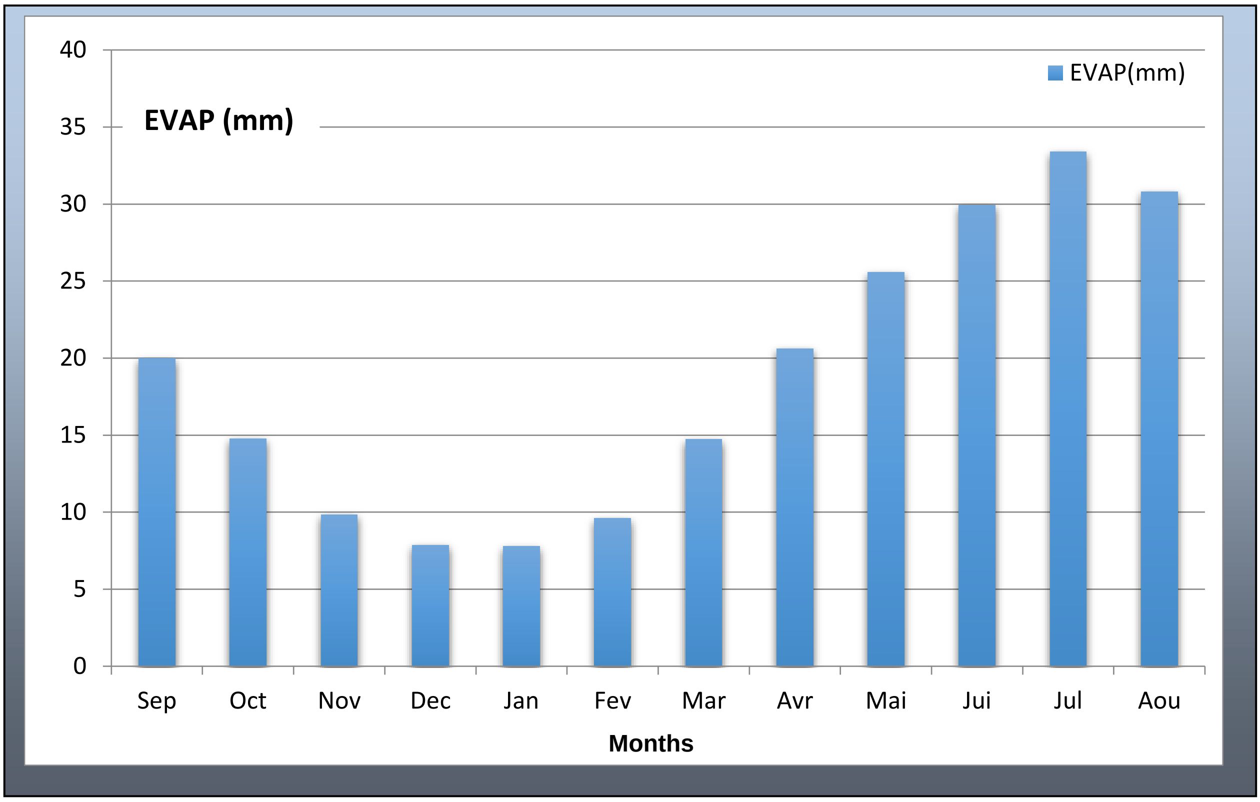


Figure 07: Histogram of average monthly evaporation in mm (2005-2014).

III.2.6 Insolation:

The city of El oued receives a relatively high amount of sunlight:

- The maximum is reached in July with a duration of sunstroke of 358.89 hours
- Minimum records in December with a duration of 220.06 hours.

Table 07: Average monthly insolation duration of Oued Souf region (2005-2014):

Months	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Ap	May	Jun	July	Aug	average
Insol. (hour)	265,51	251,97	241,83	220,06	236,29	237,15	255,86	277,74	307,98	341,22	358,89	332,93	277,29

(NOM,El-Oued Guemar, 2015).

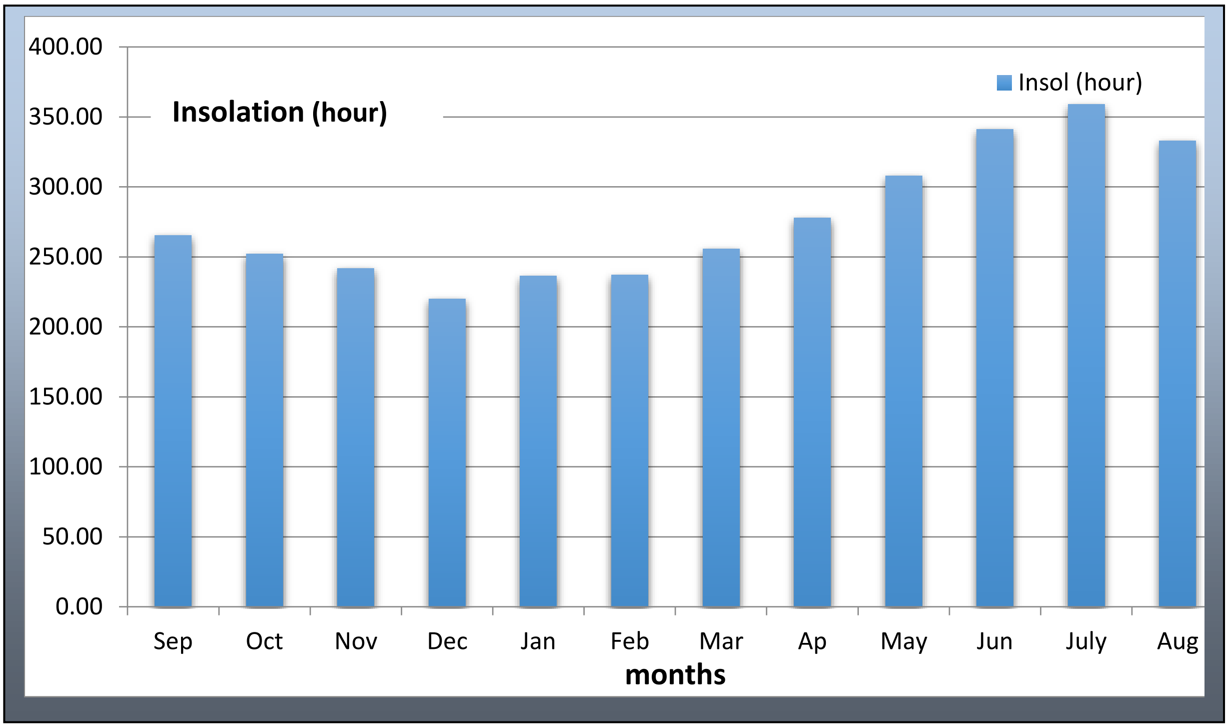


Figure 08: Histogram of average monthly insolation (2005-2015).

III.3 Conclusion:

The climatic analysis revealed the following results:

The monthly interannual precipitation is the order of 75.95mm.

The average monthly temperature is the order of 22.54 ° C.

The region of Souf is characterized by a hyper-arid climate;

The wettest month is December (63.42% interannual average) with low solar radiation (average 277.29 hours).

The driest month is July, with a low humidity (average of 33.42%). The brightness of the sun is very high (average 358.89 hours) which reflects an excessive evaporative power.

The agricultural deficit is of the order of 1099.08 mm.

These results show that climatic conditions (effective infiltration) do not contribute to the recharge of the free water layer.

Chapter IV : Hydrogeology Study

IV.1 Introduction:

Hydrogeology is the science of groundwater. It is a discipline of earth sciences that aims to study the role of underground materials and hydrogeological structures (aquifers) and, by acquisition of numerical data by prospecting or experimentation in the field, allow the planning of catchments, as well as the exploitation and management of groundwater. Hydrogeology specializes in the research and exploitation of groundwater for domestic or industrial use and studies how geological materials influence the circulation and quality of groundwater. In addition to geological knowledge, Scientists must have good knowledge of hydraulics. It intervenes in the research and the exploitation of deposits of aquifers, in the study of the quality of the waters as well as in their protection. Scientists must be able to estimate the quantity and quality of water and predict its behavior in aquifers.

The hydrogeological study is preponderant to the understanding of the feeding processes aquifers on the one hand, and the recognition of flow directions on the other, as well as the variation of the hydraulic gradient, the hydrodynamic characteristics, and the determination boundary conditions of the aquifer system and finally the determination of the geometry of the plies.

In a first stage is to understand the evolution of the piezometric level over time and in space.

In a second stage to know the hydrodynamic regime of the layer by identifying finally the zones of high transmissives on the one hand, and on the other hand the zones of high permeabilities.

These descriptions will help us better understand the vulnerability of the water table to different pollutants.

IV.2 Purpose of the hydrogeological study of El Oued region:

The hydrogeological study of El Oued region aims to:

- The identification of aquifer systems (structures and geometry)
- The understanding of the hydrodynamism of the water table (piezometric, meaning

flow and hydraulic gradient).

- The determination of hydrodynamic parameters.

IV.3 Hydrogeological framework:

According to Mehellou and al. (2017):

The study area is part of the sedimentary basin of the northern desert whose extension covers an area of 780,000 km^2.

This basin, a vast area of spreading, constitutes an important topographical depression, which is subtended by a structural bowl in the form of an asymmetrical syncline. The sedimentary series is marked, in the center of the pit, by important tectonic subvertical.

The dips of the banks are generally weak, with the exception of the Northeast of the basin. It has, at its base, Paleozoic formations marines unconformable surmounted by the continental formations of the Secondary and Tertiary thick of several thousand meters. The Quaternary succeeds. It consists essentially sand dunes whose thickness can reach a few hundred meters.

Only the upper series has a hydrogeological interest. From Cretaceous to Quaternary, it is an alternation of sandstone, sand, clay sand and clay, limestone, dolomite and marl, as well as evaporates. This series has three major permeable sets to which three major aquifer systems correspond: the Continental Intercalaire aquifer, the Terminal Complex aquifer and the water layer.

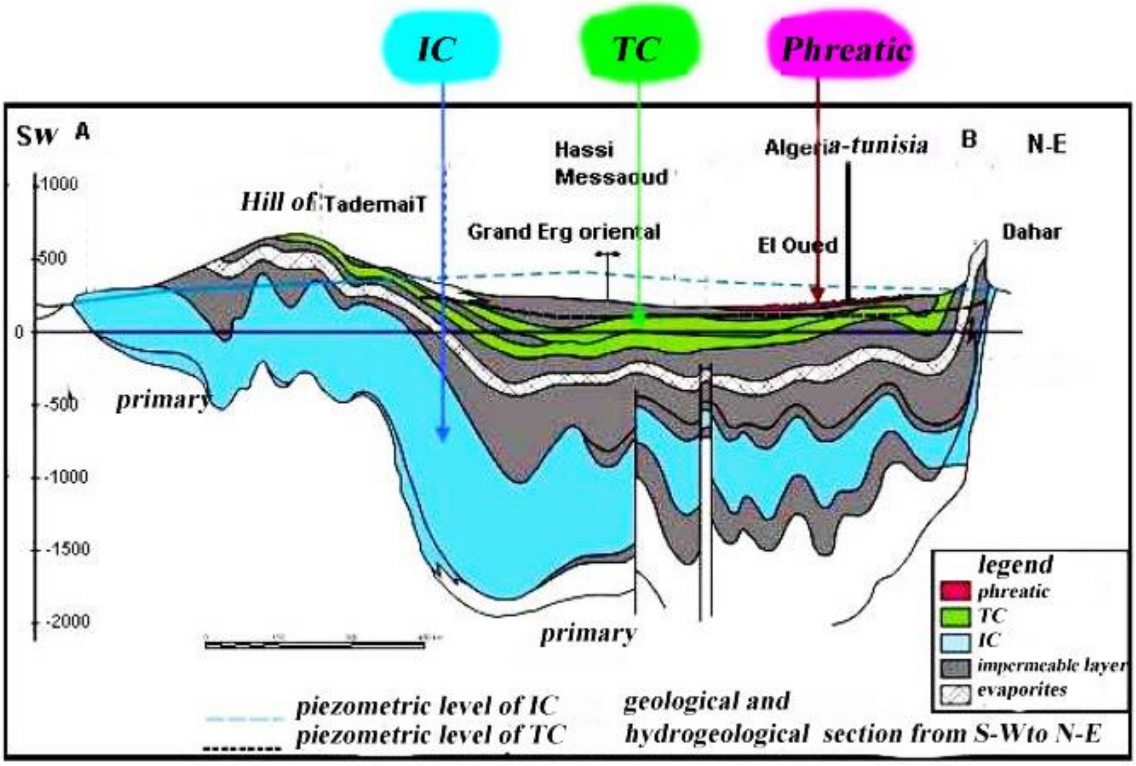


Figure 01: Hydrogeological section across the desert *(after UNESCO, 1972).*

IV.3.1 Groundwater:

The groundwater present at Souf region corresponds essentially to the upper part of the continental formations deposited at the end of the Quaternary. It is locate at depths between 10 and 60 meters.

Given its importance, this aquifer represents the main source of water for palm groves.It is mostly exploited by traditional wells.

The circulation of water in this aquifer is relatively rapid throughout the Souf region and particularly in areas characterized by the existence of clayey lenses that influence on the permeability of sands. Except in the region of the Chotts the free tablecloth is present throughout the study area.

The water table in the Souf region is mainly fed by the water has used by populations (irrigation, industrial and domestic water) and the absolute source of these are deep layers of the Terminal and Continental Intercalaire Complex (Cote, 1998).

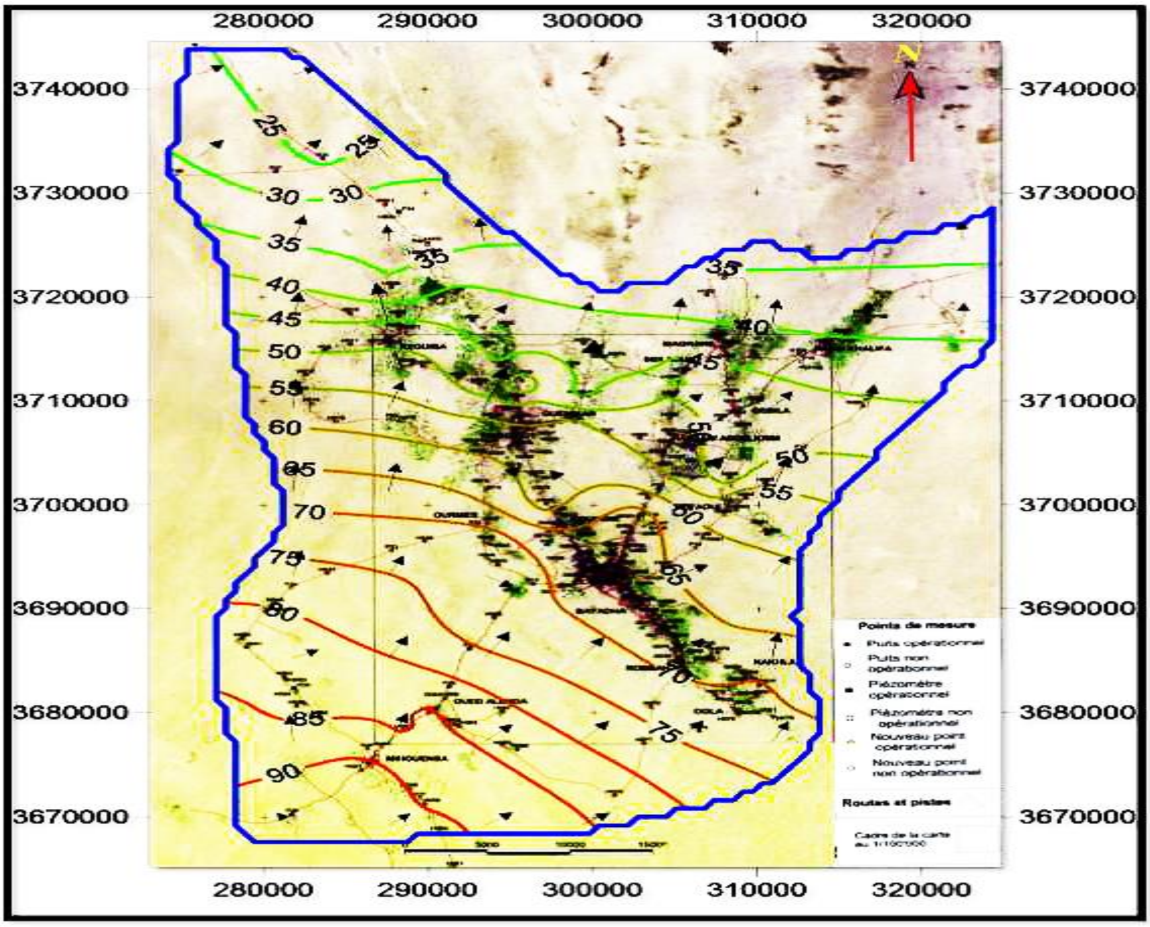


Figure 02: **Piezometric map of the phreatic *(January 2010)*.**

IV.3.2 The aquifer of Terminal Complex (TC):

This term groups together under the same name, a set of aquifers, which are located in the different geological formation: Senonian carbonate and Eocene, Miopliocene sandy.

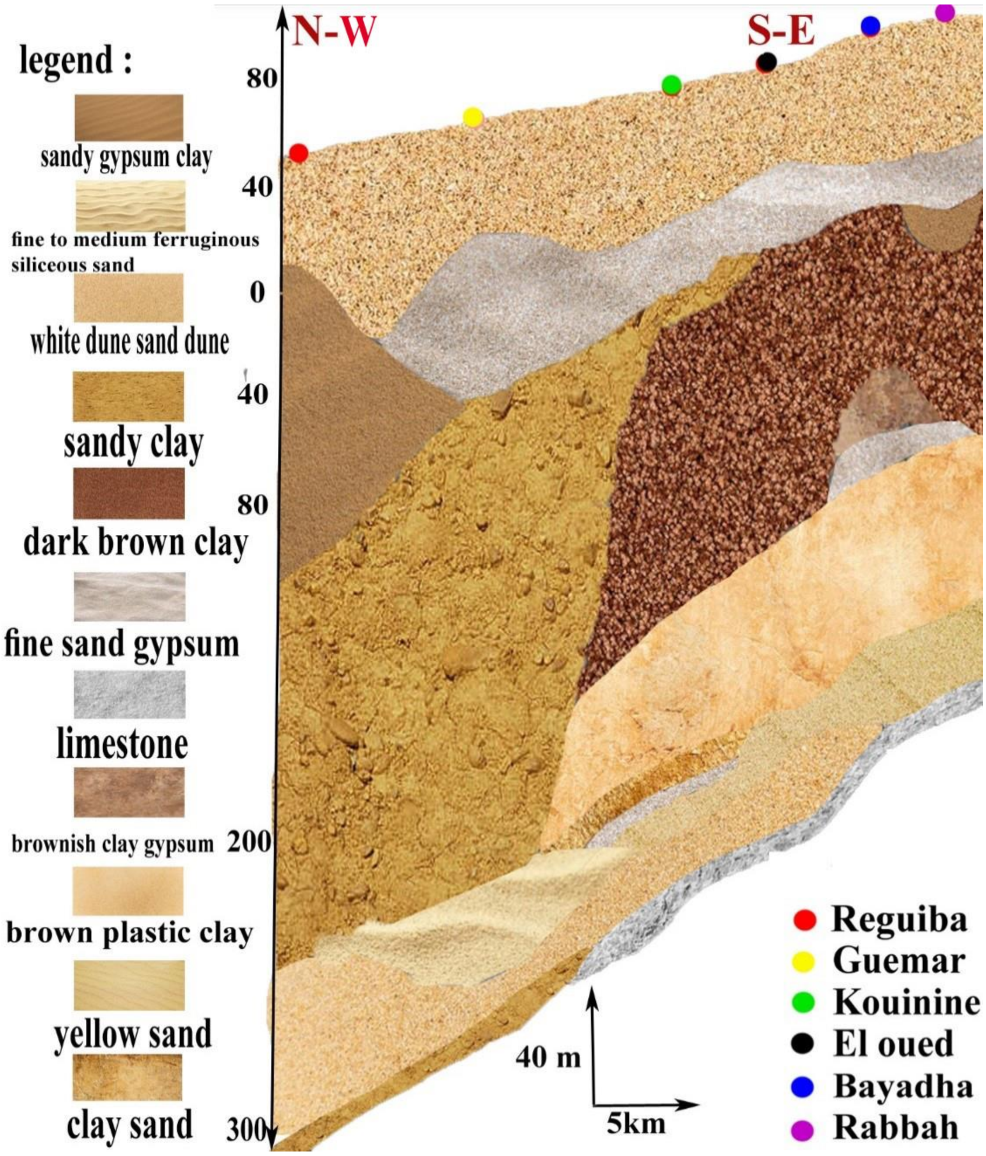


Figure 03: Geological section, Extracted from the lithological logs of the boreholes,

(SAADINE and OUED RIGH company, 2019)

a) Aquifer of sand:

Within these sandy levels, comes two captive layers, the first of which corresponds to the higher formation of the Terminal Complex commonly called reservoir of the "Sub-Souf". This layer consists of coarse sands and part of the Terminal complex progressively leads to the North of the Sahara towards the South, in the study area it is 280 meters deep.

It should be mentioned also the existence of a second layer of sands Pontian age. The above the upper banks of the limestone layer in contact with the Eocene marls inferior and siliceous gravel thus constituting a second captive layer in continuity with the layer of the Pontian of South Tunisia. The depth of this tablecloth varies between 400 and 450 meters. As for the useful thickness of this layer, it is about 50 meters. The flow of water in these last two layers is from South-West to Northeast, in other words, towards the chotts zone.

In the zone with strong exploitations such as the city of El-Oued, the water extraction is done by pumping. On the other hand, in the regions where exploitation is less in Taleb Laarbi and Douar El Maa, the tablecloth is exploited to this day by hand. This is the case of the tablecloth Pontian.

b) Aquifer of limestones:

The Terminal Complex has a more complex litho-stratigraphy; drilling capturing this layer show us the existence of two levels serving as a benchmark for the classification groundwater; from south to north, we observe the existence of a first level limestone better individualized, sometimes it is purely limestone, sometimes it is formed by gypsum limestones. It corresponds to the lower level.

The upper level, mainly represented by siliceous limestones, is considered as a transition zone between the tablecloth of limestones and that of sands. In On the whole, these two levels are separated by formations sometimes marly, sometimes sandy with past of red clay.

IV.3.3 Aquifer of the Intercalary Continental (IC):

The term "CI" thus corresponds to the continental formations of the Lower Cretaceous this period is between two sedimentary cycles governed by a marine regression followed by a transgression of the Upper Cretaceous.

The Intercalary Continental occupies the stratigraphic interval between the Triassic base and the Albien roof, the missing treatment of the Intercalary Continental aquifer and its volume due to its extension over more than 600 000 square kilometers and its average thickness several hundred meters. Although the major interest of this aquifer system is constituted by the large quantities of water that were stored during the periods rainy Quaternary and can now be exploited.It still receives our days a natural diet by the meteoric waters and therefore presents a functioning characterized by a feed, a flow and a series of outlets.

IV.4 Piezometry:

The purpose of the piezometric map is to represent the configuration of the aquifer and schematize the reservoir driving function and the hydrodynamic behavior of the aquifer; it translates the morphology of the water surface of the aquifer at a given time.

A piezometer company during the low water allow us to follow the evolution of the piezometer of the layer.

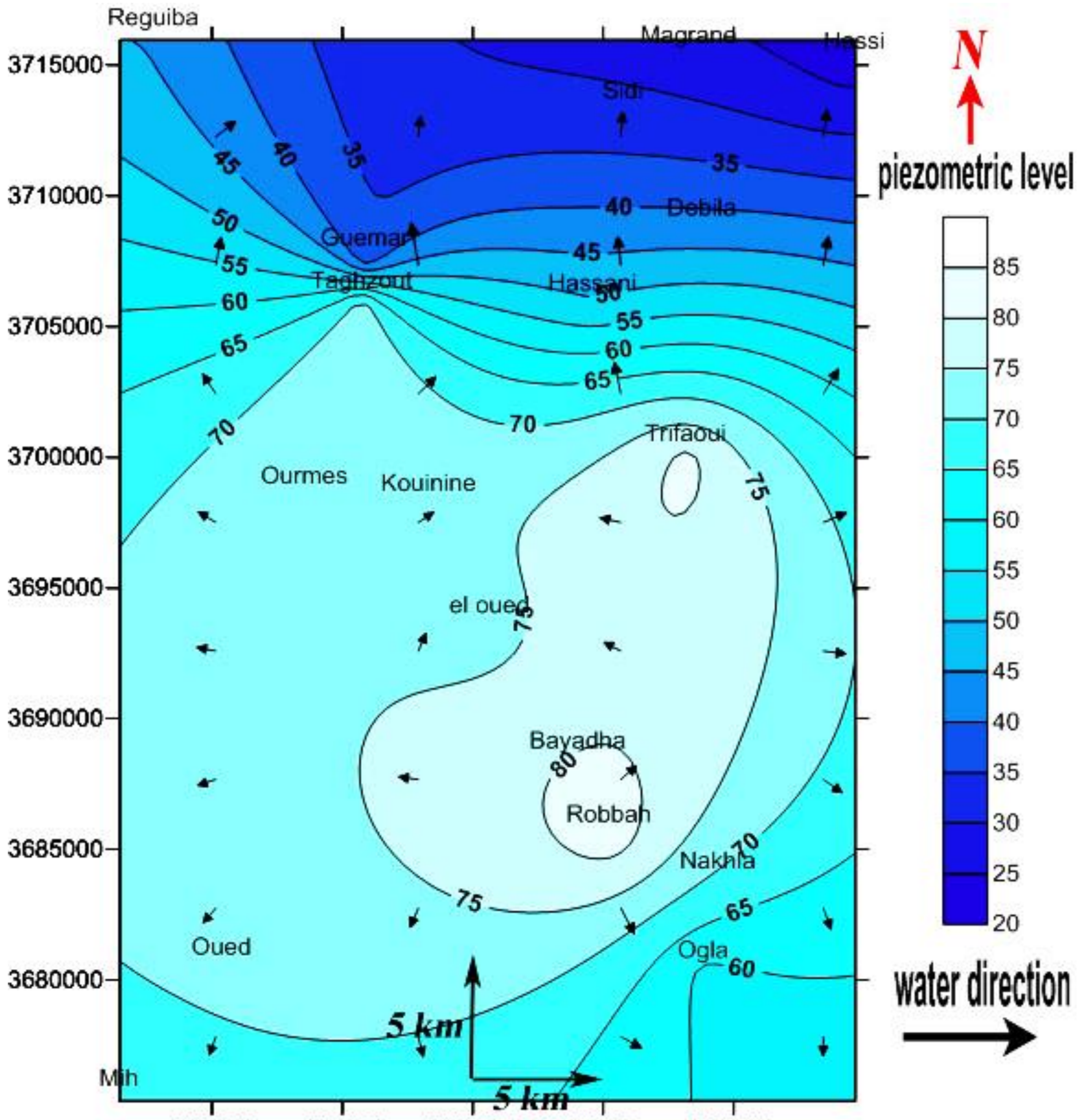


Figure 04: Piezometric map of the aquifer of TC of the valley of Souf *(El oued,DWR, 2011).*

Chapter V : Hydrodynamic study

V.1 Introduction:

According to (Kobbi and Atallah, 2014):

The aquifer is a dynamic system characterized by its configuration its structure, and the functions of its reservoir and its behavior.

Well testing and pumping tests are two methods of experimentation which aims to evaluate the characteristics of the aquifer / complex structure on the one hand and the determination of hydrodynamic parameters on the other hand.

V.2 Identification of well tests and test pumping:

V.2.1 Pumping tests in short duration flow stages:

The short-term flow rate well tests evaluate the characteristics of the aquifer / reservoir complex are:

- Critical speed;
- Specific flow;
- Loss of charge;
- The maximum operating flow or productivity allows to establish the program of technical equipment of the structure.

V.2.2 Pumping long-term tests:

Long-term test pumping is performed at only one flow rate, at constant flow, for at 72 hours (or at least 48 hours).

Pumping tests has three main goals:

- Measurement on hydrodynamic characteristic terrains (transmissivity and storage coefficient).
- Quantitative study of the particular characteristics of the aquifer.
- Direct observation of the effect of exploitation on the aquifer.

V.2.3 A descriptive diagram that summarizes the method used:

As part of the evaluation of the characteristics of the drilling performed in the soil of the aquifer of the Terminal Complex, computer technology have used. It is the **OUAIP software.**

Using this software, 14 boreholes have analyzed to evaluate the productivity expressed in specific capacity (Cs).

The specific capacity is defined as follows:

Cs = Q / S in m^2 / h

- **Q:** pumping rate in m^3 / h.
- **S:** the drawdown in m due to the pressure drop.

Which is the result of the sum of the losses of charges in form following the turbulent flow through the pumping strainers.

The specific capacity has estimated on a graph on which the flow places on the abscissa and the drawdown on the ordinate and by the measurement of the adjustment of the slope of the straight line.

- **The conditions of application of this formula are:**

• The pumping rate must be long enough for the equilibrium to stabilize and to be constant.

• The drawdown in the well is a curve of the decrease of the piezometric level in the aquifer and of the pressure loss due to the technical characteristics of the drilling between the decrease of the pressure in the aquifer and the loss of the pressure due from loss of then.

V.2.4 Constant Flow Test

A 72-hour steady-state constant flow test was conducted in the aquifer at **14** boreholes distributed in the study area, to calculate the hydraulic characteristics of the borehole, followed by an observation of ascent. Twenty-four (24) hours. Measurements taken are on the pump plugs of the constant flow test, from these measurements we have plotted the following curves:

- Curve of drawdown as a function of time
- Curve of drawdown (s) according to Log (t)

The value of transmissivity is calculated from Theis's formula:

- **T = 0.183. Q Log (t) / s = (0.183.Q) / C**

s: drawdown in m .

T: transmissivity in m^2 / s, **Q:** flow in m^3 / s, **t:** time in mn.

The objective of the interpretation of the pumping tests is to evaluate the hydrodynamic parameters of the aquifer system.

From these measurements, we have plotted the characteristic curves:

- Curve of the drawdown.
- Diagram for the determination of the coefficients B and C of the Jacob equation Characteristic curve of the drilling: $s = BQ + CQ^2$

Linear pressure loss: **B** / Quadratic load loss: **C** / Implies that drilling is well developed.

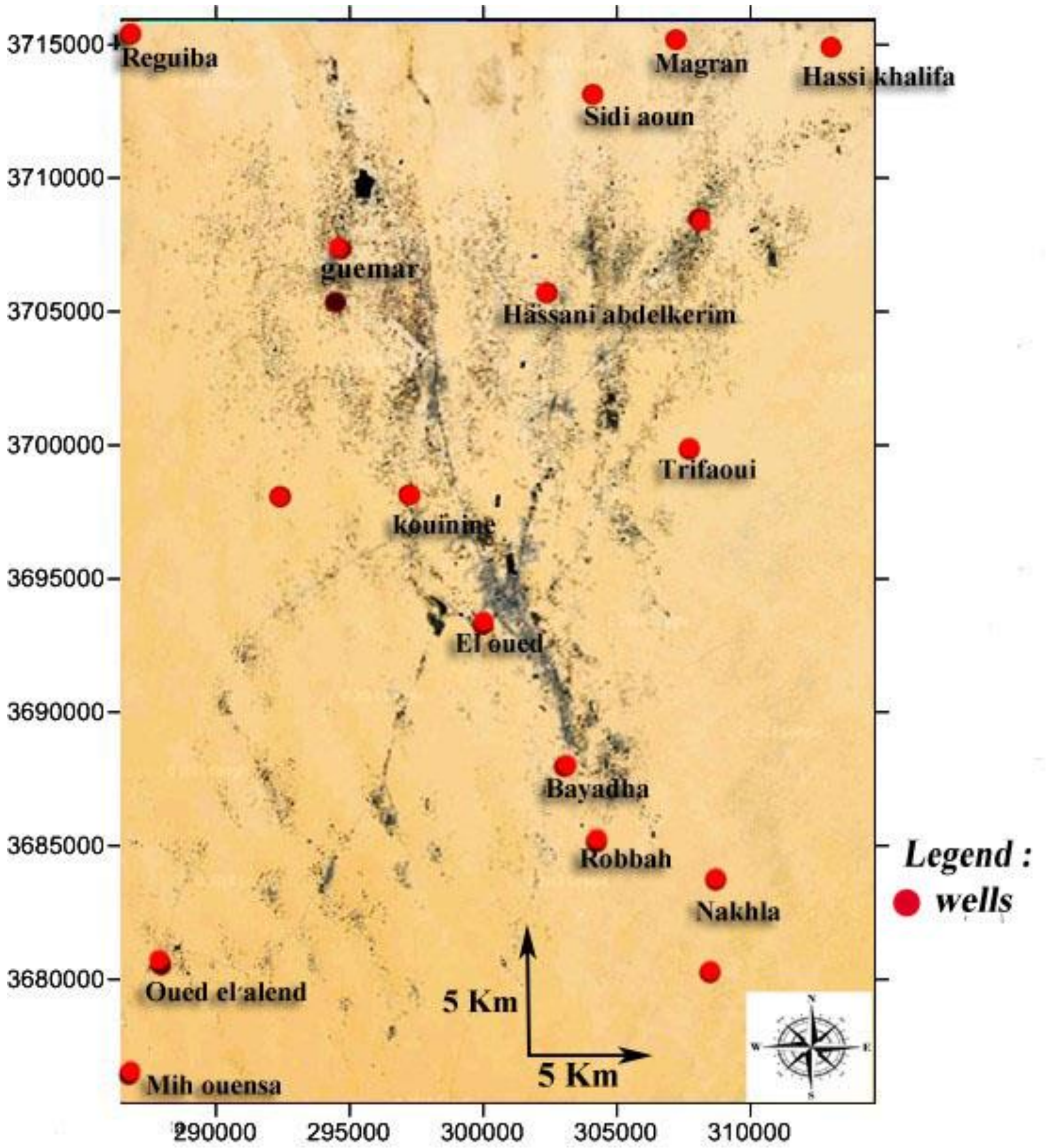


Figure 01: UTM coordinates of pumping test sites (satellite map, 2019)

The figure (05) show the UTM coordinates (satellite map) of 14 wells that we have studied.

V.3 Pumping tests:

Interpretation of the long-term test:

Test interpretation of log duration, (72 h, 17 min and 30 s) at constant flow (in l /s):

I have used the OUIP software to obtain these curves and I have taken the parameters from the companies (FOREMHYD, Saadine Hamza).The pumping tests have realized between 2013 and 2016).

V.3.1 Pumping test at El Oued:

Aquifer width	34 m	**Observation radius**	10 m
Well type	Well		

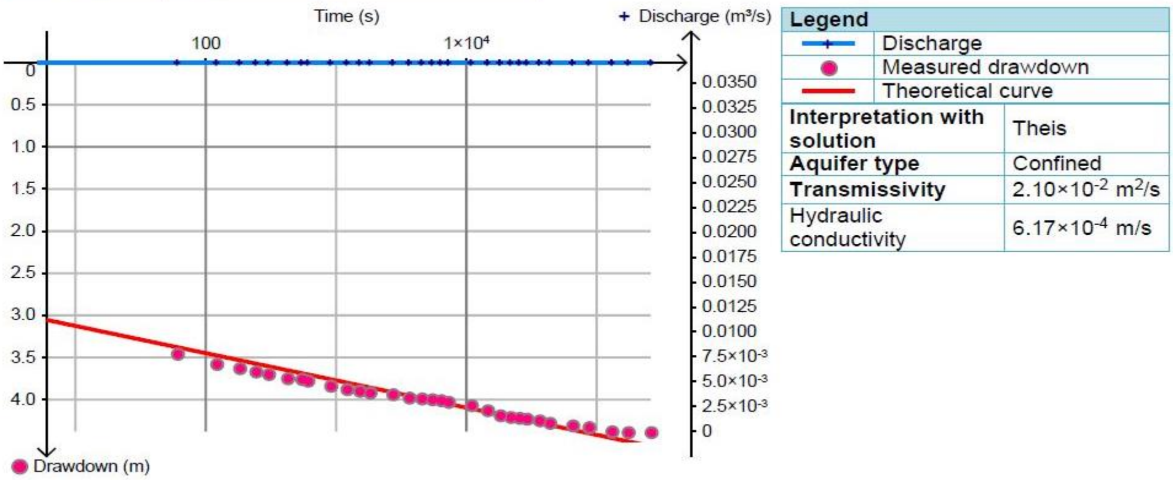


Figure 02: Long-term pumping test at El Oued interpreted by theis method.

V.3.2 Pumping test at Guemar:

Aquifer width	50 m	**Observation radius**	10 m
Well type	Well		

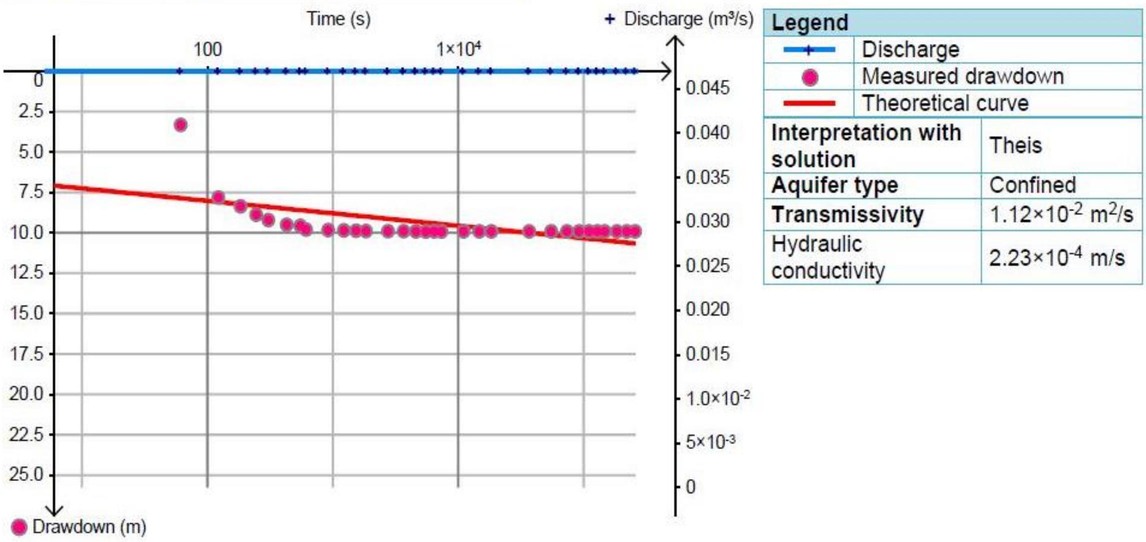


Figure 03: Long-term pumping test at Guemar interpreted by theis method.

V.3.3 Pumping test at Hassi khalifa:

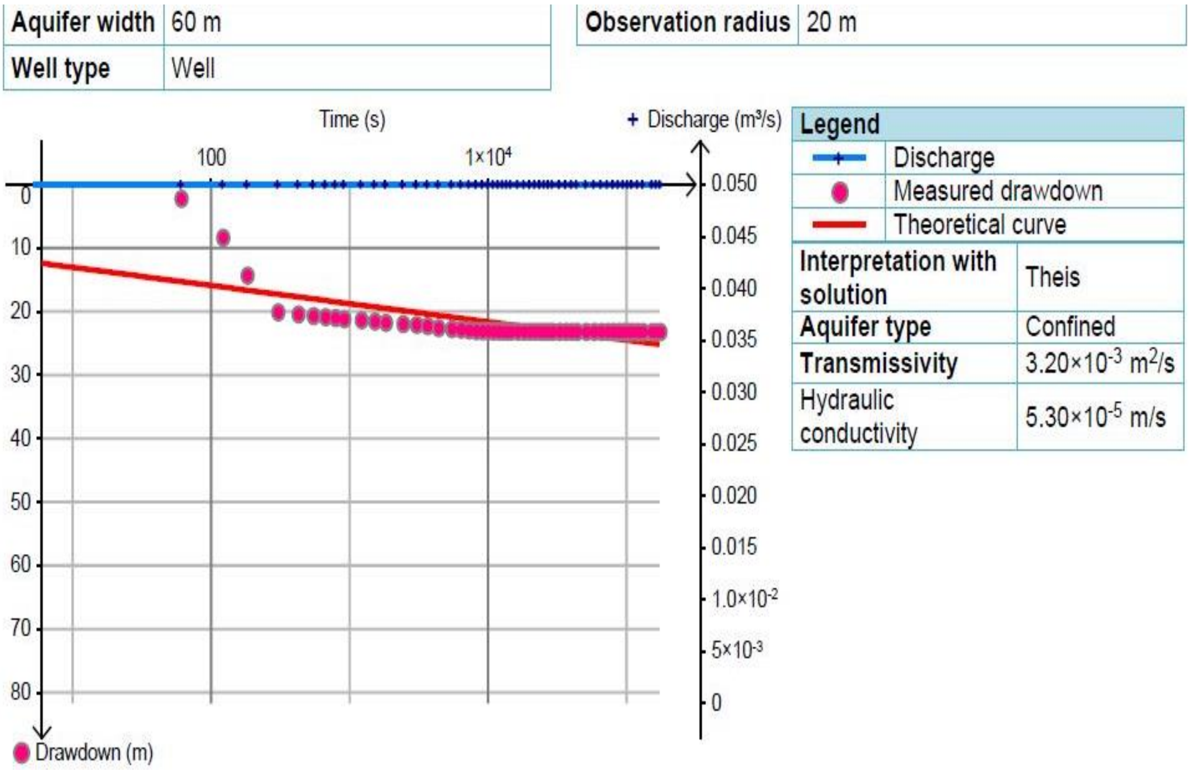


Figure 04: **Long-term pumping test at Hassi khalifa interpreted by theis method.**

V.3.4 Pumping test at Reguiba:

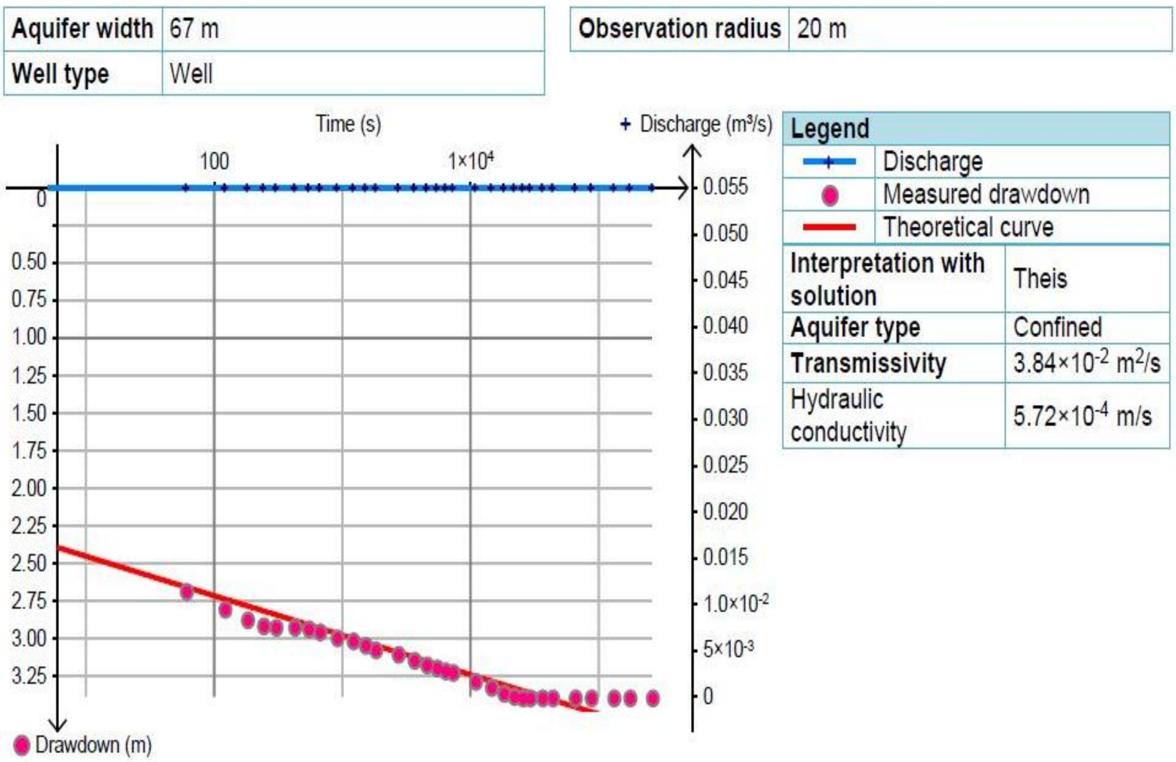
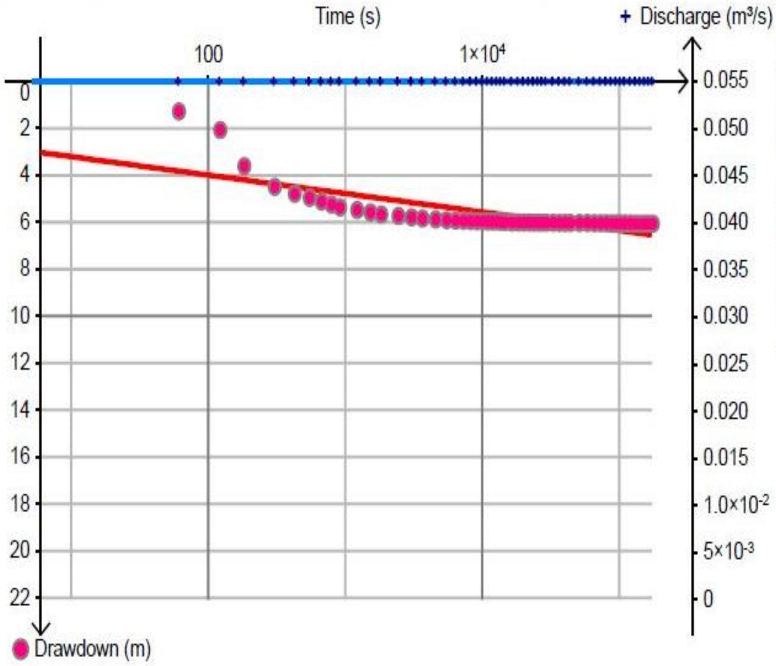


Figure 05: **Long-term pumping test at Reguiba interpreted by theis method.**

V.3.5 Pumping test at Trifaoui:

Aquifer width	72 m
Well type	Well

Observation radius	30 m



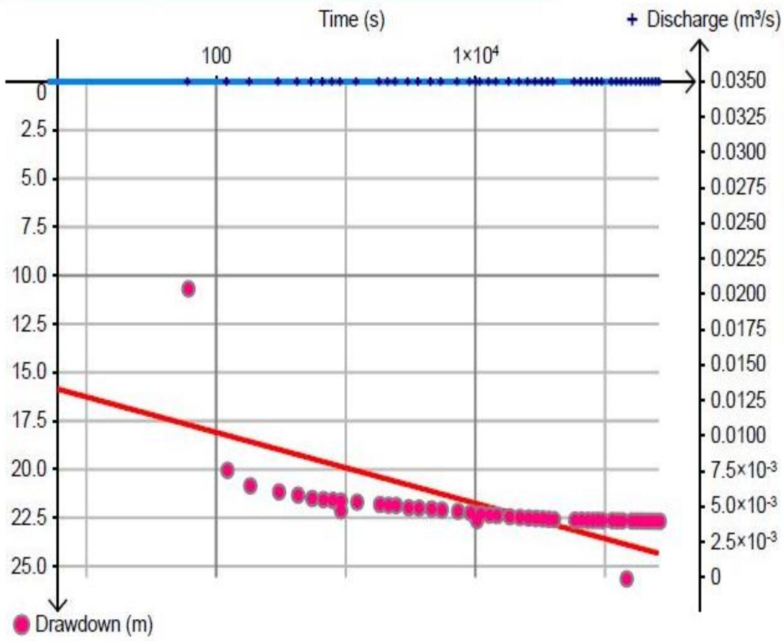
Legend	
Discharge	
Measured drawdown	
Theoretical curve	
Interpretation with solution	Theis
Aquifer type	Confined
Transmissivity	1.28×10^{-2} m²/s
Hydraulic conductivity	1.78×10^{-4} m/s

Figure 06: Long-term pumping test at Trifaoui interpreted by theis method.

V.3.6 Pumping test at Magran:

Aquifer width	54 m
Well type	Well

Observation radius	10 m



Legend	
Discharge	
Measured drawdown	
Theoretical curve	
Interpretation with solution	Theis
Aquifer type	Confined
Transmissivity	3.51×10^{-3} m²/s
Hydraulic conductivity	6.50×10^{-5} m/s

Figure 07: Long-term pumping test at Magran interpreted by theis method.

V.3.7 Pumping test at Nakhla Chamaliya:

Aquifer width	30 m	**Observation radius**	20 m
Well type	Well		

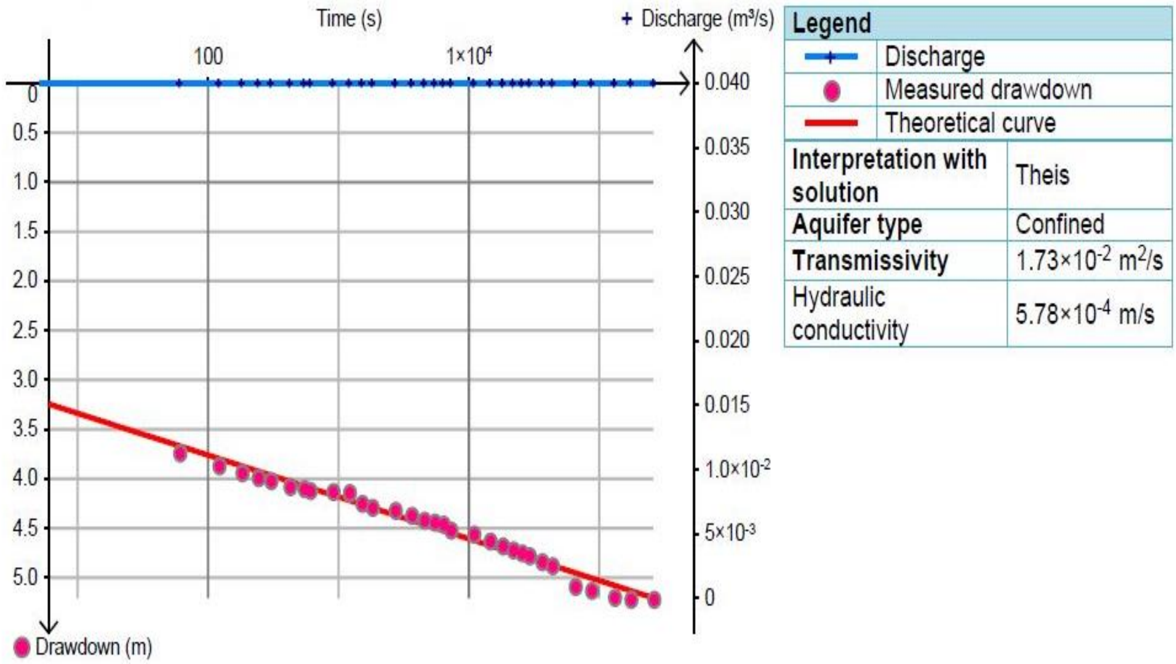


Figure 08: **Long-term pumping test at Nakhla Chamalia interpreted by theis method.**

V.3.8 Pumping test at Nakhla El Gharbiya:

Aquifer width	30 m	**Observation radius**	5 m
Well type	Well		

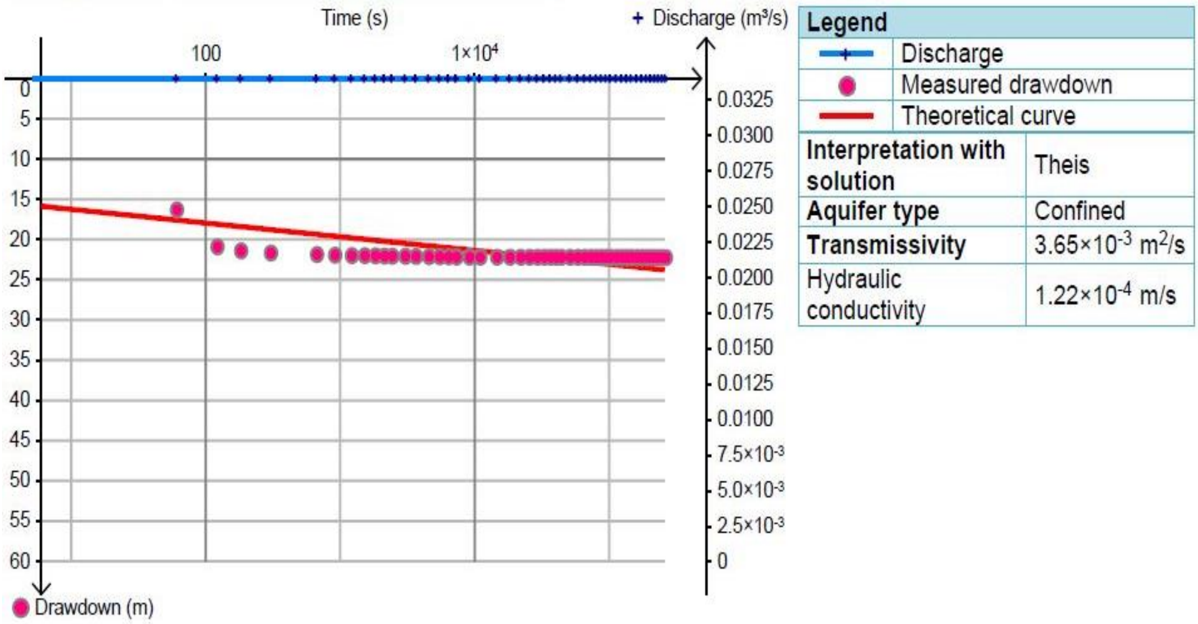


Figure 09: **Long-term pumping test at Nakhla El Gharbiya interpreted by theis method.**

V.3.9 Pumping test at Sidi Aoun:

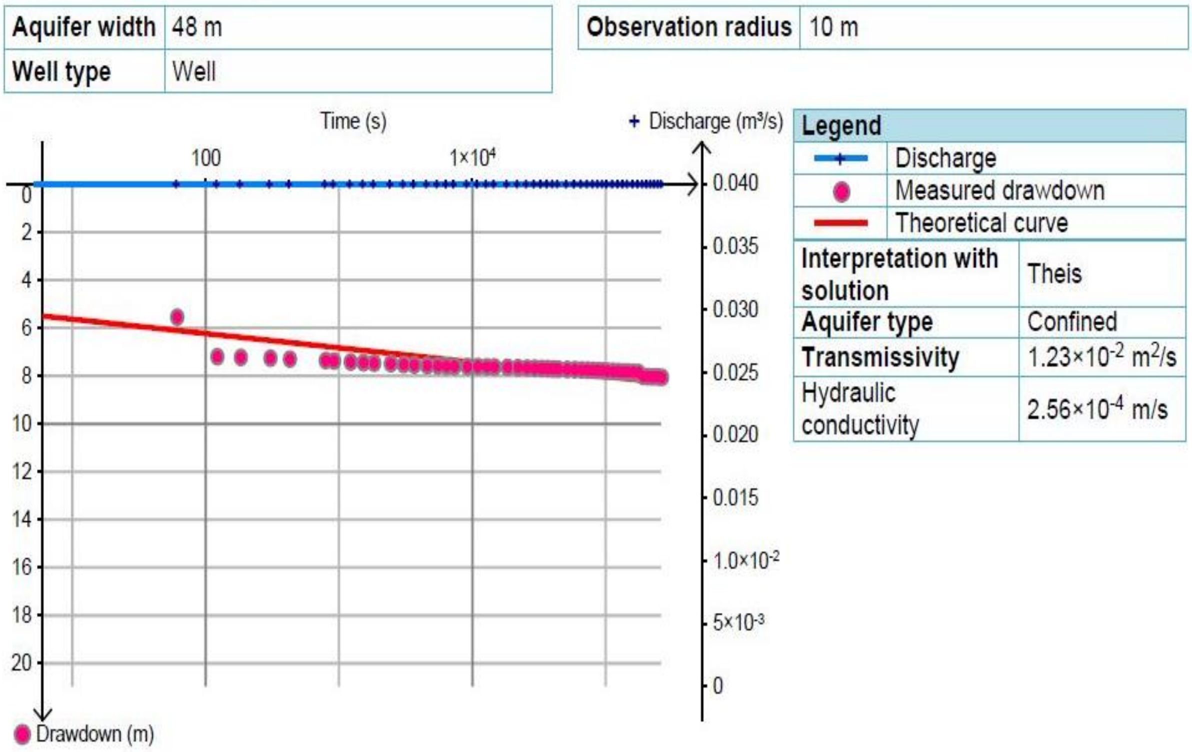


Figure 10: **Long-term pumping test at Sidi Aoun interpreted by theis method.**

V.3.10 Pumping test at Bayadha:

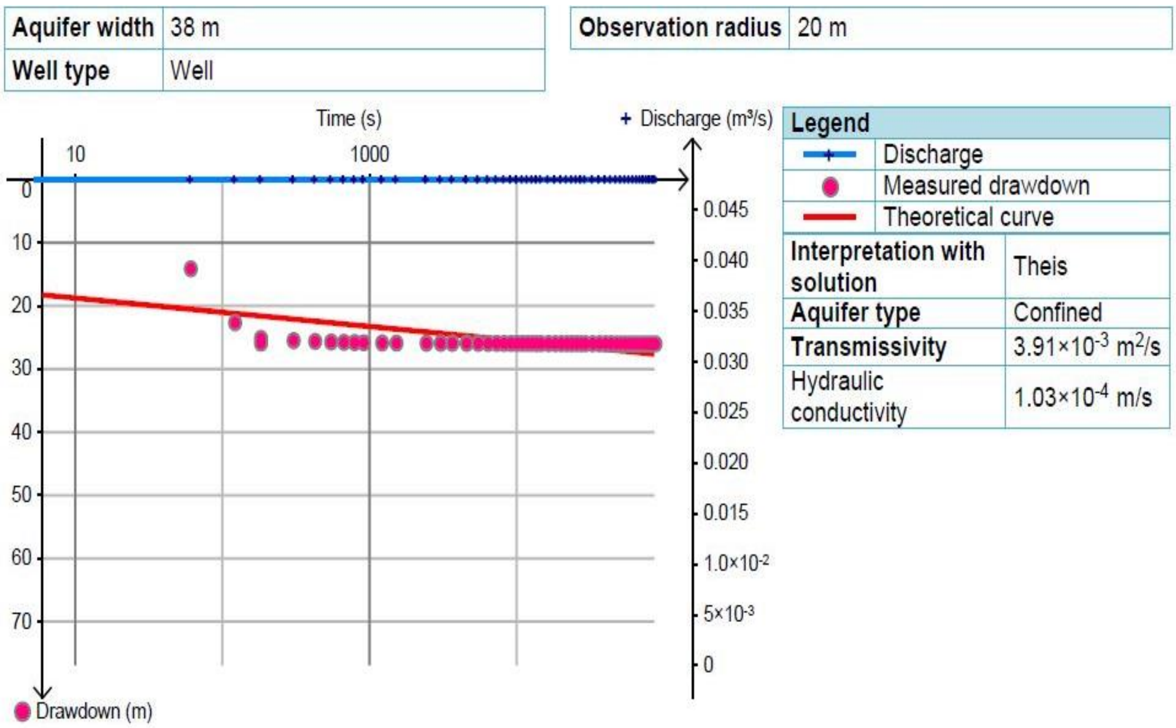


Figure 11: **Long-term pumping test at Bayadha interpreted by theis method.**

V.3.11 Pumping test at Robbah:

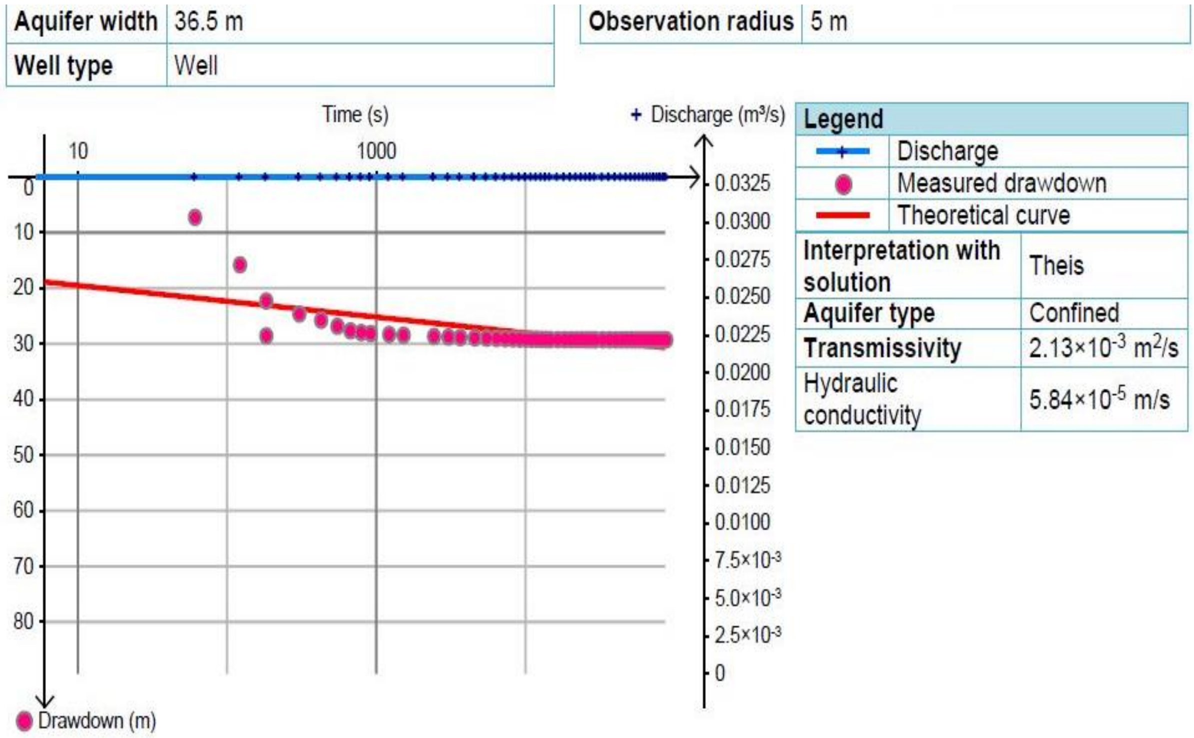


Figure 12: Long-term pumping test at Robbah interpreted by theis method.

V.3.12 Pumping test at Kouinine:

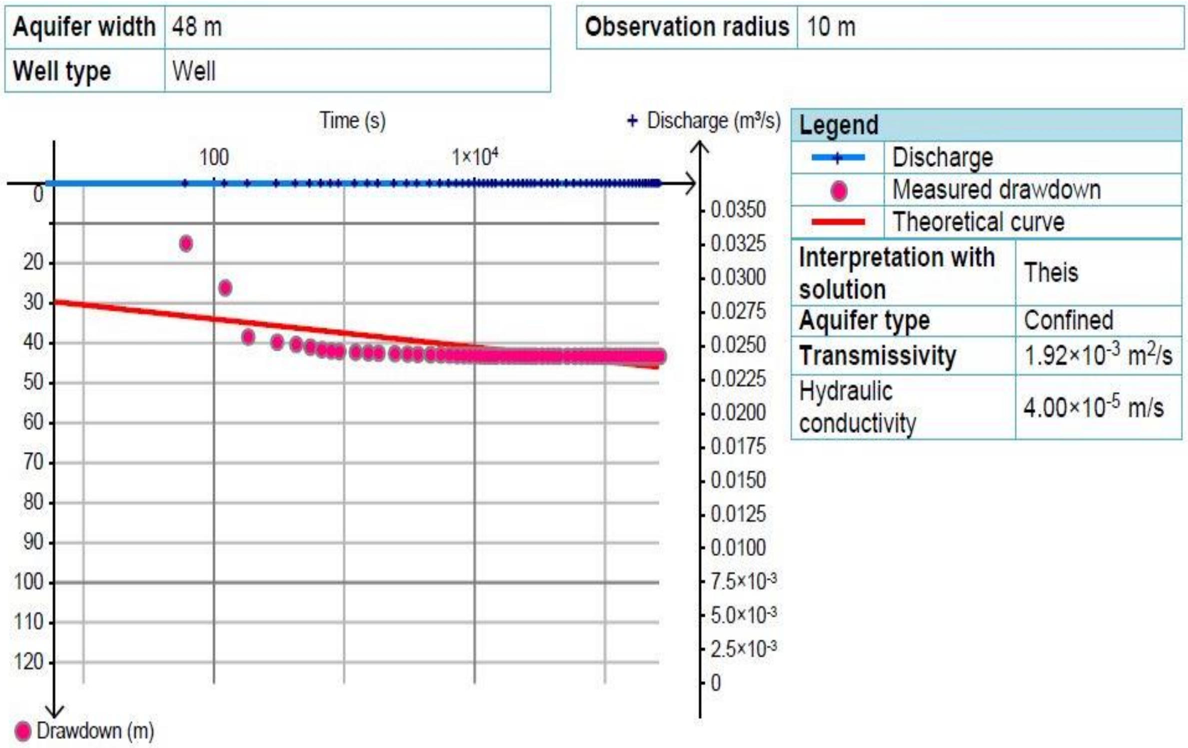


Figure 13: Long-term pumping test at Kouinine interpreted by theis method.

V.3.13 Pumping test at Oued El Alenda:

Aquifer width	56 m	**Observation radius**	10 m
Well type	Well		

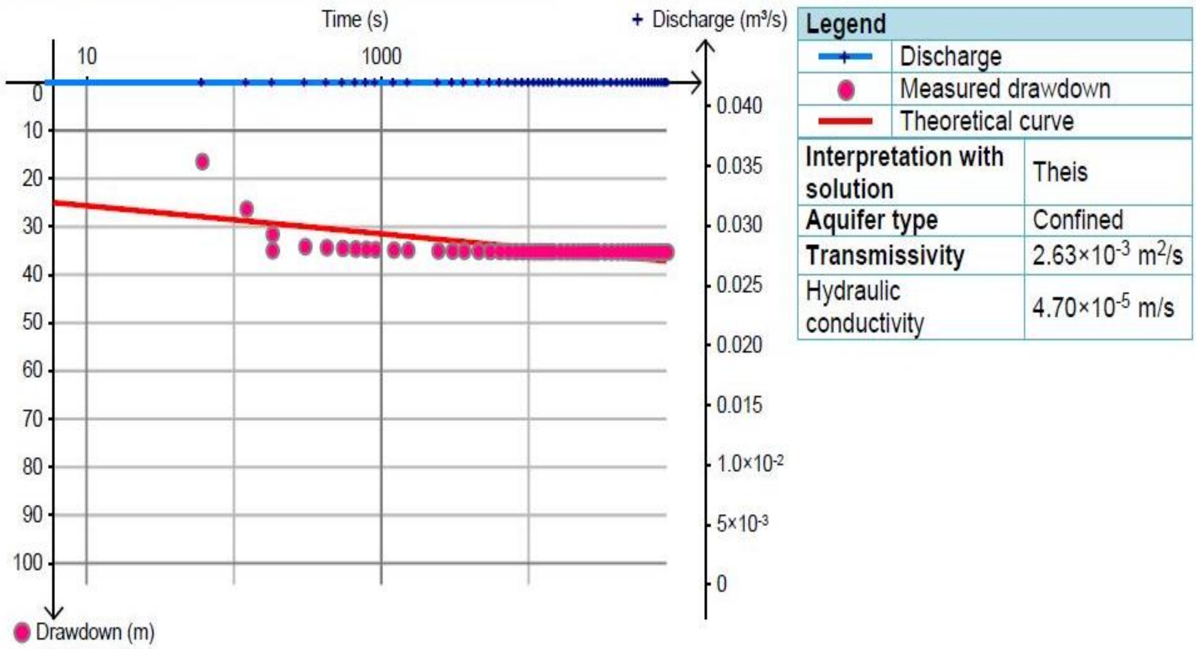


Figure 14: **Long-term pumping test at Oued El Alenda interpreted by theis method.**

V.3.14 Pumping test at Mihouensa:

Aquifer width	77 m	**Observation radius**	10 m
Well type	Well		

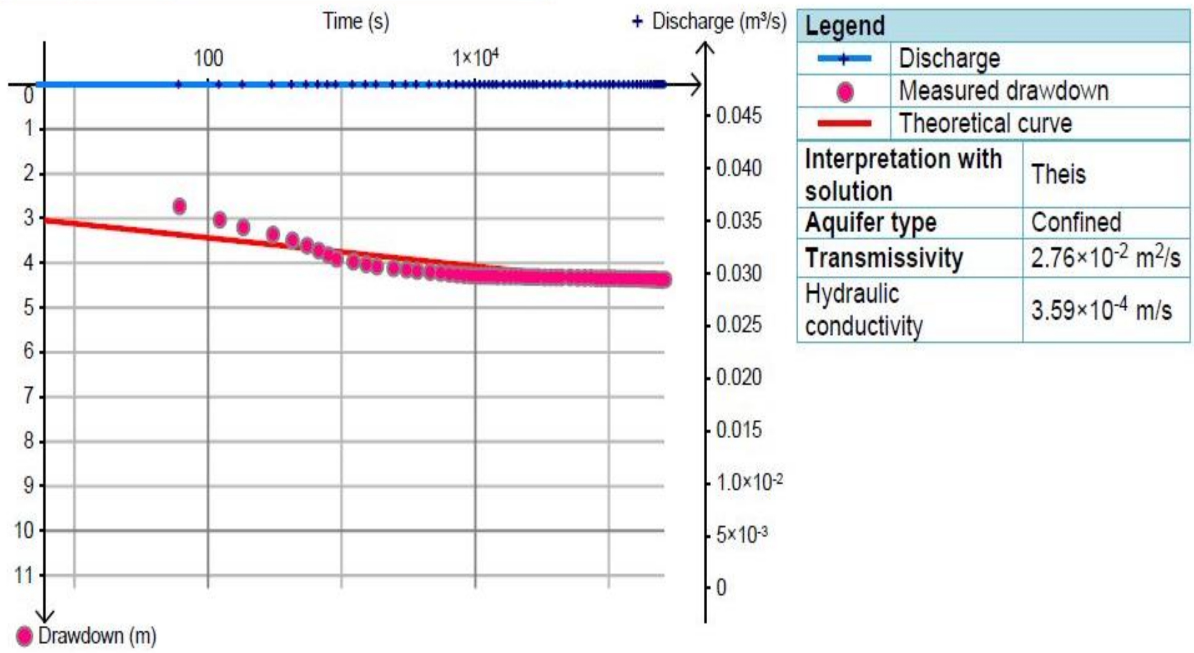


Figure 15: **Long-term pumping test at Mihouensa interpreted by theis method.**

V.4 Flow velocity:

The speed of water flow varies from one region to another. The slight variation observed at the equipotential level: **V = K × I .**

K= coefficient of the permeability, i = Hydraulique gradient.

To calculate the flow velocity, one must derive the hydraulic gradient value at from the piezometric map and multiply this value by the permeability.

The gradient hydraulic: I = ΔH / L, **ΔH:** the loss of hydraulic head and **L:** the distance between these two points.

V.5 Well data list:

Table 01: Well data list *(According to OUED RIGH, SAADINE, and FOREMHYD COMPANY).*

Site	Pumping rate	Transmissivity	Permeability	Thickness	Porosity	Hydraulic gradient	Flow rate
	Q (m^3/s)	T (m^2/s)	K (10^{-3}m/s)	E (m)	(ω %)	I (%)	U=K.I/ω (10^{-5}m/s)
Guemar	0.047	0.01120	0.2240	50	11.8	**0.12**	0. 2277970
Hassi khalifa	0.05	0.00320	0.0533	60	14.67	0.15	0. 0545331
Trifaoui	0.055	0.01280	0.1780	72	12.75	0.129	0. 1798690
Reguiba	0.05	0.03840	0.5730	67	11	0.09	0. 4689280
El oued	3.70E-02	0.02100	0.6180	34	12.72	0.09	0.4370140
Sidi Aoun	0.04	0.01230	0.2560	48	14.44	0.075	0. 1330940
Nakhla Gharbiya	0.034	0.00365	0.1220	30	13.33	0.0435	0. 0397037
Nakhla Chamalia	0.04	0.01730	0.5780	30	13.29	0.0435	0. 1891870
Magrane	0.035	0.00351	0.0650	54	14	0.15	0. 0696429
Bayadha	0.048	0.00391	0.1030	38	14.21	0.18	0. 1303380
Mih Ouensa	0.048	0.02760	0.3580	77	14.09	0.09	0. 2289550
kouinine	0.037	0.00192	0.0400	48	12.7	0.12	0. 0377953
Robbah	0.033	0.00213	0.0584	36.5	13.7	0.12	0. 0511149
Oued El Alenda	0.042	0.00263	0.0470	56	13.75	0.0345	0. 0117838

V.6 Transmissivity map:

This map at the figure (16) establish the transmissivity of the aquifer of the terminal complex, and the territory that have very good transmissivity are Reguiba, El Nakhla, Ogla, El Oued and Hassani.

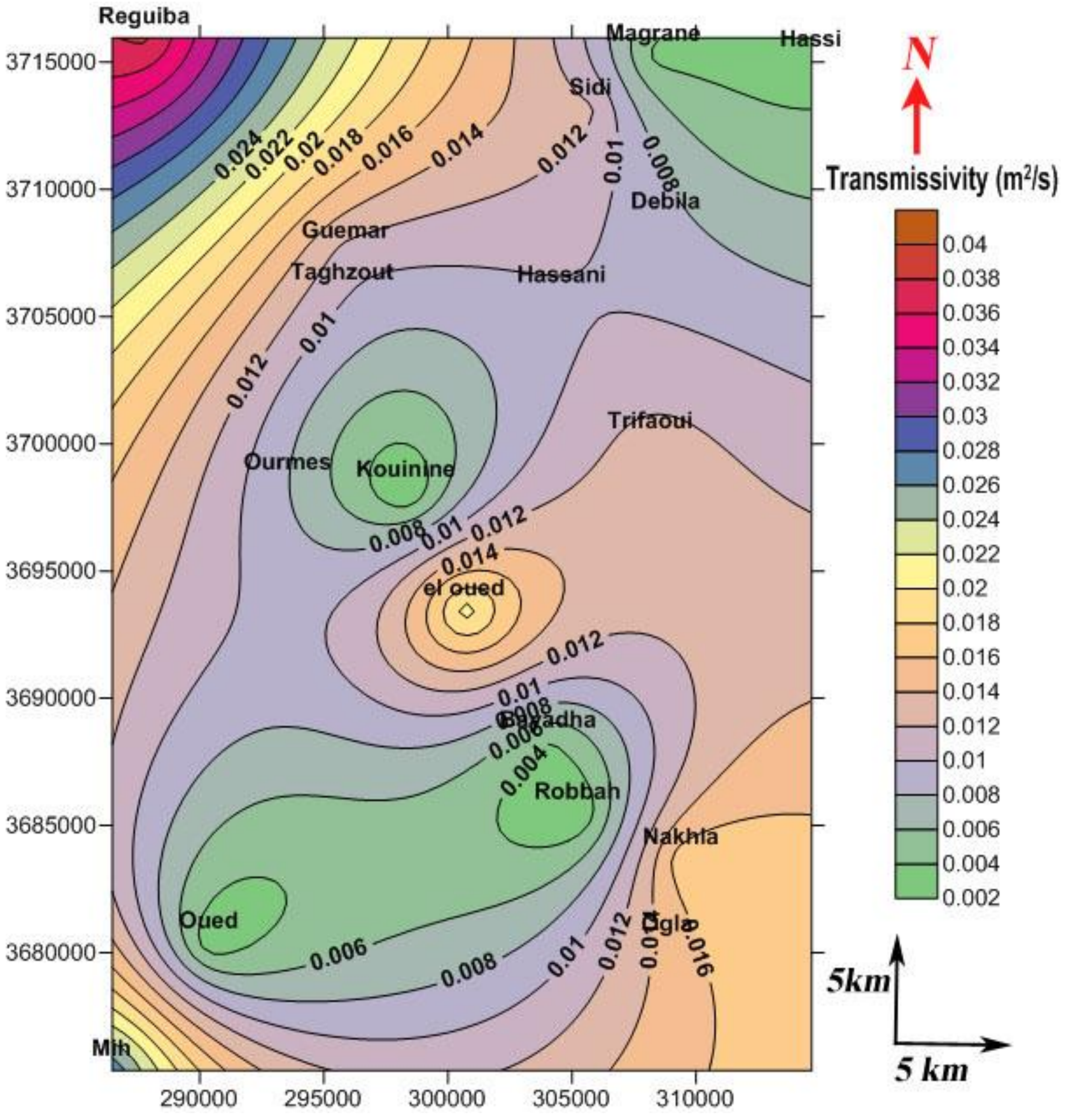


Figure (16): Transmissivity map of the valley of oued souf.

V.7 Permeability map:

The map at the figure (17) establish the permeability of the aquifer of the terminal complex, and the territory that have very good permeability are El oued, Reguiba, Mihouenssa, and Hassani.

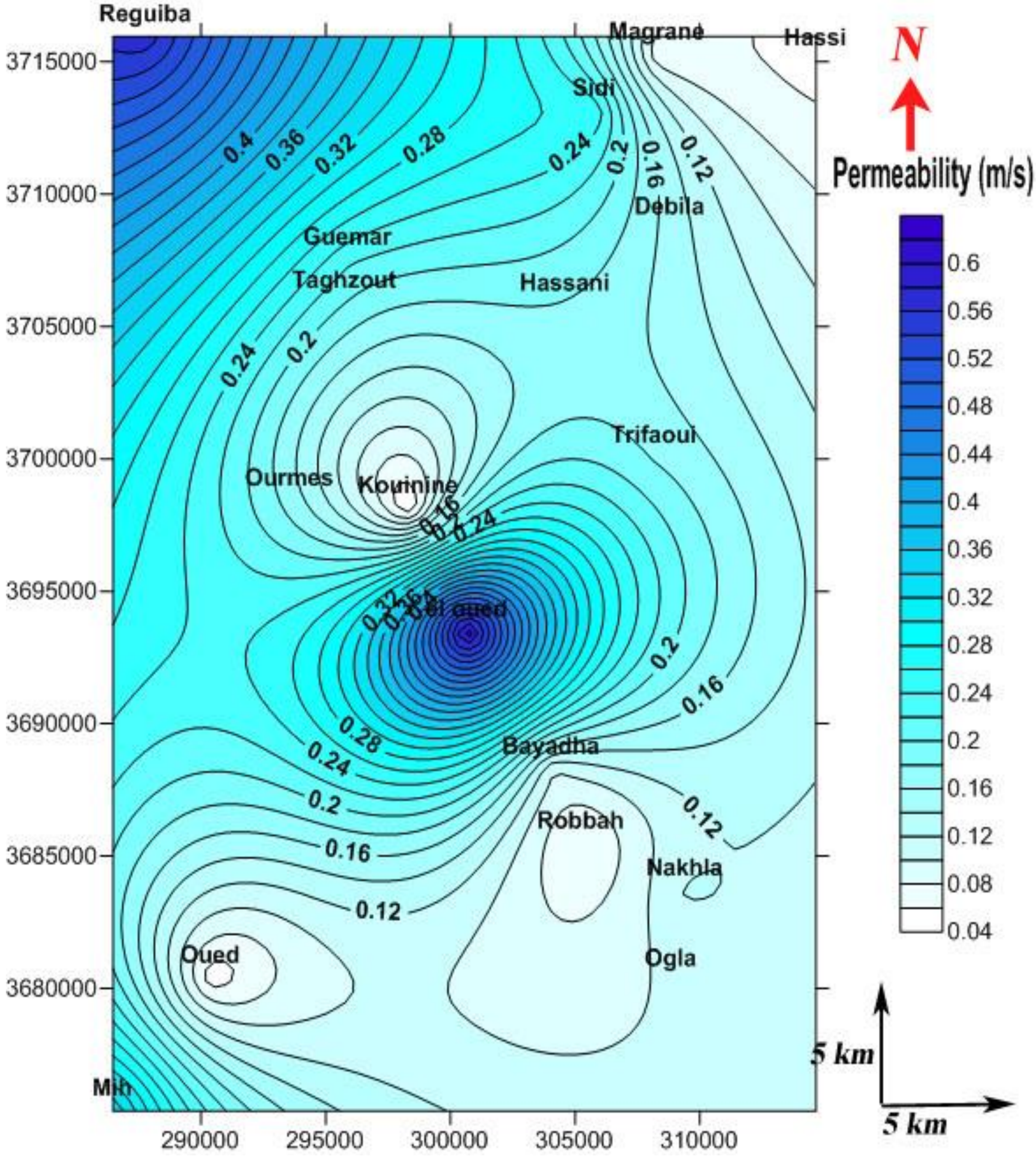


Figure (17): Permeability map of the valley of Oued souf.

V.8 Conclusion:

From this study, From this study, we find that the region has a specific geological features,, as well as tectonic and paleogeography conditions have allowed the establishment of a sedimentary series with a lithology varied in time, regular and homogeneous in space.

These conditions favored formation in Souf and throughout the lower Sahara of several aquifers with variable hydrodynamic behavior depending on their facies. The stratigraphy of the region is characterized by sedimentary series ranging from Lower Cretaceous to Quaternary deposits Recent Quaternary formations form the detrital aquifer of the aquifer phreatic, it is mostly sandy to sandstone with sometimes gypsum and localized clays especially in the north-east where it ends with a gypseous crust, its substratum is clayey impervious sometimes very little sandy at its summit or then gypsiferous In totality.

The aquifer system consists of three layers: free aquifer (phreatic), and two captive aquifers (terminal complex aquifer and inter-continental continental aquifer).

The interpretation of the stepwise and long-term pumping tests performed at the 03 stations allows us to define the hydrodynamic parameters of the aquifer from the terminal complex:

- The withdrawn flow rate oscillates between 10 l / s and 55.5 l / s
- Average transitivity of the TC web is 1.15 x 10^{-2} m^2 / s
- The permeability of TC in the region of Souf is between 10^{-3} and 10^{-4} m / s

For the most exploited layer of the miopliocene, which gives us an average value:

- Coefficient of permeability K = 2.34 x 10^{-4} m / s.

The average depth of the TC aquifer varies between 200 and 600 meters. As for the useful thickness of this layer, it is about 50 meters. *(NWRA, DWR 2016).*

Chapter VI:
Vulnerability estimation and calculates isochronous

VI.1 Introduction:

The vulnerability of groundwater is a complex concept because of the number of factors it involves and the importance that can be attributed to each of them. In other words, vulnerability is a function of the characteristics of the aquifer, essentially the soil cover and the unsaturated zone that controls the spread of pollution towards the aquifer.

The vulnerability of groundwater to pollution is expressed by the susceptibility of the aquifer to the various polluting agents exposed to the soil surface. The vulnerability of the aquifer does not vary; it is the degree of accessibility to the aquifer, which depends on physico-chemical parameters.

The method applied in our study is called **"wyssling"**. These studies carried out on 14 sites distributed in the study area of the Souf Valley.

VI.2 Purpose of the study:

The purpose of the study is:

- The vulnerability estimate for each borehole.
- Calculation and schematized the isochrones of each borehole.

VI.3 Description of the "*WYSSLING*" method:

VI.3.1 Determination of vulnerability:

It is necessary to have at least a geological section of the catchment work to assess its vulnerability. Some knowledge of the regional hydrogeological context is also required. We propose a method for a detailed vulnerability assessment where geological and hydrogeological data are known, as well as a summary evaluation method. The methods of summary and detailed evaluation are based on the findings carried out during the inventory of catchment structures carried out during the first phase of the project "Support for the establishment of a protection system for catchment areas.'AEP by the communes''.

The procedure is shown schematically in the flowchart on the following page.

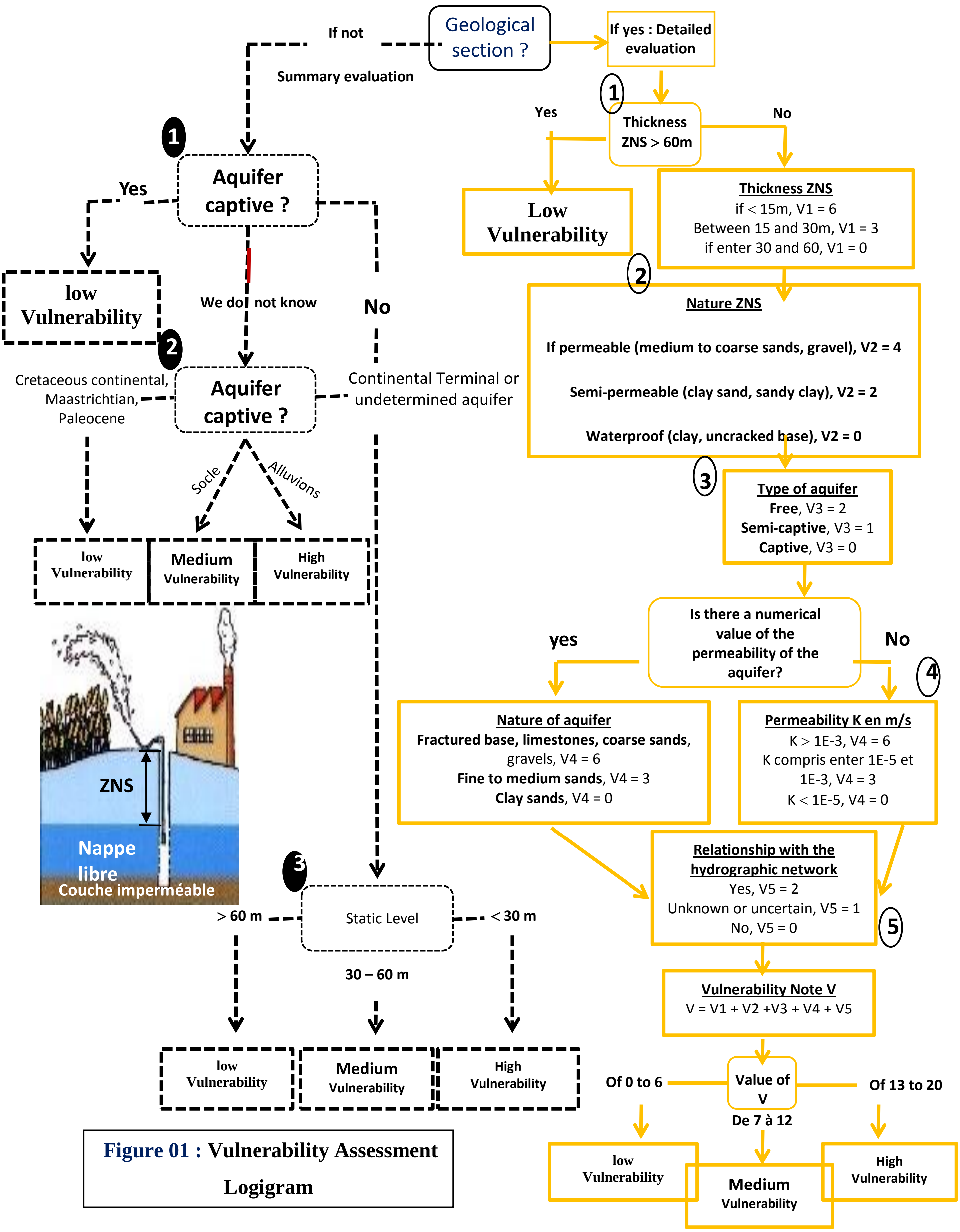


Figure 01 : Vulnerability Assessment Logigram

Presence of a geological section:

According to (Dourouni and Touahri, 2016): When a geological section is available, the detailed vulnerability assessment is based on five criteria:

1. The thickness of the unsaturated zone: it is a predominant parameter for the good geological protection of the aquifer. If the unsaturated zone is thick, the vulnerable of the aquifer is less, because the longer it will take a pollutant to reach the aquifer. In the event of a long transit time, the pollutant will thus be able to adsorb in the unsaturated formations or biodegrade before reaching the aquifer.

2. The nature of the unsaturated zone: after the thickness, the nature of the unsaturated zone also has a big role in the protection of the aquifer: impermeable formations (clays, uncracked base) will strongly slow or even transit of superficial infiltration towards the aquifer (low vulnerability for this criterion in this case). Conversely, permeable formations (unconsolidated coarse-grained soils such as medium-to-coarse sands, gravels) will allow water to infiltrate and superficial pollution (high vulnerability). Intermediate permeability formations (sandy clay, clay sand) will give the aquifer a medium vulnerability for this criterion. In the case of a heterogeneous unsaturated zone (presence of sands and clays, for example), the most favorable case must be considered if the impermeable formation is sufficiently thick (greater than about fifteen meters, which is sufficient to play a good role). Waterproof screen). It should be noted that an aquifer well protected by a thick and impervious unsaturated zone at the catchment level may, however, be vulnerable to any aquifer outcrop areas or areas where the unsaturated zone is absent or more permeable. .

3. The type of aquifer: a captive aquifer is protected from superficial infiltration for pressure reasons (low vulnerability for this criterion), unlike a free aquifer (strong vulnerability). There may be semi-captive aquifers in the event of a semi-permeable upper limit (medium vulnerability).

4. The permeability of the aquifer: this is the other predominant criterion of vulnerability. The more the aquifer is permeable, the greater the velocity of circulation of water (and therefore soluble pollutants) and the more vulnerable the water table is, the less time it takes to react to pollution and take the necessary measures to relief that is needed. This criterion only applies, However, when the pollution has reached the aquifer (catchment insufficiently protected by the unsaturated zone or pollution introduced directly into the aquifer by means of a borehole or in an area where the aquifer is no longer protected. because flush).

5. The relationship with the hydrographic network: watercourses and water bodies can easily carry pollution and possibly transfer them to the aquifers with which they are in hydraulic relation. The criterion "soil filtration capacity" would have been interesting to take into account, but these data are very little known in Benin.

If the thickness of the unsaturated zone is greater than 60m, the vulnerability is Low, we do not consider the other criteria. In the opposite case, one calculates a score out of 20 which makes it possible to classify the vulnerability in three classes (Low, Medium or Strong). For each of the 5 criteria listed above, there are 3 classes to which we assign the score 0, 1 or 2 (0 for the weakest vulnerability, 2 for the strongest, 1 for the intermediate vulnerability). We then apply a weighting on the criteria to take into account their relative importance: the predominant criteria (UNZ thickness and aquifer permeability) were assigned a weight of 3, the important criteria weighing 2 (nature UNZ) and other criteria with a weight of 1 (type of water table, relationship with hydrographic network). The type of aquifer, although very important, has only been affected by a weight of 1 because other criteria are already taken into account for a captive aquifer (the nature of the unsaturated zone is an impermeable formation, it is not There is no relationship with the hydrographic network and often the thickness of the UNZ will be strong).

The following table specifies the classes for each of the criteria and presents the already weighted scores (so for the criteria with a weight of 3 we will have the marks 0, 3 and 6, for a weight of 2: 0, 2 and 4; weight of 1: 0, 1 and 2).

Table 01: Vulnerability Criteria with Weighted Ratings:

Detailed vulnerability estimate			
Thickness of the unsaturated zone	**< 15 m V1 = 6**	**from 15 to 30 m V1 = 3**	**from 30 to 60m V1 = 0**
Nature of the unsaturated zone	**Permeable formations (medium to coarse sands, gravel) V2 = 4**	**Intermediate permeability formations (clay sands, sandy clays) V2 = 2**	**Waterproof or very low permeability formations (clays, uncracked base) V2 = 0**
Type of groundwater	**Free V3 = 2**	**Semi-captive V3 = 1**	**Captive V3 = 0**
Permeability K of the aquifer	**Strong: K> 10^{-3} m / s or aquifer composed of limestones, coarse sands, gravelsV4 = 6**	**Average: K between 10^{-5} and 10^{-3} m / s gold aquifer compound of fine to medium sands V4 = 3**	**Low: K less than 10^{-5} m / s or aquifer composed of clay sands or low permeability formations V4 = 0**
Relationship with the hydrographic network	**YES V5 = 2**	**Unknown or uncertain V5 = 1**	**No V5 = 0**

For the criterion "Permeability of the aquifer formation", preferentially rely on a numerical value of the permeability if it is known and if not on the nature of the aquifer formation. By adding the weighted scores of each of the criteria, we obtain a score of **V = V1 + V2 + V3 + V4 + V5** between 0 (the lowest vulnerability possible) and 20 (the highest vulnerability possible). The following table shows which vulnerability class corresponds to each range of notes:

Table 02: Correspondence between the weighted score and the vulnerability class:

V = V1+V2+V3+V4+V5 (weighted score / 20)	**from 0 to 6**	**from 7 to 12**	**from 13 to 20**
Vulnerability class	**Low**	**Average**	**Strong**

VI.3.2 Entry of protective perimeters:

To determine the extent of protection perimeters of non-alluvial free water, there are 03 cases, depending on the availability of data:

Complete hydrogeological data, sufficient to calculate the water transfer times: in this case the perimeters are calculated on the basis of a transfer time: the nearest protection perimeter is based on the isochronous 50 days (it is then 50 days maximum for react to pollution in the farest protection perimeter) and the farest Protection perimeter is based on the isochronous 200 days.nearest Protection Perimeter and farest Protection Perimeter are ellipses whose major axis is oriented in the direction of flow.

If only the nature of the aquifer is known, a transfer time is calculated based on the catchment flow and an estimate of the porosity of the aquifer (possibly using a table correspondence between the nature of the aquifer formation and the porosity to be retained if this is not known), considering a layer at pause, since in this case the direction of flow is not known. Nearest Protection Perimeter and farest Protection Perimeter are then circles.

If no data is available, the NPP and FPP are concentric circles of predefined radius. The radius of the perimeters obtained in the last two cases is then modulated according to the vulnerability. The ellipses or circles obtained can then be adapted to local conditions: exclusion of certain plots such as places of worship, inclusion of other plots where there are activities likely to pollute the groundwater.

VI.3.2.1 Complete hydrogeological data:

In the case where hydrogeological studies have been carried out, or can be done, the extent of the near and far protection perimeters is determined using the transfer time criterion, which leads to isochronous calculations by the method of ***Wyssling***. It is then necessary to know:

- The direction and the gradient of flow (to have a piezometric map).

- The geometry of the aquifer (its thickness at the level of the catchment).

- The permeability of the aquifer (from a long-term pumping test that will give).

- Transmissivity T, product of the permeability by the wet thickness).

- The effective porosity of the aquifer (can be directly derived from a tracing test, or from a pumping test, which will give the storage coefficient S. In free water, we can consider that S is of the same order of magnitude as effective porosity).

- The average flow of the catchment.

Table 03: Free-ground protection perimeters, with complete hydrogeological data:

Immediate protection perimeter (IPP) Sampling area	Nearest Protection Perimeter (NPP) Protection Zone	Farest protection perimeter (FPP) Zone of Vigilance
Circle of 15m minimum radius	Isochronous 50 days	Isochronous 200 days

➢ Calculation of isochronous :

The calculation of the isochrones is based on the ***Wyssling*** method, which assumes that the environnement is homogeneous.

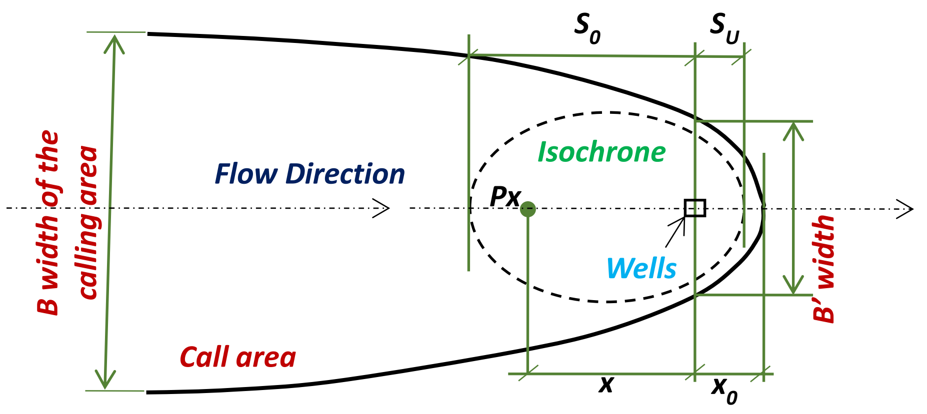


Figure 02: Determination of the calling area and isochronous by the Wyssling method.

On suppose that **B** the width of the call front, the capture rate **Q = T. B. i** with:

Q = flow of the catchment (m^3 / s).

T = Transmissivity (m^2 / s) = **K. e** / **K** = coefficient of the permeability (m / s).

e = wet thickness of the aquifer (m).

i = hydraulic gradient (dimensionless) = slope of the water table.

Hence: Q = T.B.i → B = Q / T.i

The calling radius (x0) corresponds to the downstream distance involved in the pumping.

All the water molecules included in the call zone will reach capture at some time.

All molecules outside the calling zone will flow without reaching the capture.

$$x_0 = \frac{Q}{2.\pi.T.i}$$

The width of the call front at the level of the collection B 'is equal to half of the total width of the calling area: $B' = \frac{B}{2} = \frac{Q}{2.T.i}$

Now, we know that the effective transfer speed, U = K.i / ω

With: **ω =** effective porosity.

The approximate values of S0 and Su, respectively the distances upstream and downstream on the flow axis, are:

$$S_0 = \frac{L + \sqrt{L(L + 8.x_0)}}{2}$$

$$S_u = \frac{-L + \sqrt{L(L + 8.x_0)}}{2}$$

With: L = U. t

If the direction of flow and the nature of the aquifer are known, but the data of permeability **K** and effective porosity **ω** are missing, it is possible to replace them at the standard values given in the table at the next page;

Table 04: **Permeabilities and porosities cleared standard**

Type of aquifer	Permeability K (m / s)	Effective Porosity Interval ω (%)	Effective porosity ω standard (%) to be used for calculations	Indicative radius en m of FPP for Q = 10m³ / h and e = 20m	Indicative range en m of NPP for Q = 10m³ / h and e = 20m
Gravel wholesale		30	30	25	50
Medium gravel	3.10^{-1}	25	25	28	55
Fine gravel		20	20	30	62
Sand and Gravel	1.10^{-2}	15 à 25	20	30	62
alluvium		8 à 10	10	45	87
Big Sand	2.10^{-3}	20	20	30	62
Medium sand	6.10^{-4}	15	15	36	71
Fine sand	7.10^{-4}	10	10	45	87
Very fine sand	2.10^{-5}	5	5	62	124
Silty sand	1.10^{-9}	5	5	62	124
Silt	3.10^{-8}	2	2	98	195
Vases		0.1	0.1	437	875
Cracked limestone		2 à 10	5	62	124
Chalk		2 à 5	3	80	160
Cracked sandstone		2 à 15	7	52	105
Cracked granite		0,1 à 2	0.5	195	390
Cracked basalt		8 à 10	10	44	87
shales		0,1 à 2	0.5	195	390

This table also gives the value of the radius of the circle for the NPP in each case, with the assumption of an aquifer at pause, a transfer time of 50 days, a flow of 10 m^3 / h and a thickness of 20 m. Be careful in the calculations to use the right units. In particular, the values in **%** must be divided over 100 (example 30% corresponds to 0.3). There is no need to modulate the size of the isochronous 50 days and 200 days depending at the vulnerability to define respectively the close and remote protection perimeter.

On the other hand, vulnerability plays a role on the content of the prescriptions: these will have to be more severe in case of high vulnerability.

- **Calculation of Perimeter of protection:**

Table 05: calculate the perimeter of protection (we use the List of data to obtain):

The value of :	B	B/2	X0	L50	L100	L200
Guemar	34.9702381	17.485119	5.56850925	984.081356	1968.16271	3936.32542
Hassi khalifa	104.166667	52.0833333	16.5870488	235.582822	471.165644	942.331288
Trifaoui	33.3091085	16.6545543	5.30399817	777.035294	1554.07059	3108.14118
Reguiba	14.4675926	7.2337963	2.30375678	2025.76934	4051.53867	8103.07734
El oued	19.5767196	9.78835979	3.11731203	1887.90233	3775.80466	7551.60932
sidi aoun	43.3604336	21.6802168	6.90452764	574.965374	1149.93075	2299.8615
nakhla gharbiya	214.139506	107.069753	34.0986474	171.51988	343.03976	686.07952
nakhla chamaliya	53.0300017	26.5150009	8.44426779	817.289391	1634.57878	3269.15756
magrane	66.4767331	33.2383666	10.5854671	300.857143	601.714286	1203.42857
bayadha	68.2011935	34.1005968	10.8600627	563.060854	1126.12171	2252.24342
mihouensa	19.3236715	9.66183575	3.07701775	989.08501	1978.17002	3956.34004
kouinine	160.590278	80.2951389	25.5717003	163.275591	326.551181	653.102362
robbah	129.107981	64.5539906	20.5585957	220.816318	441.632637	883.265274
oued el alenda	462.886428	231.443214	73.7080299	50.9058701	101.81174	203.623481
The value of :	S0	Su	S0	Su	S0	Su
Guemar	995.095109	11.0137535	1979.23741	11.074702	3947.43111	11.1056857
Hassi khalifa	265.066881	29.484059	502.284455	31.1188111	974.413152	32.081864
Trifaoui	787.502295	10.4670013	1564.60715	10.5365587	3118.71321	10.5720366
Reguiba	2030.36642	4.5970814	4056.14096	4.60228567	8107.68224	4.60489665
El oued	1894.1165	6.21416967	3782.02902	6.22436329	7557.83881	6.22948523
sidi aoun	588.457809	13.4924348	1163.57784	13.6470949	2313.58862	13.7271226
nakhla gharbiya	223.788774	52.2688944	401.331657	58.291897	748.58266	62.5031406
nakhla chamalia	833.842658	16.5532679	1651.29634	16.7175577	3285.95974	16.802179
magrane	320.717097	19.8599539	622.188551	20.4742654	1224.23962	20.811046
bayadha	584.002134	20.9412802	1147.43833	21.3166181	2273.75802	21.5146066
mihouensa	995.201225	6.11621461	1984.30503	6.13500867	3962.48453	6.14449265
kouinine	204.174315	40.898724	371.505887	44.9547058	700.767094	47.664732
robbah	256.248169	35.4318506	479.502499	37.8698624	922.628243	39.3629695
oued el alenda	115.74244	64.8365698	183.571213	81.7594727	302.766963	99.1434827

VI.3.2.2 Incomplete hydrogeological data:

If the direction of flow is totally unknown, but there is still data on the nature of the aquifer and / or its porosity, the Close Protection Perimeter and Remote Protection Perimeter are also based on transfer times 50 and 200 days, calculated on the assumption that the water table is at pause.

The Close Protection Perimeter and Remote Protection Perimeter are this time circles of radius r calculated according to the following formula:

$$r = \sqrt{\frac{Q.t}{\pi.e.\omega}}$$

The radius r is equal to the square root of the number obtained. However, the radius of the circle of the CPP can not be less than 100m (not to be less binding than captive tablecloth, where the aquifer is better protected), and the radius of the circle of the RPP can not be less than 300m.

Table 06: Protected perimeters in open water, with incomplete hydrogeological data

immediate protection perimeter (IPP) Sampling area	Nearest Protection Perimeter (NPP) Protection Zone	Farest protection perimeter (FPP) Zone of Vigilance
Circle of 15m minimum radius	**Circle corresponding to a transfer time of 50 days, to be modulated according to vulnerability. The radius of this circle can not be less than 100m.**	**Circle corresponding to a transfer time of 200 days, to be modulated according to vulnerability. The radius of this circle can not be less than 300m.**

The radius of the transfer time circles 50 and 200 days are modulated according to the vulnerability class of capture. The radius must increase in case of strong vulnerability (without exceeding twice the initial radius) and decrease in case of low vulnerability (without falling beyond half of the initial radius and without becoming smaller than the IPP). The radius must also be greater than a minimum threshold: 100m for NPP, 300m for FPP.

VI.4 Vulnerability estimation and calculates the isochronous:

Table 07: Table of Vulnerability estimation and calculates isochronous:

The Cities : / Description :	Guemar	Hassi khalifa	Trifaoui	Reguiba	El Oued
Type Work:	Drilling	Drilling	Drilling	Drilling	Drilling
Diameter (m):	24	24	24	24	24
Total depth (m):	331	396	305	367	278
Hydrogeology					
Aquifer captured :	captive	captive	captive	captive	captive
Static level:	48.43	45	50	44.86	52.39
Thickness of the Layer :	50	60	72	67	34
Recovery (nature) :	fine sand	fine yellow sand	yellowish fine sand very gypsum	fine to medium yellowish sand + gypsum	fine sand dune
Aquifer lithology :	brownish yellow sand and ferruginous heterogeneous sand	fine and medium ferruginous sand	ferruginous brownish mean sand	whitish siliceous hysterogenic sand	fine and medium ferruginous sand
Max usable flow rate :	0.047	0.05	0.055	0.05	0.037
The captured resource:	underground water	underground water	underground water	underground water	underground water
Type of aquifer:	sedimentary basin	sedimentary basin	sedimentary basin	sedimentary basin	sedimentary basin
Type of Layer :	captive	captive	captive	captive	captive
Alluvial aquifer?	no	no	no	no	no
Hydrodynamic data :	known	known	known	known	known
Determination of vulnerability:					
Geological section ?	Yes	Yes	Yes	Yes	Yes
Thickness (UNZ)> 60m ?	Yes	Yes	Yes	Yes	Yes
Result :	**low**	**low**	**low**	**low**	**low**

The Cities : / Description :	Sidi Aoun	Nakhla Gharbiya	Nakhla Chamaliya	Magran	Bayadha
Type Work:	Drilling	Drilling	Drilling	Drilling	Drilling
Diameter (m):	26	26	24	26	24
Total depth (m):	354	238	255	388	255
Hydrogeology					
Aquifer captured :	captive	captive	captive	captive	captive
Static level:	34.41	37.56	47.87	31.39	46.1
Thickness of the Layer :	48	30	30	54	38
Recovery (nature) :	fine whitish sand (dune)	fine whitish sand (dune)	fine sand dune	gypsum (sand rose)	fine whitish sand (dune)
Aquifer lithology :	fine and medium ferruginous sand	medium sand and ferruginous grains	medium sand and ferruginous grains	Fine sand, medium to coarse, siliceous with ferruginous grains	Fine sand, medium to coarse, siliceous with ferruginous grains
Exploitation					
Max usable flow rate :	0.04	0.034	0.04	0.035	0.048
The captured resource :	underground water	underground water	underground water	underground water	underground water
Type of aquifer :	sedimentary basin	sedimentary basin	sedimentary basin	sedimentary basin	sedimentary basin
Type of Layer :	captive	captive	captive	captive	captive
Alluvial aquifer ?	no	no	no	no	no
Hydrodynamic data :	known	known	known	known	known
Determination of the vulnerability :					
Geological section ?	Yes	Yes	Yes	Yes	Yes
Thickness (UNZ)> 60m ?	Yes	Yes	Yes	Yes	Yes
Result :	**low**	**low**	**low**	**low**	**low**

The Cities: / Description :	Mih Ouensa	Kouinine	Robbah	Oued El Alenda
Type Work :	Drilling	Drilling	Drilling	Drilling
Diameter(m):	22	22	24	24
Total depth(m) :	204	291	247	222
Hydrogeology				
Aquifer captured :	captive	captive	captive	captive
Static level:	34.2	47.3	53	32
Thickness of the Layer :	77	48	36.5	56
Recovery (nature) :	yellowish sand	whitish sand	fine whitish dune sand	yellowish dune sand
Aquifer lithology :	fine to medium ferruginous yellowish sand	medium to coarse fine sands, gravel,	medium sand and ferruginous grains	medium sand and ferruginous grains
Exploitation				
Max usable for rate :	0.048	0.037	0.033	0.042
The captured resource :	underground water	underground water	underground water	underground water
Type of aquifer:	sedimentary basin	sedimentary basin	sedimentary basin	sedimentary basin
Type of Layer :	captive	captive	captive	captive
Alluvial aquifer ?	no	no	no	no
Hydrodynamic data :	known	known	known	known
Determination of the vulnerability:				
Geological section ?	Yes	Yes	Yes	Yes
Thickness (UNZ)> 60m ?	Yes	Yes	Yes	Yes
Result :	**low**	**low**	**low**	**low**

VI.5. Isochronous drilling (using the method of Wyssling):

I have established these isochronous by using the results of calculation in the table (05).

VI.5.1 Isochronous drilling (El Oued):

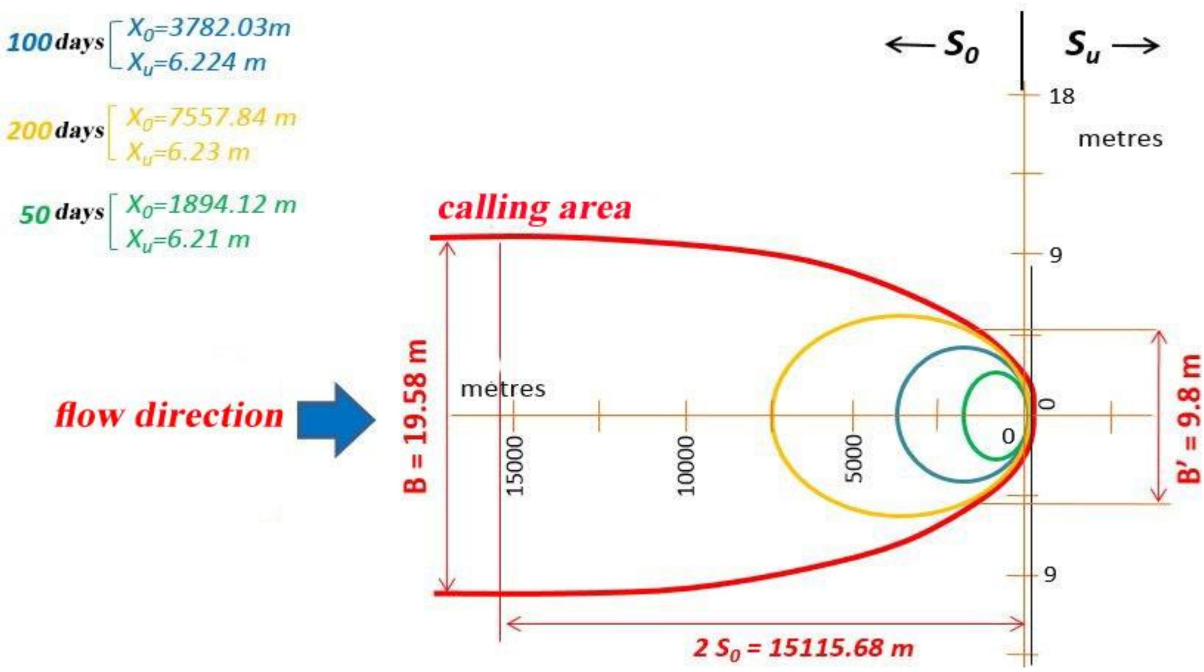


Figure 03: Determination of the calling area and the isochronous (El Oued).

VI.5.2 Isochronous drilling (Guemar):

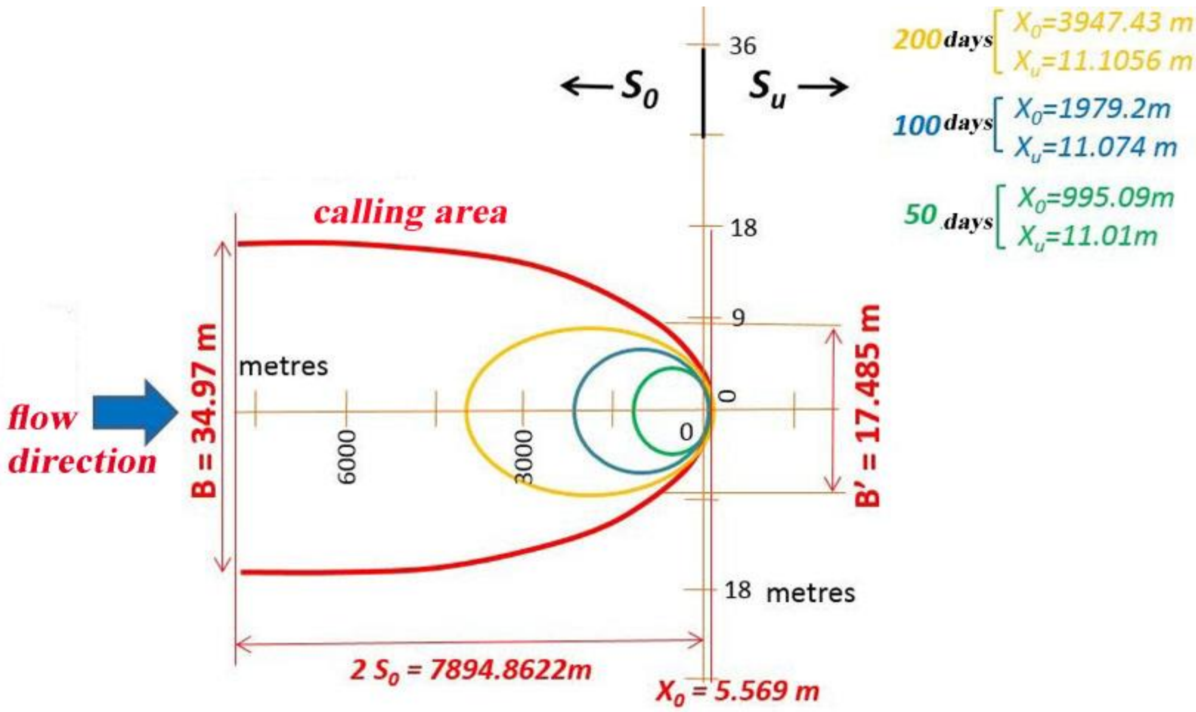


Figure 04: Determination of the calling area and the isochronous (Guemar).

VI.5.3 Isochronous drilling (Hassi khalifa):

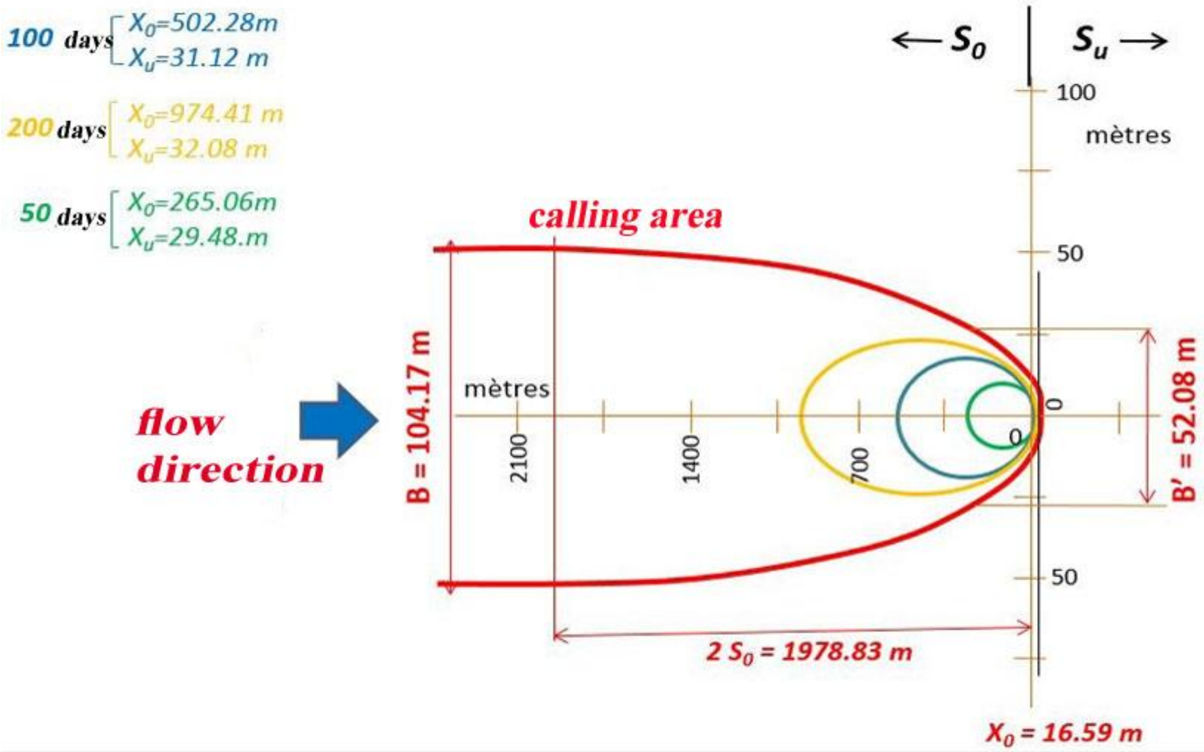


Figure 05: Determination of the calling area and the isochronous (Hassi khalifa).

VI.5.4 Isochronous drilling (Bayadha):

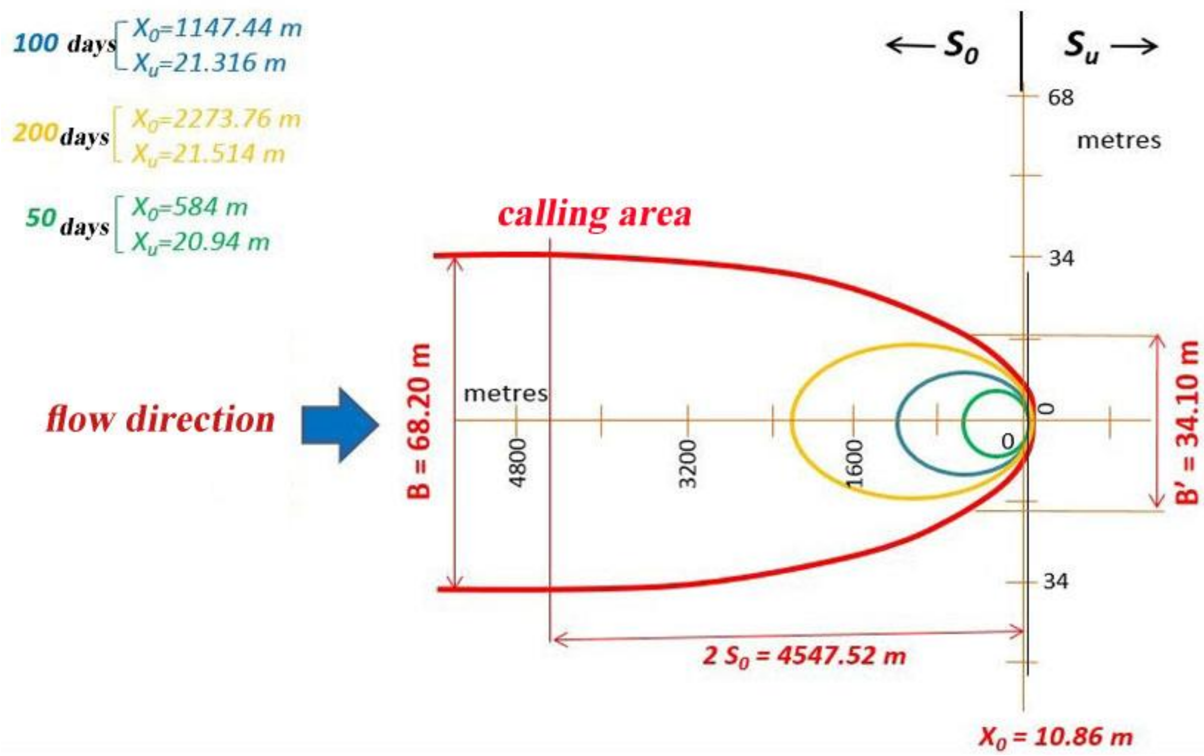


Figure 06: Determination of the calling area and the isochronous (Bayadha).

VI.5.5 Isochronous drilling (kouinine) :

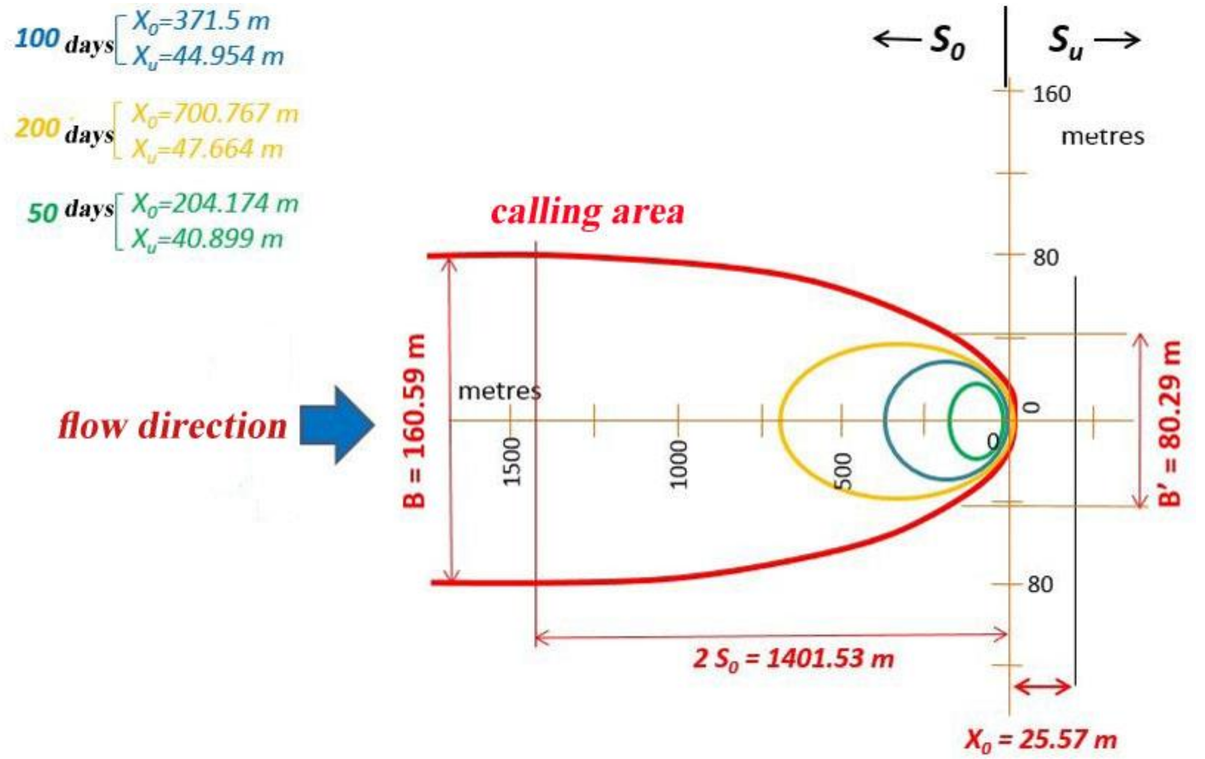


Figure 07: Determination of the calling area and the isochronous (kouinine).

VI.5.6 Isochronous drilling (Magran) :

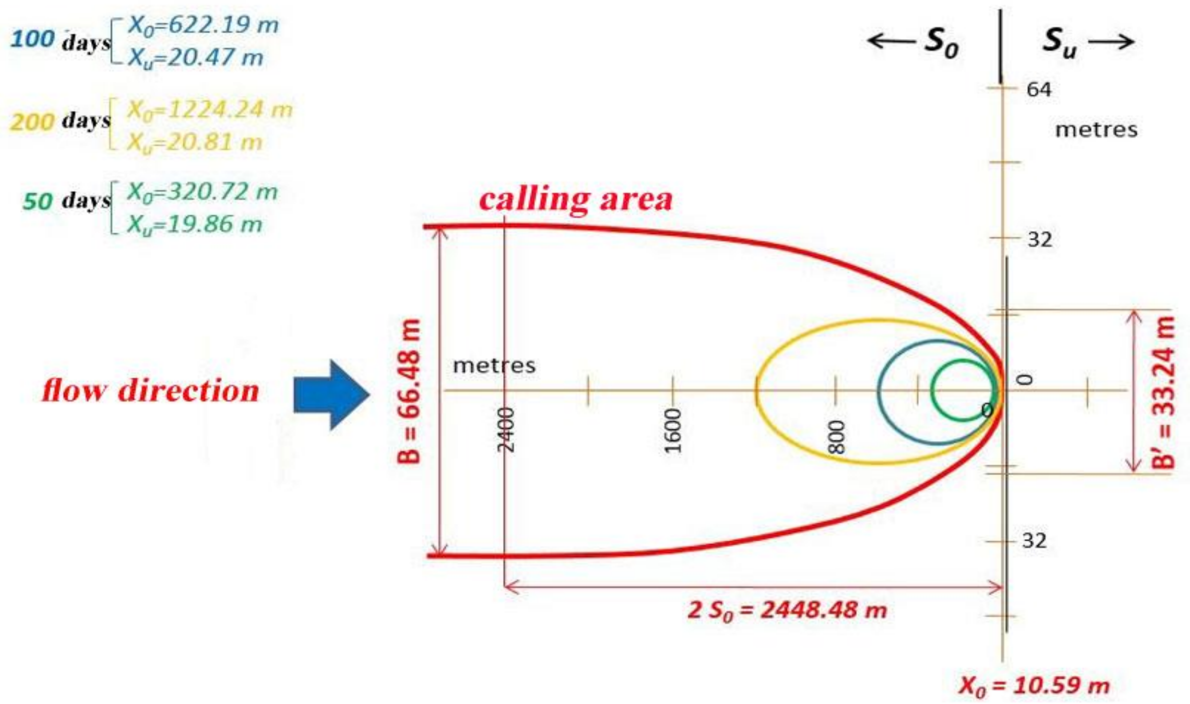


Figure 08: Determination of the calling area and the isochronous (Magran).

VI.5.7 Isochronous drilling (Mihouensa) :

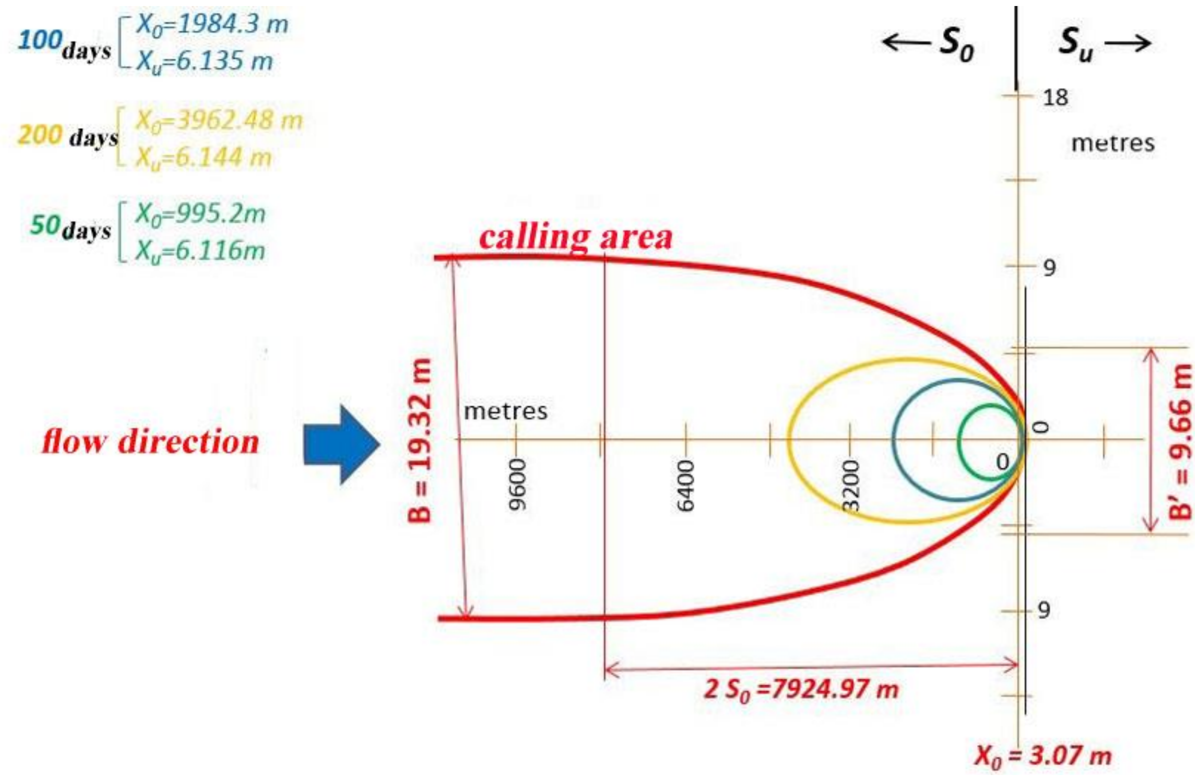


Figure 09: **Determination of the calling area and the isochronous (Mih Ouensa).**

VI.5.8 Isochronous drilling (Nakhla El Chamaliya):

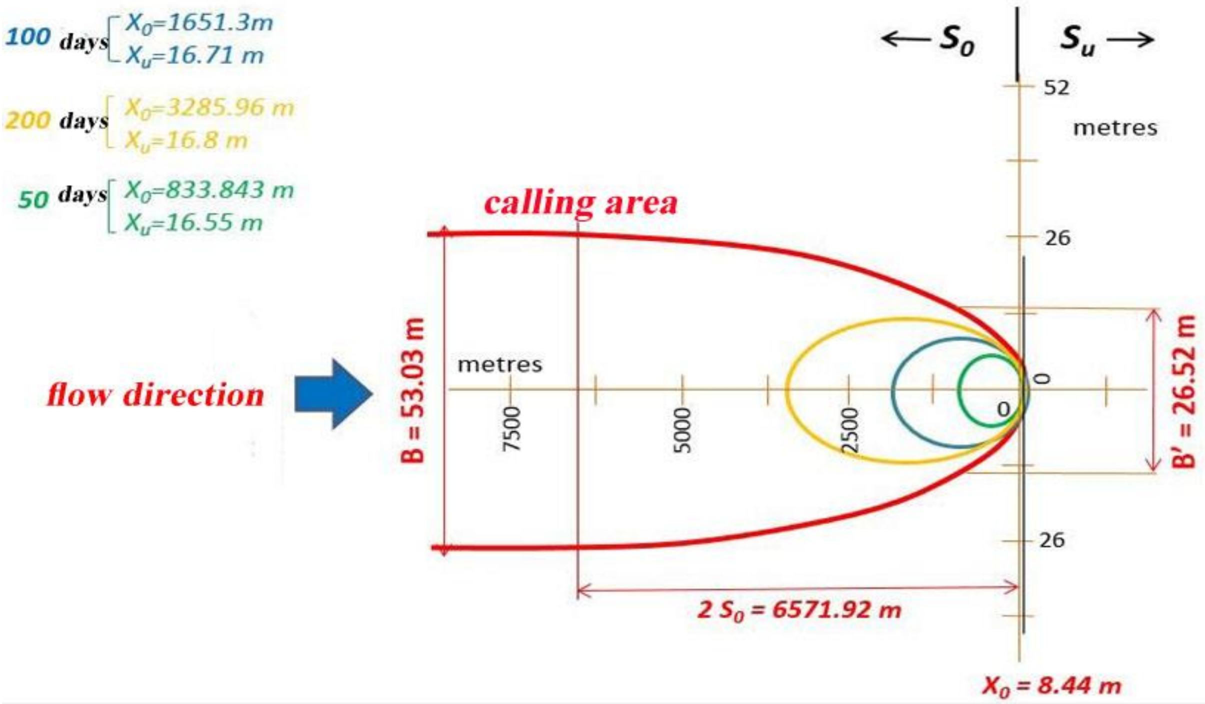


Figure10: **Determination of the calling area and the isochronous (Nakhla El Chamaliya).**

VI.5.9 Isochronous drilling (Nakhla El Gharbiya):

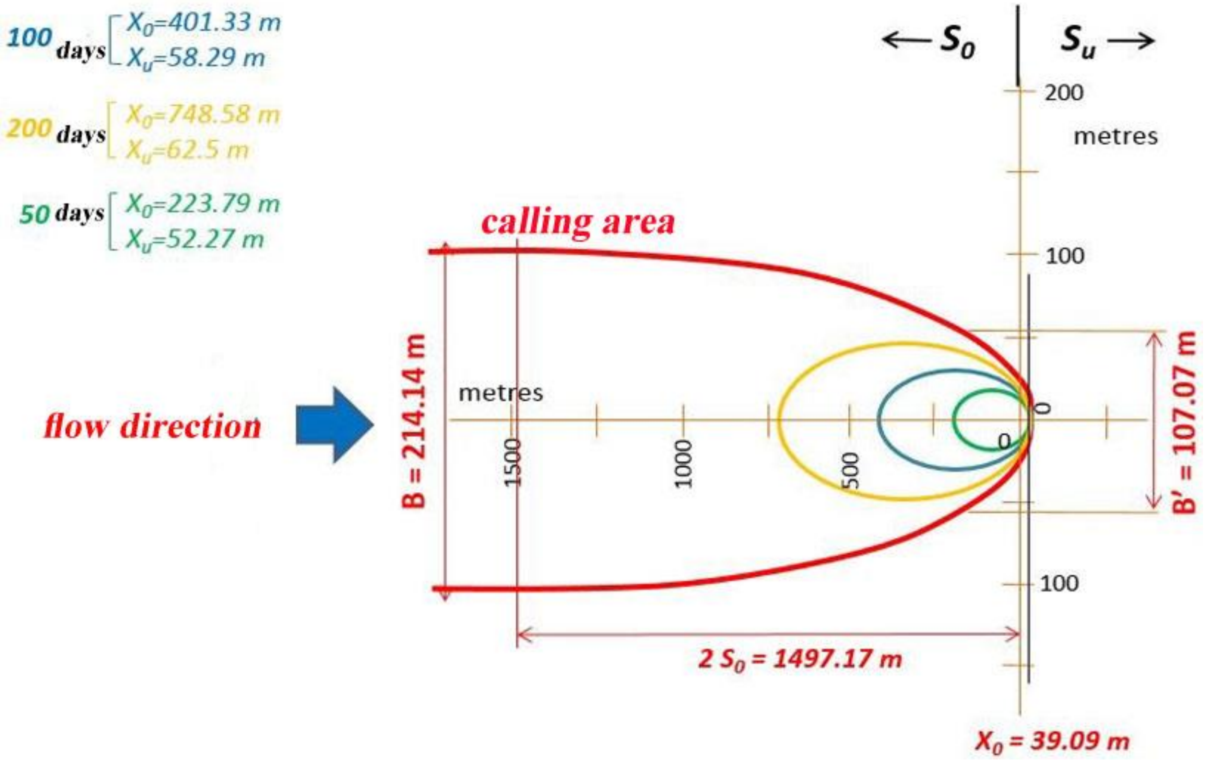


Figure 11: Determination of the calling area and the isochronous (Nakhla El Gharbiya).

VI.5.10 Isochronous drilling (Oued El Alenda):

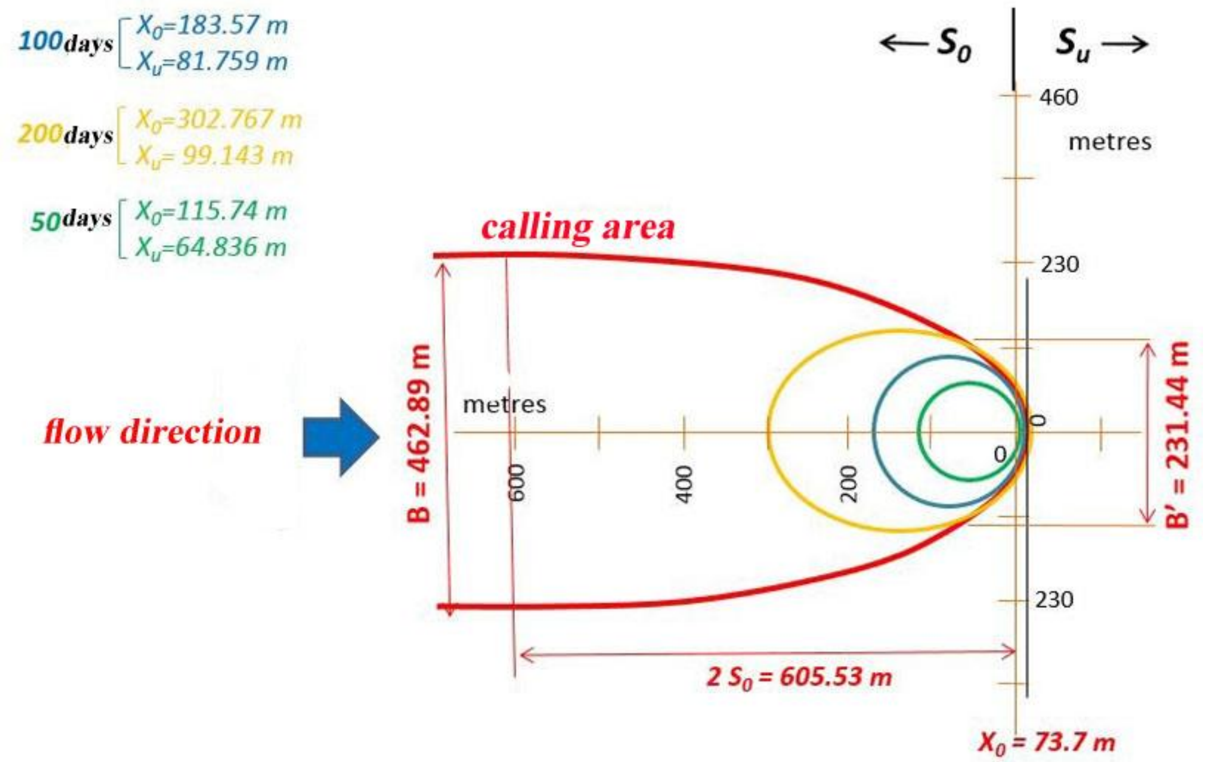


Figure 12: Determination of the calling area and the isochronous (Oued El Alenda).

VI.5.11 Isochronous drilling (Reguiba) :

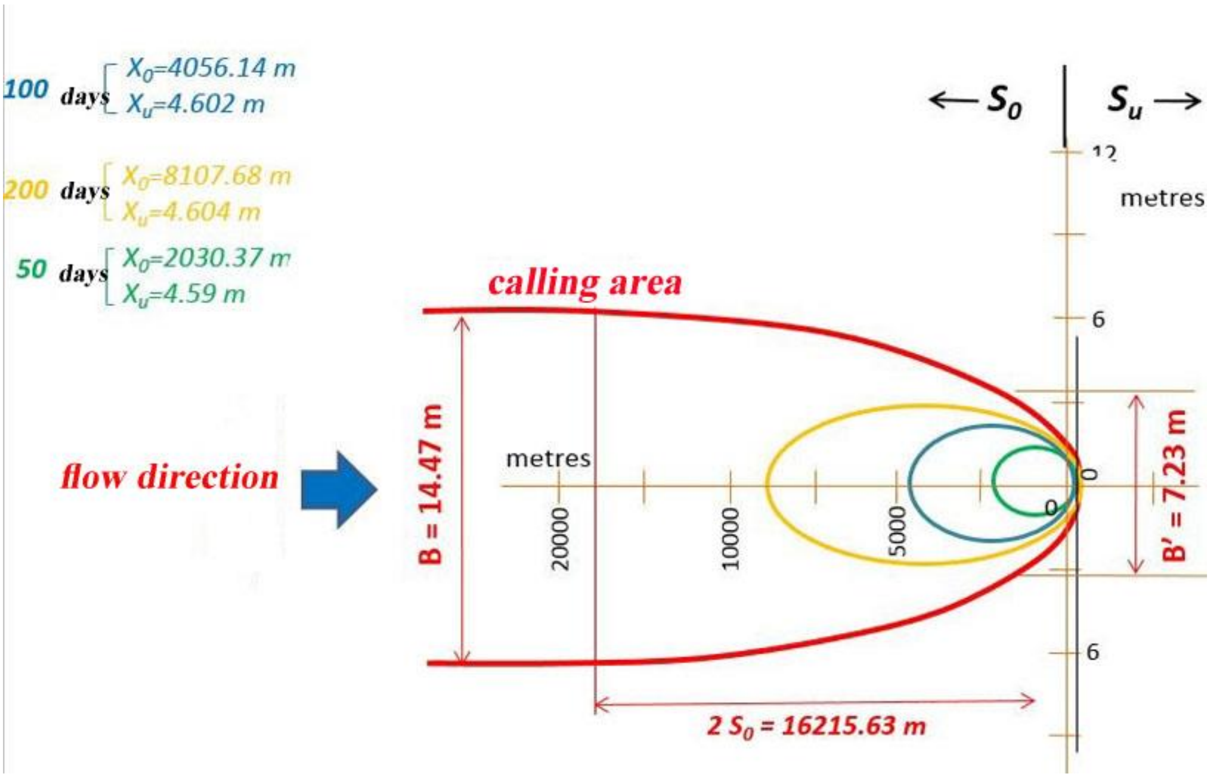


Figure 13: **Determination of the calling area and the isochronous (Reguiba).**

VI.5.12 Isochronous drilling (Robbah) :

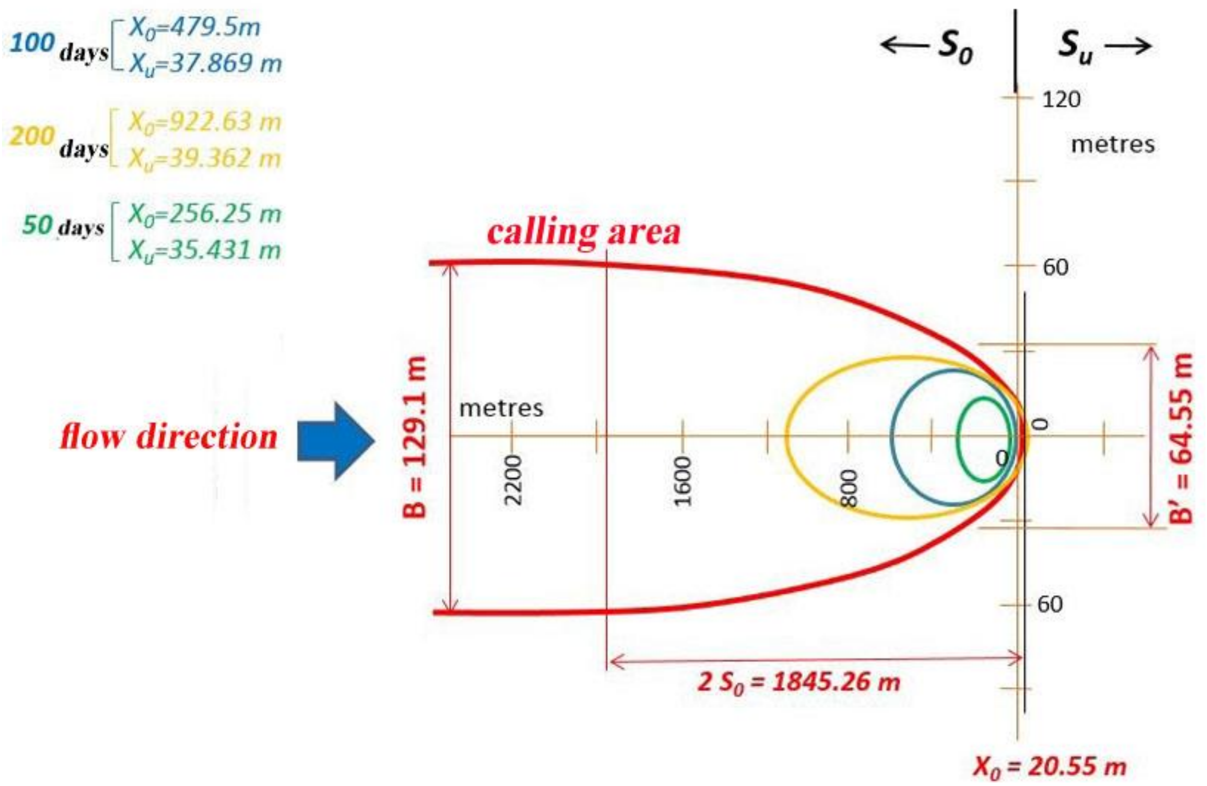


Figure 14: **Determination of the calling area and the isochronous (Robbah).**

VI.5.13 Isochronous drilling (Sidi Aoun):

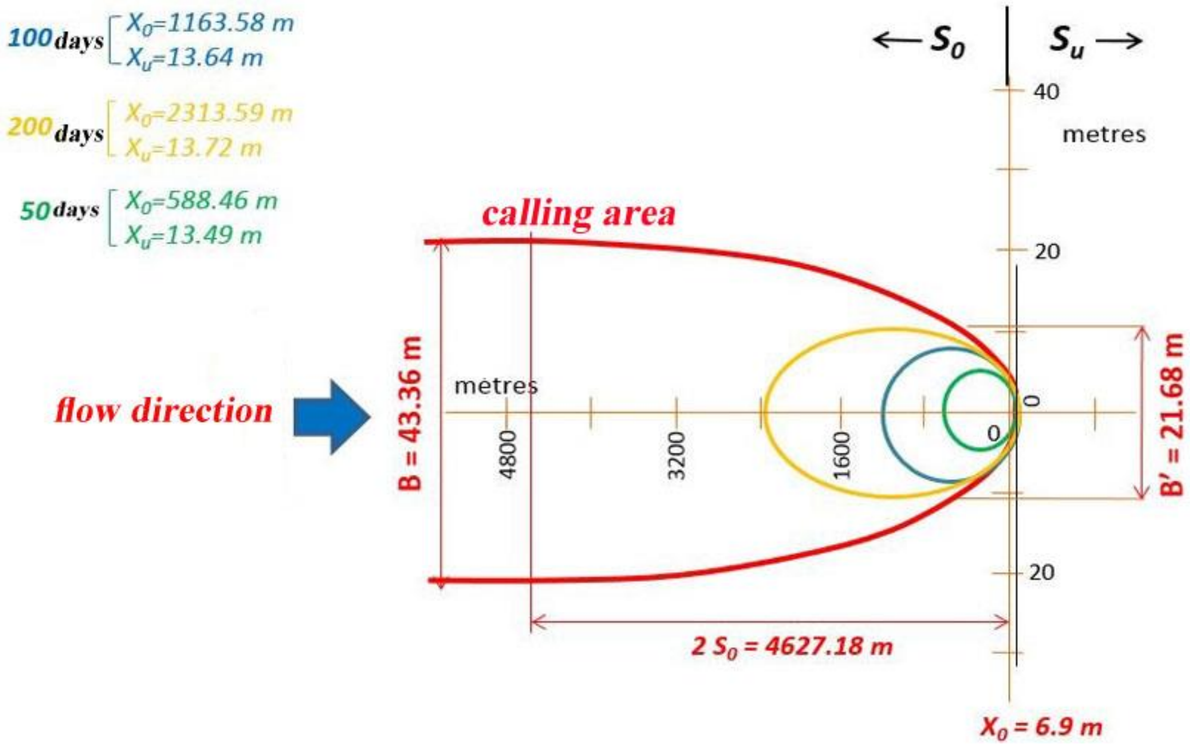


Figure 15: **Determination of the calling area and the isochronous (Sidi Aoun).**

VI.5.14 Isochronous drilling (Trifaoui) :

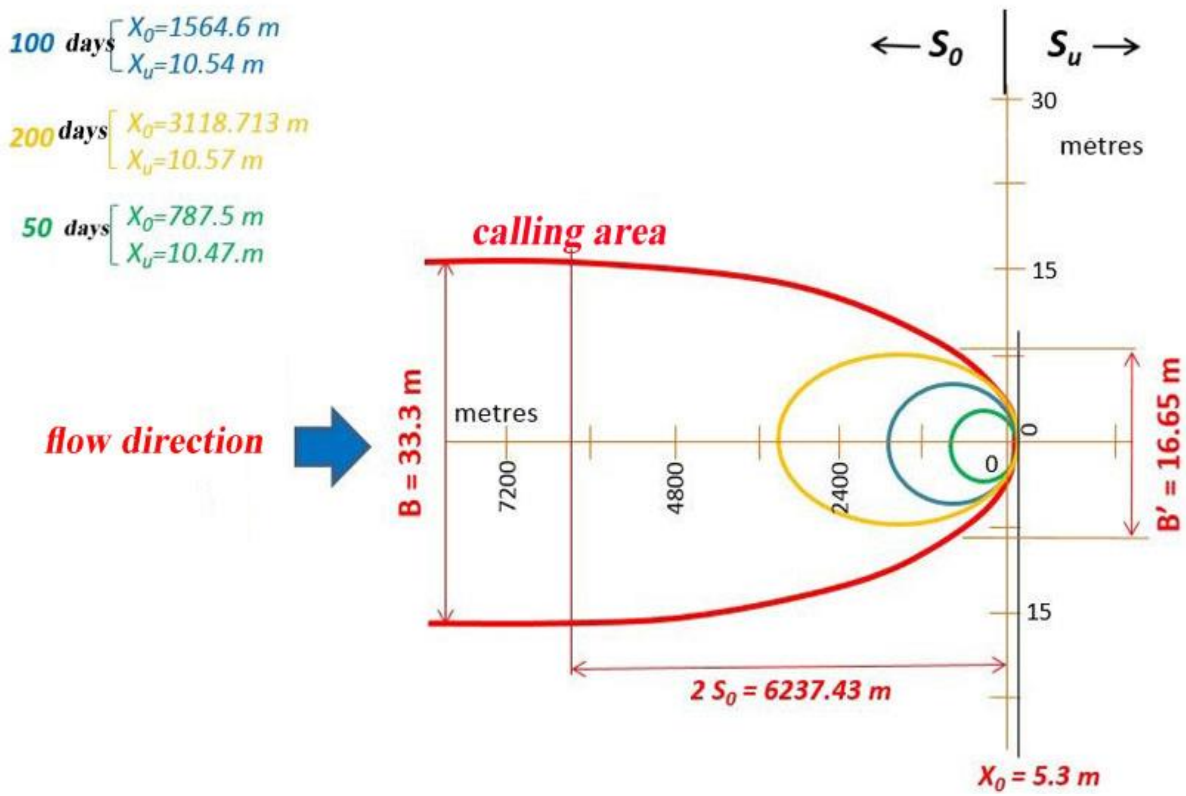


Figure 16: **Determination of the calling area and the isochronous (Trifaoui).**

VI.6 Conclusion:

After this study of vulnerability estimates and isochronous calculations it can be deduced that the aquifer of the terminal complex of the valley of Oued Souf is characterized by low vulnerability, and well-protected areas vary from place to other place according to geological features of the region and it can vary also according to other reasons like the water rising.

General conclusion

The valley of Oued souf has an important resource of water in the underground. It occupies an area of 44,586 km^2, represents 18 municipalities and includes a number of population of 529,842 inhabitants (in 2005).

The geological study allowed us to define the general framework of our region, represent the different layers deposited in the region that are of Miopliocene age until the Quaternary.

The hydroclimatology study define that the region of souf is characterized by an hyper-Saharan type climate with high temperatures and low rainfall.

From a hydrogeological study, the area has an underground water reserve very important: Phreatic, TC layer and IC layer.

The hydrodynamic study is used to determine the different parameters of the aquifer.

The results of the Wyssling method showed that the aquifer of the terminal complex is characterized by low vulnerability and weak sensitivity to pollotion.

The Wyssling's study allowed us to identify wellhead protection area (a remote protection perimeter and close protection perimeter), with the protection distance varying according to the surrounding characteristics of the well. This study is also important to preserve aquifers from pollution.

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- District of Hassi Khalifa.
- District of Bayadha, 18 February.
- District of Bent Lemkocher, Mih Ouensa.
- District of Oued Alanda, Dabadib.
- District of Robbah, Dridi.
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Used software :

- ***QUAIP-1.9.3 (help tool for interpreting test pumping).***
- ***Surfer software.***
- ***Microsoft Office 2013 (Excel, Word...).***
- ***Ps (Photoshop CS5 software).***

Annex:

01) Drilling pumping test: Guemar,Reguiba,El oued (DWR):

Guemar			Reguiba			El oued		
Time (min)	Dynamic level / well (m)	s (m)	Time (min)	Dynamic level / well (m)	s (m)	Time (min)	Dynamic level / well (m)	s (m)
0	48.43	0	0	44.86	0	0	52.39	0
1	51.68	3.25	1	47.54	2.68	1	55.84	3.45
2	56.18	7.75	2	47.66	2.8	2	55.96	3.57
3	56.72	8.29	3	47.73	2.87	3	56.01	3.62
4	57.24	8.81	4	47.77	2.91	4	56.05	3.66
5	57.57	9.14	5	47.78	2.92	5	56.08	3.69
7	57.86	9.43	7	47.78	2.92	7	56.13	3.74
9	57.93	9.5	9	47.79	2.93	9	56.14	3.75
10	58.16	9.73	11	47.81	2.95	10	56.16	3.77
15	58.19	9.76	15	47.85	2.99	15	56.22	3.83
20	58.21	9.78	20	47.87	3.01	20	56.26	3.87
25	58.23	9.8	25	47.9	3.04	25	56.28	3.89
30	58.25	9.82	30	47.93	3.07	30	56.3	3.91
45	58.26	9.83	45	47.96	3.1	45	56.32	3.93
60	58.26	9.83	60	48	3.14	60	56.36	3.97
75	58.27	9.84	75	48.03	3.17	75	56.37	3.98
90	58.28	9.85	90	48.05	3.19	90	56.38	3.99
105	58.27	9.84	105	48.07	3.21	105	56.39	4
120	58.28	9.85	120	48.08	3.22	120	56.41	4.02
180	58.27	9.84	180	48.14	3.28	180	56.45	4.06
240	58.27	9.84	240	48.18	3.32	240	56.51	4.12
300	58.27	9.84	300	48.22	3.36	300	56.57	4.18
600	58.27	9.84	360	48.24	3.38	360	56.59	4.2
900	58.27	9.84	420	48.25	3.39	420	56.6	4.21
1200	58.27	9.84	480	48.25	3.39	480	56.61	4.22
1500	58.27	9.84	600	48.25	3.39	600	56.63	4.24
1800	58.27	9.84	720	48.25	3.39	720	56.66	4.27
2100	58.27	9.84	1080	48.25	3.39	1080	56.69	4.3
2400	58.27	9.84	1440	48.25	3.39	1440	56.71	4.32
3000	58.27	9.84	2160	48.25	3.39	2160	56.76	4.37
3600	58.27	9.84	2880	48.25	3.39	2880	56.77	4.38
4200	58.27	9.84	4320	48.25	3.39	4320	56.77	4.38
4320	58.27	9.84						

02) Drilling pumping test: Hassi khalifa,Trifaoui,Nakhla Chamalia(DWR):

Hassi khalifa			Trifaoui			Nakhla chamalia		
Time (min)	Dynamic level / well (m)	s (m)	Time (min)	Dynamic level / well (m)	s (m)	Time (min)	Dynamic level / well (m)	s (m)
0	45	0	0	50	0	0	47.87	0
1	47.02	2.02	1	51.22	1.22	1	51.6	3.73
2	53.15	8.15	2	52.01	2.01	2	51.73	3.86
3	59.12	14.12	3	53.55	3.55	3	51.8	3.93
5	64.9	19.9	5	54.43	4.43	4	51.85	3.98
7	65.23	20.23	7	54.73	4.73	5	51.88	4.01
9	65.5	20.5	9	54.9	4.9	7	51.94	4.07
11	65.67	20.67	11	55.06	5.06	9	51.96	4.09
13	65.8	20.8	13	55.19	5.19	10	51.98	4.11
15	65.98	20.98	15	55.31	5.31	15	51.99	4.12
20	66.15	21.15	20	55.42	5.42	20	52	4.13
25	66.35	21.35	25	55.52	5.52	25	52.11	4.24
30	66.56	21.56	30	55.61	5.61	30	52.15	4.28
40	66.76	21.76	40	55.67	5.67	45	52.18	4.31
50	66.88	21.88	50	55.73	5.73	60	52.23	4.36
1h	67.07	22.07	1h	55.78	5.78	75	52.28	4.41
12	67.39	22.39	15	55.82	5.82	90	52.3	4.43
30	67.54	22.54	30	55.85	5.85	105	52.32	4.45
45	67.62	22.62	45	55.87	5.87	120	52.38	4.51
2h	67.74	22.74	2h	55.88	5.88	180	52.42	4.55
15	67.86	22.86	15	55.89	5.89	240	52.49	4.62
30	67.88	22.88	30	55.9	5.9	300	52.54	4.67
45	67.9	22.9	45	55.9	5.9	360	52.58	4.71
3h	67.91	22.91	3h	55.91	5.91	420	52.61	4.74
15	67.92	22.92	15	55.91	5.91	480	52.64	4.77
30	67.93	22.93	30	55.91	5.91	600	52.7	4.83
45	67.94	22.94	45	55.92	5.92	720	52.74	4.87
4h	67.94	22.94	4h	55.93	5.93	1080	52.95	5.08
30	67.95	22.95	30	55.95	5.95	1440	52.99	5.12
5h	67.95	22.95	5h	55.95	5.95	2160	53.06	5.19
30	67.95	22.95	30	55.95	5.95	2880	53.08	5.21
6h	67.95	22.95	6h	55.95	5.95	4320	53.08	5.21
30	67.96	22.96	30	55.96	5.96			
7h	67.96	22.96	7h	55.96	5.96			
30	67.96	22.96	30	55.96	5.96			
8h	67.96	22.96	8	55.96	5.96			
9h	67.96	22.96	9	55.96	5.96			
10h	67.97	22.97	10	55.97	5.97			

03) Drilling pumping test: Magran,Nakhla Gharbiya,Sidi Aoun (DWR):

Magrane			Nakhla Gharbia			Sidi Aoun		
Time min	Dynamic level / well (m)	s (m)	Time min	Dynamic level / well (m)	s (m)	Time min	Dynamic level / well (m)	s (m)
0	31.39	0	0	37.56	0	0	34.41	0
1	42.01	2.73	1	53.7	16.14	1	39.9	5.49
2	51.37	1.86	2	58.3	20.74	2	41.55	7.14
3	52.17	0.93	3	58.8	21.24	3	41.58	7.17
5	52.48	-1.02	5	59.07	21.51	5	41.61	7.2
7	52.65	-6.99	11	59.26	21.7	7	41.65	7.24
9	52.82	-10.93	15	59.34	21.78	13	41.71	7.3
11	52.88	-15.91	20	59.39	21.83	15	41.73	7.32
13	52.92	-20.89	25	59.4	21.84	20	41.77	7.36
15	52.95	-25.88	30	59.42	21.86	25	41.8	7.39
20	53.01	-30.87	35	59.45	21.89	30	41.82	7.41
30	53.13	-35.76	40	59.47	21.91	40	41.84	7.43
35	53.17	-45.72	50	59.48	21.92	50	41.88	7.47
40	53.18	-55.69	60	59.5	21.94	60	41.9	7.49
50	53.3	-70.64	75	59.52	21.96	75	41.92	7.51
60	53.32	-85.59	90	59.54	21.98	90	41.93	7.52
75	53.36	-100.57	105	59.55	21.99	105	41.95	7.54
90	53.41	-115.55	120	59.57	22.01	120	41.96	7.55
15	53.45	-145.49	150	59.58	22.02	150	41.96	7.55
120	53.48	-175.45	180	59.59	22.03	180	41.96	7.55
150	53.56	-235.38	240	59.59	22.03	210	41.97	7.56
180	53.63	-295.33	300	59.59	22.03	240	41.98	7.57
210	53.68	-355.29	360	59.59	22.03	300	41.99	7.58
240	53.7	-415.26	420	59.59	22.03	360	42.01	7.6
300	53.76	-475.23	480	59.59	22.03	420	42.02	7.61
360	53.8	-535.17	540	59.59	22.03	480	42.03	7.62
420	53.83	-595.13	600	59.59	22.03	540	42.04	7.63
480	53.85	-654.92	660	59.6	22.04	600	42.05	7.64
540	53.87	-714.88	720	59.6	22.04	660	42.06	7.65
600	53.89	-834.81	840	59.6	22.04	720	42.07	7.66
660	53.91	-954.79	960	59.6	22.04	840	42.08	7.67
960	53.94	-1074.7	1080	59.6	22.04	960	42.09	7.68
1080	53.94	-1200	1200	59.6	22.04	1080	42.1	7.69
1200	53.95	-1320	1320	59.6	22.04	1200	42.11	7.7
1320	53.95	-1440	1440	59.6	22.04	1320	42.12	7.71
1440	53.95	-1560	1560	59.61	22.05	1440	42.13	7.72
1560	53.96	-1680	1680	59.61	22.05	1560	42.14	7.73
168	53.96	-1860	1860	59.61	22.05	1680	42.15	7.74

Annex:

04) Drilling pumping test: Bayadha,Robbah,Kouinine (Saadine Company):

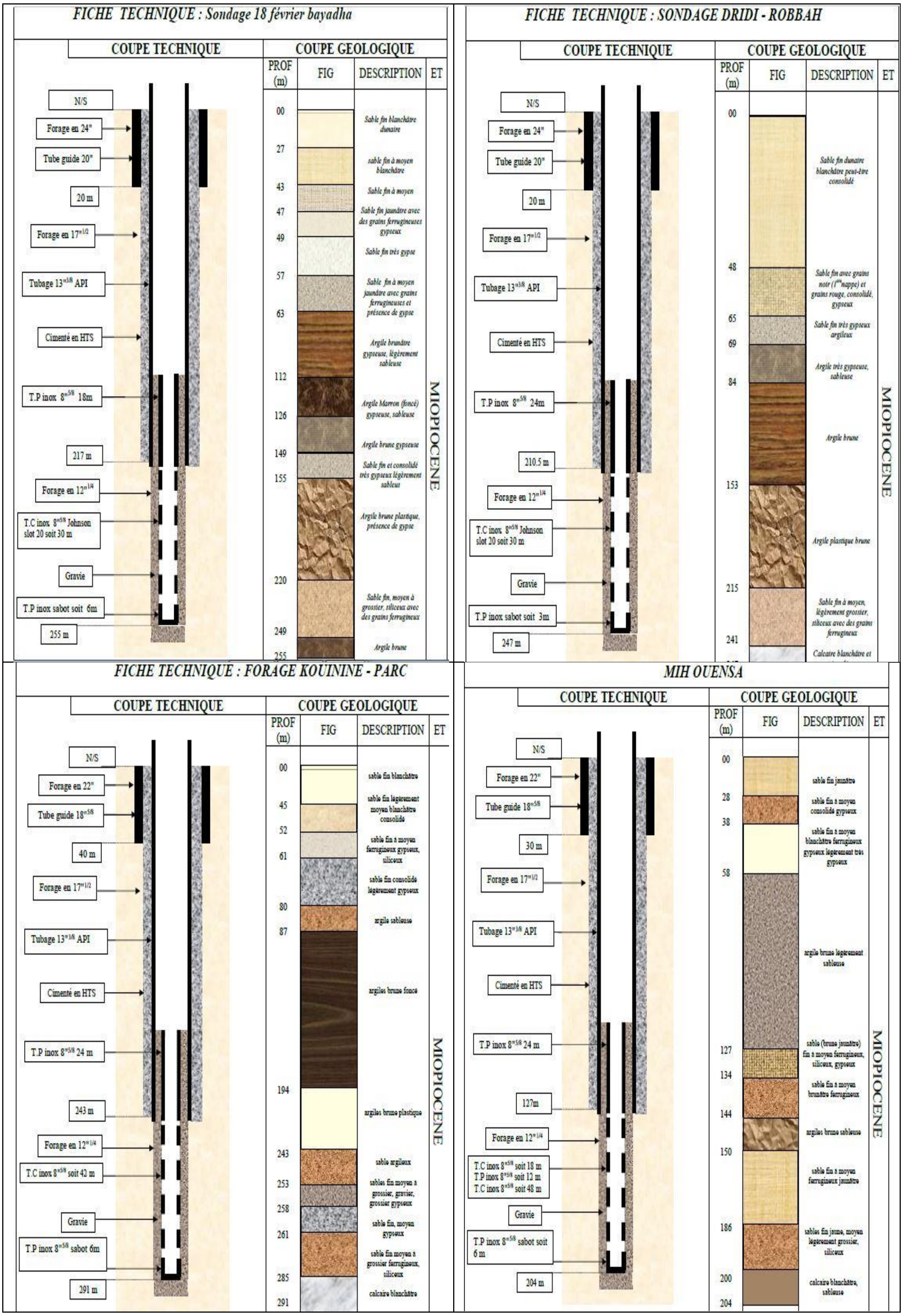
Bayadha			Robbah			Kouinine		
Time min	Dynamic level / well (m)	s (m)	min	Dynamic level / well (m)	s (m)	Time min	Dynamic level / well (m)	s (m)
0	46.1	0	0	53	0	0	47.3	0
1	60.02	13.92	1	60.02	12.92	1	62.02	12.92
2	68.55	22.45	2	68.55	20.45	2	73.15	20.45
3	71.04	24.94	3	75.04	21.94	3	85.45	21.94
5	71.39	25.29	5	77.39	20.29	5	86.74	20.29
7	71.51	25.41	7	78.51	18.41	7	87.32	18.41
9	71.6	25.5	9	79.6	16.5	9	88	16.5
11	71.65	25.55	11	80.43	14.55	11	88.63	14.55
13	71.7	25.6	13	80.73	12.6	13	88.93	12.6
15	71.73	25.63	15	80.9	10.63	15	89.1	10.63
20	71.76	25.66	20	81.06	5.66	20	89.26	5.66
25	71.78	25.68	25	81.19	0.68	25	89.39	0.68
30	71.79	25.69	3	81.31	22.69	3	89.51	22.69
40	71.8	25.7	40	81.42	-14.3	40	89.62	-14.3
50	71.81	25.71	50	81.52	-24.29	50	89.72	-24.29
60	71.81	25.71	60	81.61	-34.29	60	89.81	-34.29
75	71.82	25.72	75	81.67	-49.28	75	89.87	-49.28
90	71.82	25.72	90	81.73	-64.28	90	89.93	-64.28
105	71.83	25.73	105	81.78	-79.27	105	89.98	-79.27
120	71.83	25.73	120	81.82	-94.27	120	90.05	-94.27
135	71.84	25.74	135	81.85	-109.26	135	90.08	-109.26
150	71.84	25.74	150	81.88	-124.26	150	90.1	-124.26
165	71.84	25.74	165	81.9	-139.26	165	90.12	-139.26
180	71.85	25.75	180	81.92	-154.25	180	90.14	-154.25
195	71.85	25.75	195	81.94	-169.25	195	90.16	-169.25
210	71.85	25.75	210	81.96	-184.25	210	90.17	-184.25
225	71.86	25.76	225	81.97	-199.24	225	90.18	-199.24
240	71.86	25.76	240	81.98	-214.24	240	90.19	-214.24
270	71.86	25.76	270	81.99	-244.24	270	90.2	-244.24
300	71.86	25.76	300	82	-274.24	300	90.2	-274.24
330	71.87	25.77	330	82	-304.23	330	90.2	-304.23
360	71.87	25.77	360	82	-334.23	360	90.21	-334.23
390	71.87	25.77	390	82	-364.23	390	90.21	-364.23
420	71.87	25.77	420	82.01	-394.23	420	90.21	-394.23
450	71.87	25.77	450	82.01	-424.23	450	90.22	-424.23
480	71.88	25.78	480	82.01	-454.22	480	90.22	-454.22
540	71.88	25.78	540	82.01	-514.22	540	90.22	-514.22
600	71.88	25.78	600	82.01	-574.22	600	90.22	-574.22
660	71.88	25.78	660	82.02	-634.22	660	90.22	-634.22
720	71.88	25.78	720	82.02	-694.22	720	90.23	-694.22

05) Drilling pumping test: Oued Alanda,Mih ouensa (Saadine Company) :

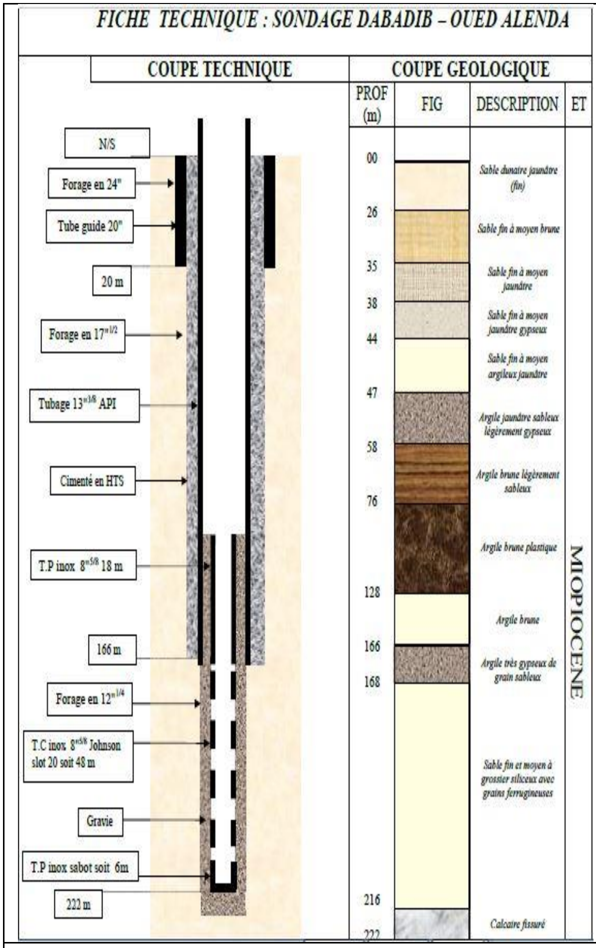
Mihouensa			Oued Alanda		
Time min	DL / well(m)	s (m)	Time min	DL / well (m)	s (m)
0	34.2	0	0	32	0
1	36.9	10.92	1	48.17	10.92
2	37.2	16.45	2	58.05	16.45
3	37.37	15.94	3	63.33	15.94
5	37.53	10.29	5	65.88	10.29
7	37.66	4.41	7	66.08	4.41
9	37.78	-1.5	9	66.24	-1.5
11	37.89	-7.45	11	66.35	-7.45
13	37.99	-13.4	13	66.42	-13.4
15	38.08	-19.37	15	66.5	-19.37
20	38.14	-34.34	20	66.57	-34.34
25	38.2	-49.32	25	66.64	-49.32
30	38.25	-10.31	3	66.7	-10.31
40	38.29	-94.3	40	66.75	-94.3
50	38.32	-124.29	50	66.78	-124.29
60	38.35	-154.29	60	66.81	-154.29
75	38.37	-199.28	75	66.83	-199.28
90	38.39	-244.28	90	66.86	-244.28
105	38.41	-289.27	105	66.88	-289.27
120	38.43	-334.27	120	66.9	-334.27
135	38.44	-379.26	135	66.91	-379.26
150	38.45	-424.26	150	66.92	-424.26
165	38.46	-469.26	165	66.92	-469.26
180	38.46	-514.25	180	66.93	-514.25
195	38.46	-559.25	195	66.93	-559.25
210	38.46	-604.25	210	66.94	-604.25
225	38.46	-649.24	225	66.94	-649.24
240	38.47	-694.24	240	66.94	-694.24
270	38.47	-784.24	270	66.95	-784.24
300	38.47	-874.24	300	66.95	-874.24
330	38.47	-964.23	330	66.95	-964.23
360	38.47	-1054.23	360	66.96	-1054.23
390	38.48	-1144.23	390	66.96	-1144.23
420	38.48	-1234.23	420	66.96	-1234.23
450	38.48	-1324.23	450	66.97	-1324.23
480	38.48	-1414.22	480	66.97	-1414.22
540	38.49	-1594.22	540	66.97	-1594.22
600	38.49	-1774.22	600	66.98	-1774.22
660	38.49	-1954.22	660	66.98	-1954.22
720	38.49	-2134.22	720	66.98	-2134.22
840	38.49	-2374.21	780	66.98	-2374.21

Annex:

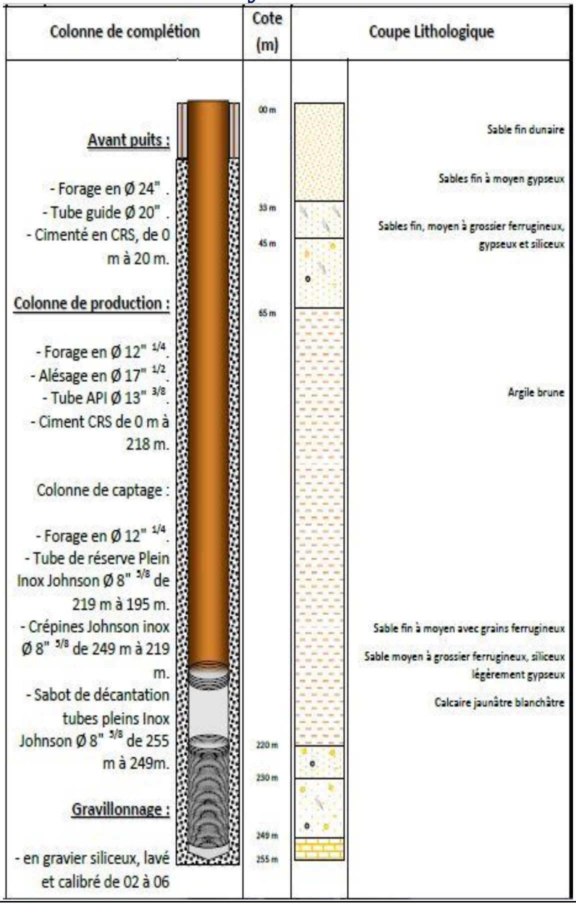
06) Technical sheet: (SAADINE and FOREMHYD Company)



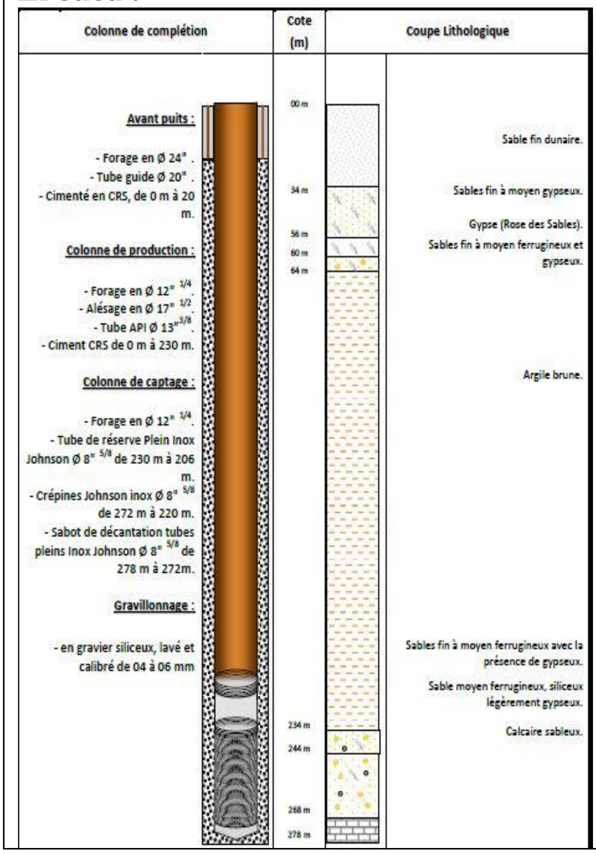
Annex:



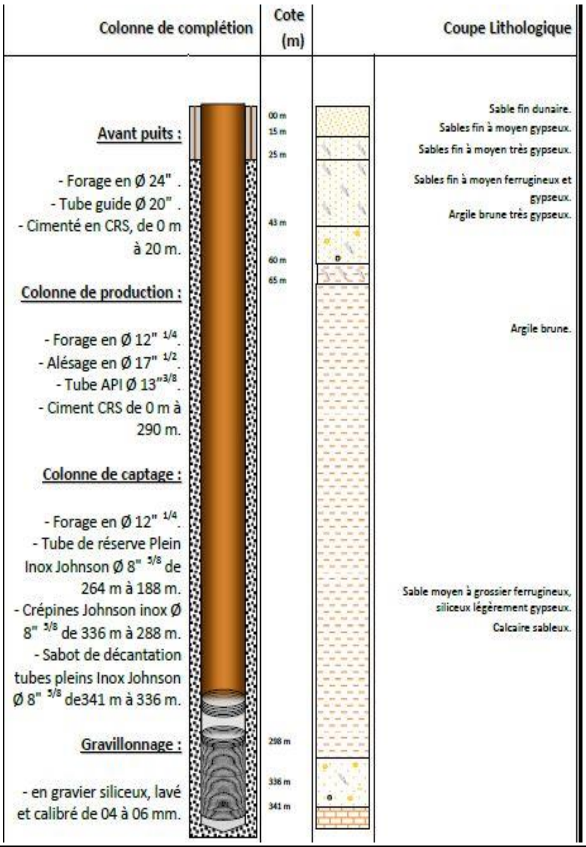
Nakhla Chamaliya



El oued :

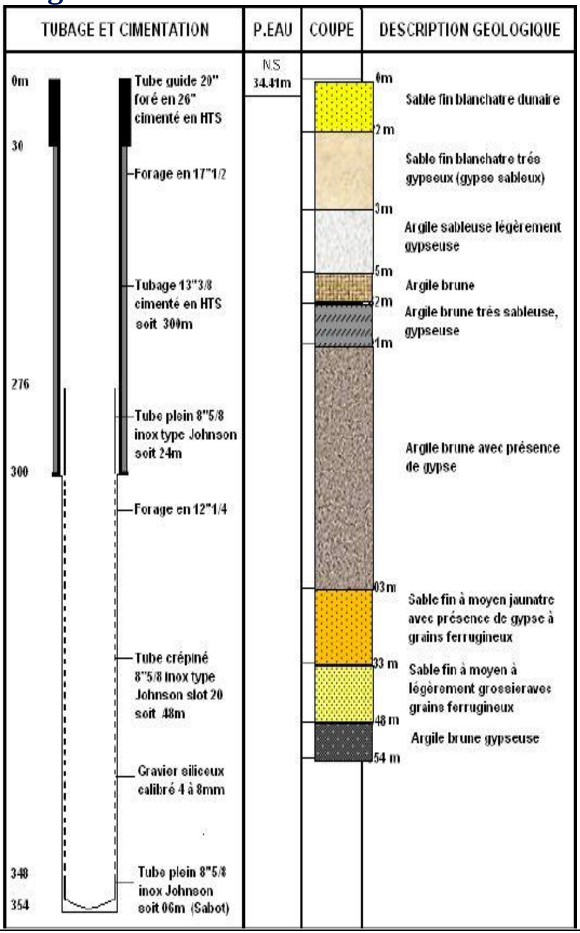


Trifaoui :

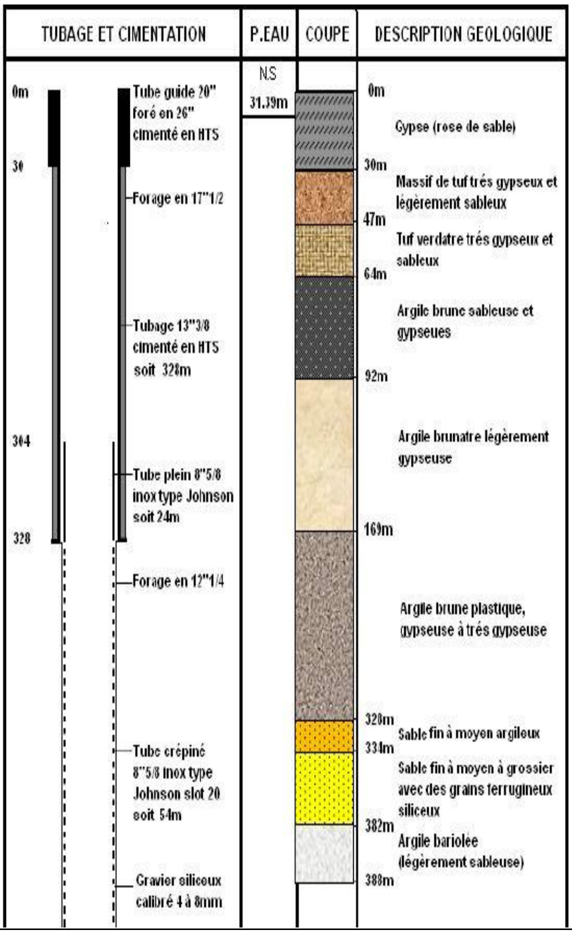


Annex:

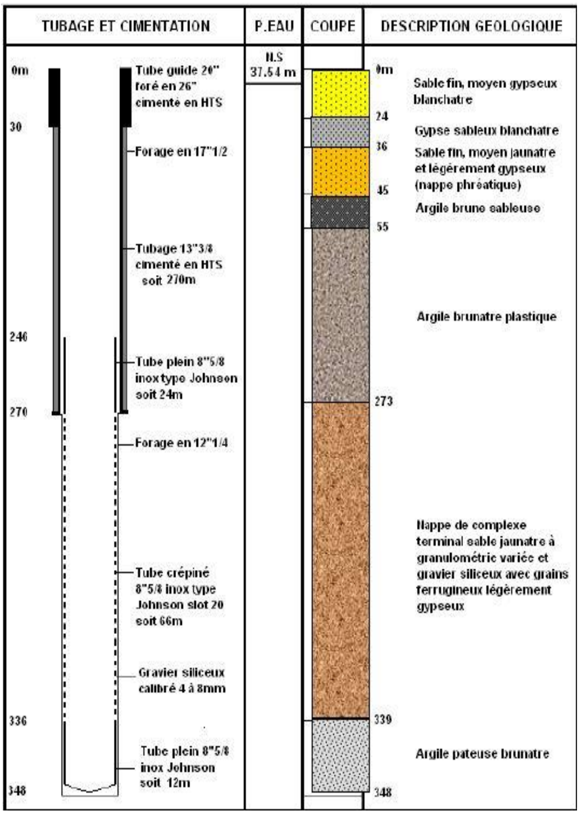
Magrane :



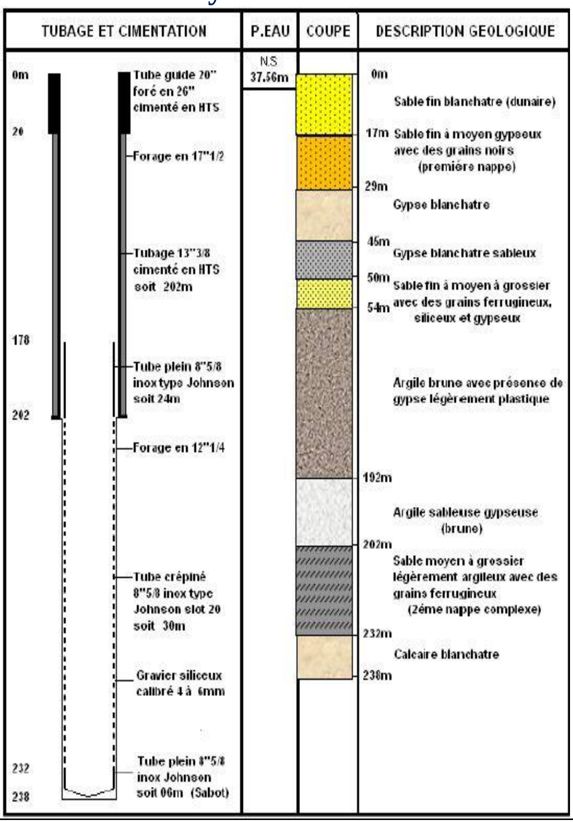
Sidi Aoune :



Guemar :



Nakhla Gharbiya :



07) Topography of El Oued, the Altitude (DWR):

x	y	Altitude	Region	x	y	Altitude	Region
287791.6	3715942	57	Reguiba	287791.6	3715942	57	Reguiba
295915.6	3707528	64	Guemar	295915.6	3707528	64	Guemar
295770.1	3705884	78.5	Taghzout	295770.1	3705884	78.5	Taghzout
304621.6	3705787	66	Hassani Abdelkrim	304621.6	3705787	66	Hassani Abdelkrim
308817	3708664	62	Debila	308817	3708664	62	Debila
305785.7	3713137	54	Sidi Aoun	305785.7	3713137	54	Sidi Aoun
308307.8	3715265	60	Magrane	308307.8	3715265	60	Magrane
314661.5	3715047	77	Hassi khalifa	314661.5	3715047	77	Hassi khalifa
308194.1	3700046	81	Trifaoui	308194.1	3700046	81	Trifaoui
298345.6	3698145	75	Kouinine	298345.6	3698145	75	Kouinine
300688.6	3693473	77	El oued	300688.6	3693473	77	El oued
304064.1	3688287	90	Bayadha	304064.1	3688287	90	Bayadha
305255.4	3685476	93	Robbah	305255.4	3685476	93	Robbah
308869.2	3680289	91	Ogla	308869.2	3680289	91	Ogla
290403.2	3680408	83	Oued El Alanda	290403.2	3680408		Oued El Alanda
286471.8	3675380	91	Mihouensa	286471.8	3675380	91	Mihouensa
293580.2	3698422	85	Ourmes	293580.2	3698422	85	Ourmes
309425.2	3683694	85	Nakhla	309425.2	3683694	85	Nakhla

Abbreviation:

TC: Aquifer of the Terminal Complex.

IC: the Intercalary Continent.

NW-SW-NE-SE: northwest-southwest-northeast-southeast.

° C: degrees Celsius.

Abstract: Water is a raw material of great importance for the survival of human beings and their environment, Population growth in the study area requires a growing need for water. This work consists of a description of the geometry and the structure of the aquifers, geological study shows that the aquifers consists of medium to coarse ferruginous sand, siliceous and sand. The substratum and the roof of this layer consist of clays, from the climatic studies; dry climate characterized this region, hot in summer, cold in winter with low precipitation.

The hydrogeological study has shown that the city of El Oued contains three aquifers of various depths.

The study of the vulnerability of the aquifer of the terminal complex of this region by the method of WYSSLING shows that most areas of the city have a low susceptibility to pollution, and that the wellhead protection area varied from one place to another according to the hydrogeological characteristics of the well.

Keywords: Terminal complex aquifer, Hydrogeological, Vulnerability to pollution, Wellhead protection area.

حساسية طبقة المياه الجوفية المعقدة النهائية ومحيط حماية مستجمعات المياه في واد ولاية الوادي

ملخص: الماء مادة خام ذات أهمية كبيرة لبقاء الكائنات البشرية وبيئتها. النمو السكاني في منطقة الدراسة بحاجة متزايدة للمياه. يهدف هذا العمل من وصف للهندسة وهيكل طبقات الماء الجوفية، حيث تبين الدراسة الجيولوجية أن الطبقات الجوفية تتكون من رمال حمراء متوسطة إلى خشنة ورمل سيليسي، ورمال، كما تتكون قاعدة وسقف هذه الطبقة من طين، ومن الدراسات المناخية، هذه المنطقة تتميز بمناخ جاف، حار في الصيف وبارد في فصل الشتاء مع ندرة تساقط الأمطار، كما أظهرت الدراسة الهيدروجيولوجية أن ولاية الوادي تحتوي على ثلاث طبقات من المياه ذات أعماق مختلفة.

دراسة حساسية طبقة مياه المركب النهائي في هذه المنطقة بواسطة طريقة (WYSSLING) تبين أن معظم مناطق الولاية لديها حساسية منخفضة للتلوث، وأن مناطق حماية الآبار تختلف من مكان لآخر حسب الخصائص الهيدروجيولوجية للبئر.

كلمات البحث: طبقة مياه المركب النهائي، الهيدروجيولوجيا، التعرض للتلوث، محيط حماية الأبار.

Vulnérabilité de la nappe complexe terminale et périmètre de protection des captages d'eau dans la vallée d'El Oued

Résumé : L'eau est une matière première d'une grande importance pour la survie des êtres humains et de leur environnement. La croissance démographique dans la zone d'étude nécessite un besoin croissant en eau. Ce travail consiste en une description de la géométrie et de la structure des nappes, l'étude géologique montre que les nappes souterraines sont constituées de sable ferrugineux moyen à grossier, de sable siliceux et de sable. Le substratum et le toit de ces formations sont constitués d'argiles. Des études climatiques, cette région est caractérisée par un climat sec, Chaud en été, froid en hiver avec de faibles précipitations. L'étude hydrogéologique a montré que la wilaya d'El-oued contient trois formations d'eau de différentes profondeurs.

L'étude de la vulnérabilité de la nappe complexe terminale de cette région par la méthode de WYSSLING montre que la plupart des districts de la wilaya présentaient une faible sensibilité à la pollution et que les périmètres de protection des puits varient d'un endroit à l'autre en fonction des caractéristiques hydrogéologiques du puits.

Mots clés : La nappe complexe terminale, Hydrogéologique, Vulnérabilité à la pollution, Périmètre de protection des puits.