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Presented by

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Groundwater vulnerability mapping in the karstic system of Ghar Boumaza, using the C.O.P. method

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Declaration

I, Mohammed Elhadi BOUABDALLAH, hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here, have been fully cited and reference in accordance with the academic rules and ethics.

Suppervisor Signature:

Student Signature:

Abstract

After an extensive literature review on the methods of vulnerability mapping, analysis of the European project COST action 620, a geological and hydrological study of Merchich watershed, we saw the possibility of the application of COP method. It has been selected to assess the value of intrinsic vulnerability of groundwater resources in the watershed, with varying degrees of karstification.

The cartography of the intrinsic groundwater vulnerability of this system was realized by applying the COP method (Concentration of flow, overlying and precipitation).The resulting map has shown that more than 38% of the surface of the system is in high vulnerability area,more than 18% in low vulnerability,44% with moderate vulnerabilit.

The superposition of the map of intrinsic groundwater vulnerability with the map of polluting sources established for Ghar Boumâaza system helped to develop a map of pollution risks in which the areas that are most threatened by the pollution of the surrounding area A.Taga are highlighted.Indeed a bacteriological analysis campaign of water of this system performed recently allowed to see that some water sources are contaminated and therefore undrinkable.

The water analyses of the fourth points assessed showed the real pollution of the groundwater which should be controlled and protected.

Key words:

Vulnerability mapping, Ghar Boumaza, Groundwater, COST620, COP, water analyses

Résumé

Après une revue approfondie de la littérature sur les méthodes de cartographie de la vulnérabilité, l'analyse du projet européen COST action 620, un aperçue geologique et hydrologique de système karsitque de Ghar Boumaza, nous avons vu la possibilité d'appliquer la méthode COP. Elle a été sélectionné pour évaluer la valeur de la vulnérabilité intrinsèque des ressources en eaux souterraines dans le bassin versant, avec divers degrés de karstification.

La cartographie de la vulnérabilité intrinsèque des eaux souterraines de ce système a été réalisée en appliquant la méthode COP (concentration de flux, recouvrement et précipitations). La carte obtenue a montré que plus de 38% de la surface du système se trouve dans une zone de vulnérabilité élevée, moins de 18% de vulnérabilité faible, 44% de vulnérabilité modérée.

La superposition de la carte de vulnérabilité intrinsèque des eaux souterraines avec la carte des sources de pollution établie pour le système de Ghar Boumâaza a permis de dresser une carte des risques de pollution dans lesquels les zones les plus menacées par la pollution sont mises en évidence. Une campagne d'analyses bactériologiques de l'eau de ce système a récemment permis de constater que certaines sources d'eau étaient contaminées et donc non potables. La protection de ces eaux donc s’impose.

Mots clés:

Cartographie de la vulnérabilité, Ghar Boumaza, Eaux souterraines, COST620, C.O.P.

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This thesis could not have been written without the encouragement of our institute Pan African institut of water and energy science , and all its student , professors and staff , the ideas received in courses illuminate my way, this courses was my laboratories for working out ideas, incorporating new ones and sharing it in my work .

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Abbreviations	
ANRH	Agence national des resources hydrique
C	Concentration of flow
COP	Concentration, overlying, precipitation
CW	Chemin wilaya
Ha	Hectar
km	Kilometer
L	Liter
m	Meter
mm	Milimiter
O	Overlayer
P	Precipitation
RN	Route Nationale
s	Seconde

Introduction

Groundwater is water that saturates materials such as topsoil, gravel, sand, silt, clay, glacial till, and bedrock below the water table. It comes from precipitation and surface water (water in lakes, ponds, rivers, streams, wetlands, etc.) seeping into the ground (T.S.Burack, et al., 2008).

Water is an indispensable resource for life. Usually when people think about water sources, they think of rivers and streams; in other words, waters of surface. But from all the useable fresh water in the world, “approximately 97% is groundwater” (T.S.Burack, et al., 2008).

By the time, the population is in fast growing, which affects the water demand in all sectors. This comes back to the importance of this resource which is indispensable for life. Even if groundwater is hidden and invisible, but it’s vulnerable to many sources or contamination from human activities. The treatment of a contaminated groundwater takes too much time and very expensive (and in some cases impossible.

As the years go by, the population grows faster, increases increasingly its unitary water needs, for itself and for all its activities such as agriculture, industry, ect. This is because water is an indispensable resource for life. Groundwater, while hidden and invisible, is fragile and often vulnerable to many sources of contamination from human activities. The treatment of a Contaminated groundwater can be time consuming and expensive, or even impossible in some cases.

Tlemcen is known as the city of water, and this comes back to the important quantity of water which is available into the ground. This considerable amount has the role to supply the drinking system of Tlemcen and the riparian cities.

This water is located in different aquifers, and the more vulnerable are those in Tlemcen's mountains, principally in the karstic aquifers, even if their water is considered as the best in term of quality according to the diversity of rocks which bring all kind of minerals. However, we consider them as vulnerable and sensible due to the high permeability of their reservoirs.

The growth of population and high density of urbanization, are the factors that push up the sensibility of these aquifers, so the demand of water is always increasing which brings out an important quantity of water rejected in the natural surface, also irrigation with wastewater and the use of fertilizers let us be alarmed from this actual situation and high risks for our water.

The government has implemented a real legislation to fight against the bad uses in the catchment level, but the rules are not applied in all sectors and it's still difficult to manage and to monitor all points in the Algerian wilaya.

The mapping of the vulnerability of these waters is therefore essential in order to better guide the development of urban centers, particularly with all that they can generate as a potential source of pollution and other polluting activities.

In this work, we try to adapt and apply a vulnerability mapping method, developed in the framework of the COST Action 620 project that was created for an application to two aquifers in south of Spain (J.M.Vias, et al., 2006). This method requires a minimum of data, and we'll apply it for the karstic système of (Ghar Boumaza).

This work is divided into four chapters which are:

1- A literature review of different information related to the aquifers, groundwater but also a review of Algerian legislation toward the management of water.
2- The second chapter is for data collection and description of the study area (geology, topography, hydrology and climate); these data are essential to apply the COP method.

3- This chapter is for the application of the method and the water analyses to confirm the vulnerability of our resource.

4- The last chapter is for the conclusion and recommendations related to the results obtained.

Research questions and hypothesis

Does the european COP model used for mapping the vulnerability give a significant results when applied to the region of Ghar Boumaaza in order to protect undergroundwaters of this area ?

The answer to this question can be given just after carrying out this research work.

The most important hypothesis on which this work is initiated is that the region of Ghar Boumaza is very similar to the european regions over which the COP model was applied successeffully.

Research objectives

The objective of this research is to map the vulnerability of groundwater in the following ways:

• Mapping the vulnerability of the groundwater of the systeme karstic ofGhar Boumaza.

• Carrying out the analyses of the water which is provided from the aquifer.

Chapter one: Literature review

Introduction

Karst fascinates amateurs and professionals by its very diversified form which begin at the surface and extend to vertiginous depths still untouched by any exploration (K.Zeghid, 2013).

The necessities of social and economic development require the use of water management to meet the needs of populations that are constantly growing, making the process of water management difficult and difficult to implement (O.Khatir, et al., 2016).

For these facts it's important to valorize water which is so essential for human uses, and also to see how this resource is seen by the policy makers.

1.1. Groundwater definition

"Groundwater is water stored under the surface of the ground, in the tiny pore spaces between rock, sand, soil, and gravel" (A.D.E.C, 2009). The water which is available on the ground comes from the infiltration of rainfall or snow, this infiltration varies from one point to another one, because the intensity of rainfall changes and also by soil factors, which are slope and land use. The rest of water that flow in the surface and does not seep into the ground will disappear by the fact of evaporation. "As water seeps through permeable ground, it continues

downward until it reaches a depth where water has filled all the porous areas in the soil or rock, this is known as the saturated zone, the top of the saturated zone is called the water table" (Y.S.Farkoul, et al., 2011).

Once the aquifer is completely recharged, water can rise from the underground to the surface which gives a spring, it happens only when there is a contact between the ground and surface. It's so important to protect this resource from several threats.

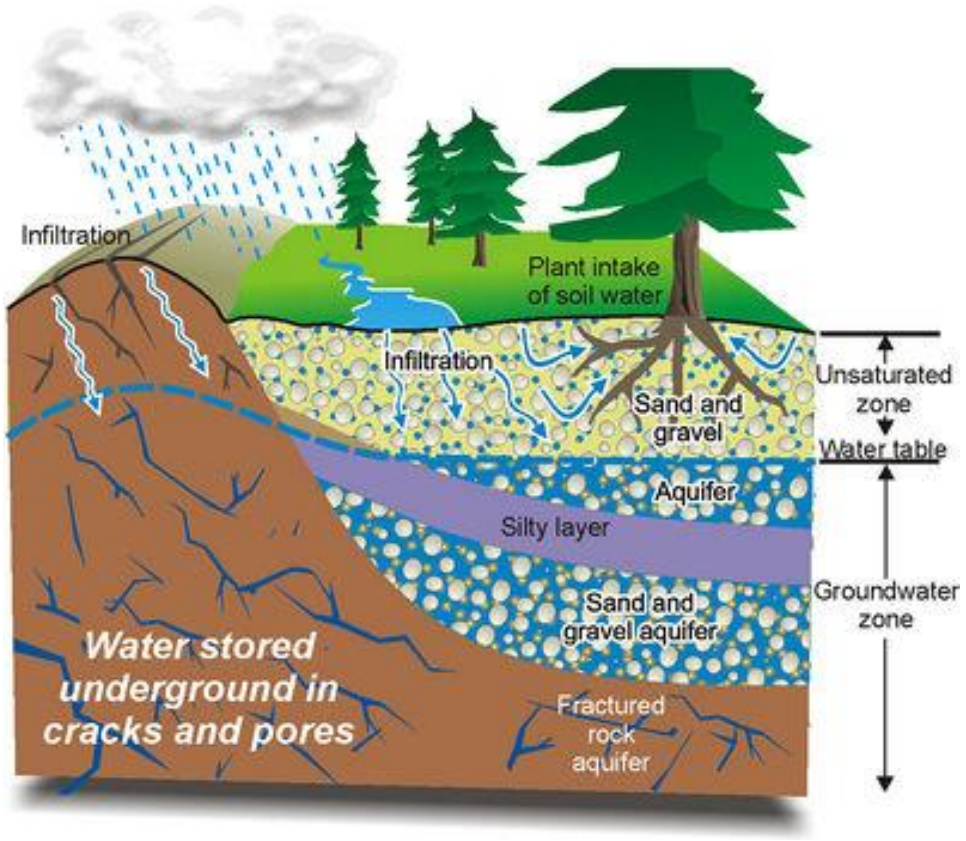

Figure I- 1 : process of recharge of the aquifer (G.Freid, 2016)

1.1.1 Groundwater recharge

The recharge can come from different point, the main source are rain and snow. However, streams and artificial recharge have too their percentage. We call to the streams that recharge as losing streams due to the lost of water to the surrounding soil.

"Recharge occurs where permeable soil allows water to seep into the ground. Areas in which this occurs are called recharge areas, they may be small or quite large, a small recharge area may supply all the water to a large aquifer" (Y.S.Farkoul, et al., 2011)

1.1.2 Groundwater discharge

"Groundwater can supply the surface in several points like stream, springs, lake, oceans shorelines and wetlands" (Y.S.Farkoul, et al., 2011). In the dry season, it's sometimes the groundwater which supplies streams because the water table is close to the surface.

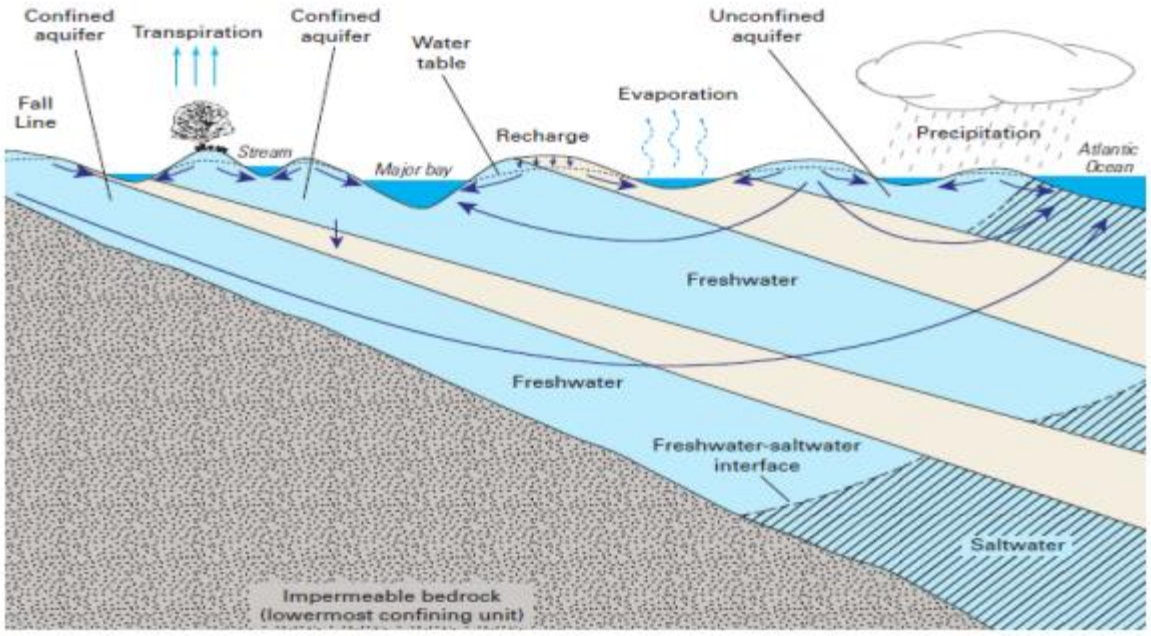

Figure I- 2 :Types of aquifer (M.Nelson, 2013)

1.1.3 Groundwater movement

Groundwater usually moves slowly from recharge areas to discharge points. Flow rates within most aquifers can be measured in feet per day, though in karst bedrock the rate of flow can be measured in miles per hour (L.Allen, et al., 2006). Flow rates are faster when cracks in rocks or very loose soil allow water to move freely. However, in dense soil, groundwater may move very slowly or not at all. Groundwater typically moves in parallel paths, or layers.

This can be an important factor in locating and determining the movements of contaminants that might enter the groundwater supply. But eventually contaminants will disperse through part or all of an aquifer. Wells affect groundwater flow by taking water out of an aquifer and lowering the nearby water table. Removed water is recharged from the water table, and the lowered water table caused by the well is called a cone of depression.

The cone of depression from a well may extend to nearby lakes and streams, causing the stream to lose water to the aquifer. This is known as induced recharge. Streams and wetlands have been completely dried up by induced recharge from well pumping.

1.2. Aquifer definition

Aquifer is defined as “a geologic formation from which significant amounts of ground water can be pumped for domestic, municipal, or agricultural uses is known as an aquifer” (T.Harter, 2003) . The depth of the aquifer could vary between some meter to a thousand, and we can find different type of aquifers: Confined, semi-confined and unconfined. All of them depend on the permeability and the geology of the surface.

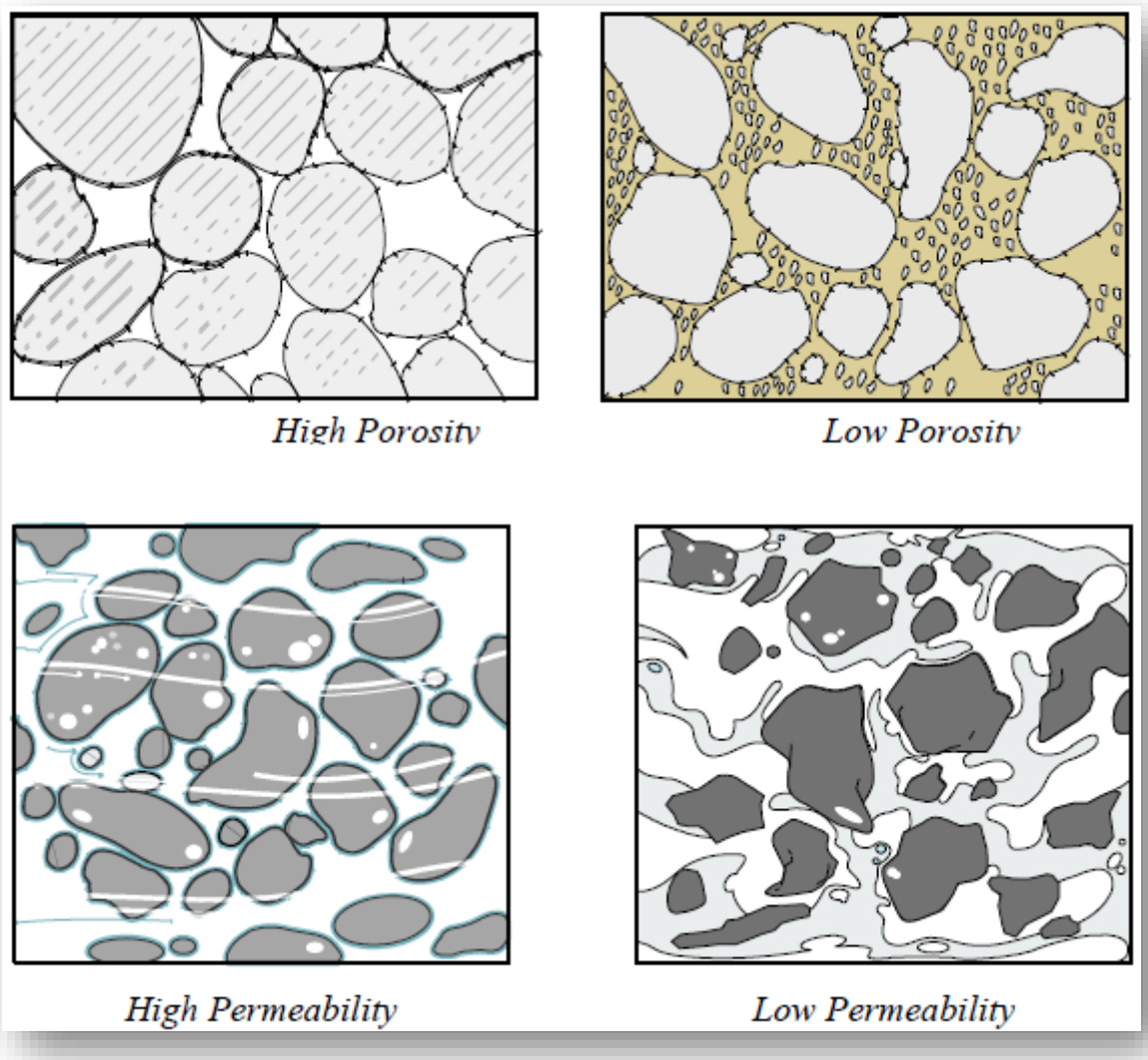

Figure I- 3 :type of porosity and permeability (A.D.E.C, 2009)

1.3. Types of aquifer

"Aquifers are classified in terms of their structure, hydraulic performance, texture, lithology, and the mobility of their water. As to their structure and hydraulic behavior they can be classified into "free", "unconfined" or "semi confined", the same aquifer may be free, confined and semi-confined by sector and area of study" (M.Nelson, 2013).

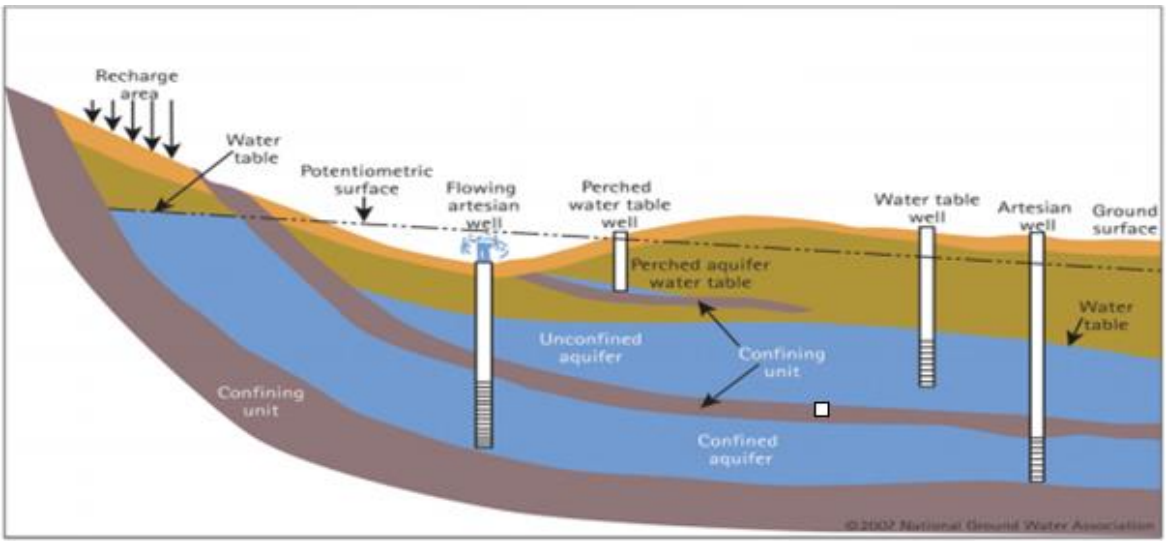

Figure I- 4 : Types of aquifer (M.Nelson, 2013)

1.3.1. Free aquifer:

The “free” aquifer is such in which there is free shallow water in contact with air and atmospheric pressure, so that its pressure is actually equal to the atmospheric pressure. This type of aquifer does not have a layer of waterproof material above them.

1.3.2. Unconfined:

In such types of aquifers, groundwater level works like the upper layer of the zone of saturation. It is also called free or non-artesian groundwater. Wavy form and slope of groundwater is changeable, which depends on replenishing of groundwater, abandoned area and permeability (G.Parul, 2014).

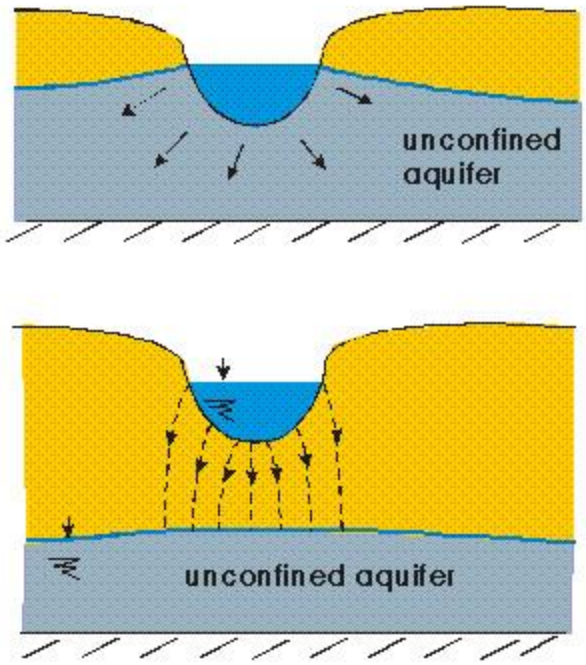

Figure I- 5 : Unconfined aquifer (J.J.Roling, 2018)

1.3.3. Confined:

Confined aquifers are found at such places where pressure of groundwater is comparatively more than atmospheric pressure due to non-permeable layers (G.Parul, 2014).

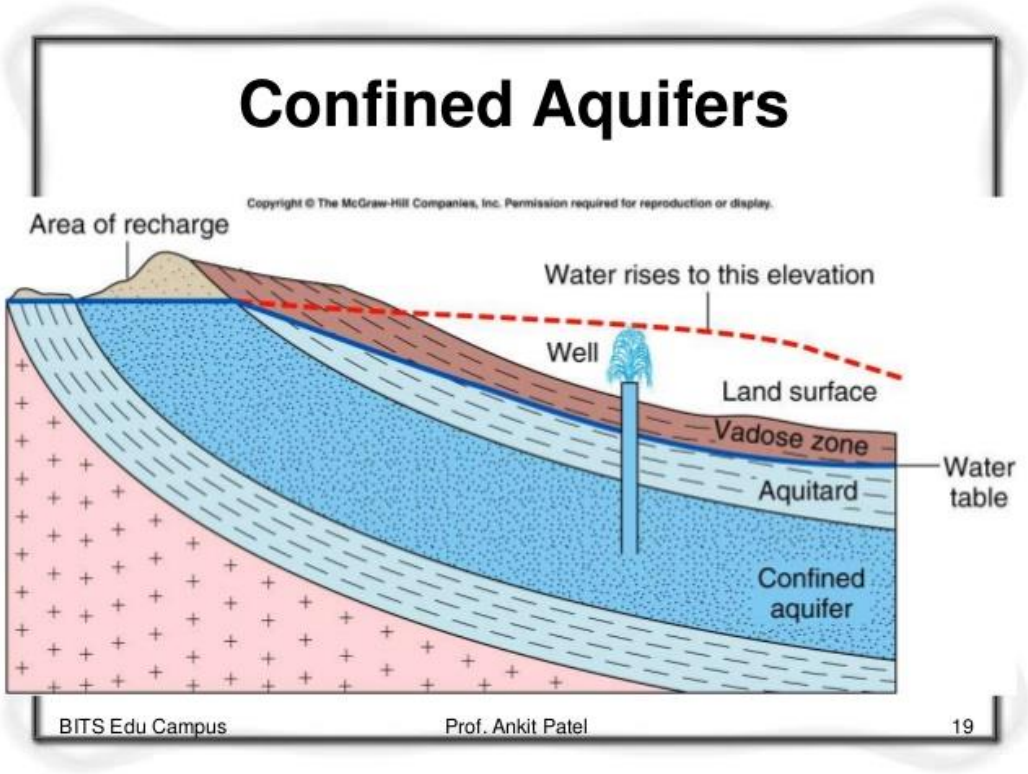

Figure I- 6 : Confined aquifer (A.Patel, 2016)

1.4. Karst definition:

Karst landforms are created by water sinking and circulating underground, and the resulting chemical erosion of bedrock. For this reason, the development of karst landforms is limited to areas where comparatively soluble rocks principally limestone exist. Approximately 8 per cent of the earth's land surface is karst terrain (W.Kate, et al., 2013)

Karst comprises some of the most unique landscapes in the world, but it is also characterized by distinctive landforms. These characteristic landforms can be found both on the surface and below ground. Surface landforms commonly include enclosed depressions, sinkholes, sinking streams and springs (D.Senara, 2018).

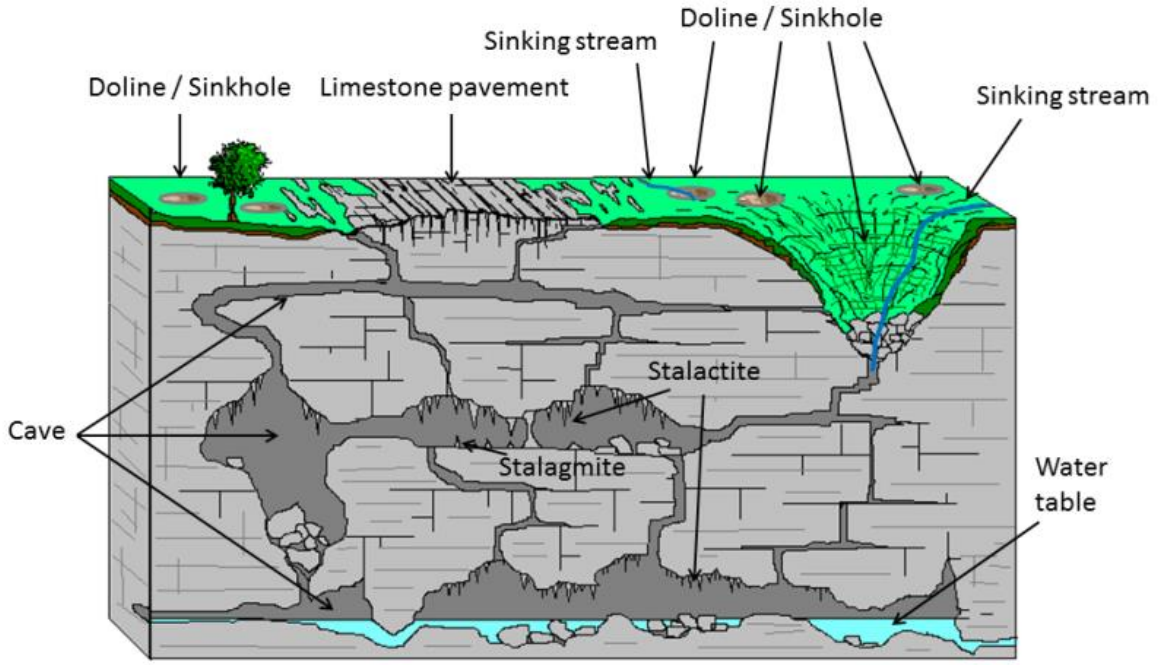

Figure I- 7 :Karst landforms (D.Senara, 2018)

1.4.1 Karst landforms:

The most common types of karst landforms are:

- Sinkhole:

  "The most recognizable karst landform is the sinkhole. This is a bowl, funnel or cylinder-shaped depression in the earth which feeds water underground. There may be a periodic or permanent pond in the base. The length or diameter of sinkholes ranges from 10 to 1,000 m" (W.Kate, et al., 2013).

- Sinking streams or swallow holes:

  "Sinking streams are streams that disappear underground at a distinct sink point, they're also streams that gradually lose water through an unconsolidated alluvial channel bed, or through a series of indistinct small openings, fractures or sink points " (government of british colombia, 2016).

- The avens:

These are chasms characteristic of karst regions. They are most often formed by the collapse of the vault of an underground cavity during the dissolution of limestone. An aven generally communicates with an underground cave and a whole network of galleries (O.Khatir, et al., 2016).

- The stalactites

When a drop of water oozes from the ceiling of a cavity, the degassing that occurs causes a deposit of calcium carbonate. A small tube will be formed which lengthens and grows as the arrival of water in the open air (O.Khatir, et al., 2016).

- Caves

Caves are formed by the dissolution of limestone. Rainwater picks up carbon dioxide from the air and as it percolates through the soil, which turns into a weak acid. This slowly dissolves out the limestone along the joints, bedding planes and fractures, some of which become enlarged enough to form caves (18).

- Limestone pavement

Although limestone rocks occur all over the world, limestone pavement is only found in places that were covered by ice during the last ice age. Therefore it is thought that pavements owe much of their existence to the weathering and removal of overlying rock and soil by ice sheets (British geological survey, 2017).

- Epikarst:

The epikarst or subcutaneous zone is located at the top of the aerated or vadose zone in carbonate rocks. The vadose zone in karst comprises the soil (if there is any), the epikarst zone, and the transmission zone (O.Khatir, et al., 2016).

1.4.2 Groundwater vulnerability:

The term ‘vulnerability of groundwater to contamination’ was introduced by MARGAT in 1968. However, the term ‘vulnerability’ is not restricted to groundwater

but is used in a wide sense to describe the sensitivity of whatever to any kind of stress, e.g. the vulnerability of global climate to human impacts (F.Zwahlen, 2003).

The concept of groundwater vulnerability is based on the assumption that the physical environment provides some natural protection to groundwater against human impacts, especially with regard to contaminants entering the subsurface environment (VRBA, et al., 1994).

COST 65 (1995) presents an overview on the various definitions of vulnerability that have been proposed until present. Most of them are quite similar. The COST Action 620 evaluated and discussed this issue and consequently proposes the following definitions:

- **The intrinsic vulnerability** of groundwater to contaminants takes into account the geological, hydrological and hydrogeological characteristics of an area, but is independent of the nature of the contaminants and the contamination scenario (F.Zwahlen, 2003).
- **The specific vulnerability** takes into account the properties of a particular contaminant or group of contaminants in addition to the intrinsic vulnerability of the area (F.Zwahlen, 2003).

1.5 Issues related to groundwater protection:

The protection of groundwater is for a number of reasons a priority of the state's environmental policy:

-Once contaminated groundwater is more difficult to clean than surface water and the consequences can be prolonged for several years.

-Since groundwater is widely used for drinking water supply, for industry and for agriculture, its pollution can be dangerous for human health and for the smooth running of economic activities.

-Groundwater provides the baseline for many rivers (can account for up to 90% of the flow of some streams) and can thus influence the quality of surface

waters they serve as buffers in periods of and then become essential to conserve wetlands (P.Alexander, 1982).

1.6 Types of pollution:

Water is said polluted once its properties are lost; it means that its quality is deteriorated. Various categories of pollution exist which have diverse sources (from household, agricultural or industrial activities).

1.6.1. Chemical pollution

These are different substances dissolved in water (including nitrates, phosphates or micropollutants), resulting from human activities. Micropollutants are pollutants likely to be toxic at very low concentration (of the order of one microgram or nanogram per liter) (J-P.Marchal, 2007).

They are essentially derived from the use of substances produced by the chemical industry. These substances are present in cosmetics, drugs, paints, pesticides and many other consumer products (J-P.Marchal, 2007).

1.6.2. Microbiological pollution

It is linked to micro-organisms, bacteria, viruses and fungi that can be found in water. This type of pollution is frequent and usually comes from pollution by animal or human feaces (P.Muet, et al., 2011).

1.6.3. Physical pollution

This type of pollution can modify the transparency of the water (turbidity, due to suspended matter) or its temperature.

1.7 Groundwater contamination

Hydraulic properties play a significant role in the migration of contaminants in a karst system. The existence of a dual porosity differentiates residence times.

Water flow is very rapid in karst conduits and slow in the fissured matrix of the carbonate rocks (F.Zwahlen, 2003).

1.8 Types of contaminants

1.8.1 Infrastructural contaminants:

Waste water:

Numerous parts of the world are currently suffering from water scarcity, which means clean water is of the utmost importance. When wastewater is discharged on these dry lands, it can seep into the underground water tables and well sources. Because we need to draw from these natural bodies of water for generations to come, this can render entire water supplies useless for people in multiple locations (R.A.Stratton, 2017).

Fuels:

From extraction to end use, petroleum products affect surface water and groundwater, impairing water quality with hydrocarbons, salts, nutrients, a host of organic compounds, and various heavy metals. In many areas around the world, oil spills and storm water runoff containing oil derivatives have degraded ecosystems and human water supply (L.Allen, et al., 2006)

1.7.2 Industrial contaminants:

Minning:

Water pollution is also caused by mining and can include metal contamination, increased sediment levels in streams, and acid mine drainage. The sources of water pollution as a result of mining can include processing plants, tailing ponds, underground mines, waste-disposal areas, active or abandoned surface or haulage roads. The sediments are most likely from increased soil erosion causing siltation or the smothering of stream beds (S.Asghari, et al., 2017).

Shale gas exploration:

Exploitation of shale gas by hydraulic fracturing (fracking) is highly controversial and concerns have been raised regarding induced risks from this technique. Some of the most important issues surrounding unconventional oil and gas (UOG) extraction are the possible impacts of this activity on potable groundwater resources and how to minimise and mitigate such impacts.

1.7.3 Livestock contaminants:

Livestock:

While manure is an important source of nitrogen (N) and phosphorus (P) for crop production, the nutrients and pathogens in manure have the potential to reduce the quality of groundwater, which is an important source of water in many parts of the province. In particular, manure application and the potential seepage of liquid manure storage from earthen manure storages (EMSs) have been previously identified as potential concerns for groundwater quality (K.Lorenz, et al., 2014).

Agricultural:

"Irrigation has an impact on the environment, and scientific evidence suggests that it inevitably leads to salinization of both soil and aquifers. The effects are most pronounced under arid and semi-arid conditions. In considering the varied impacts of irrigation practices on groundwater quality, these can be classed as either direct the direct result of applying water and accompanying agrochemicals to cropland or indirect the effects of irrigation abstractions on groundwater hydrogeochemistry" (A.Vallejos, et al., 2018).

1.9 Groundwater protection

The water protection legislation aims to protect groundwater against harmful impacts and to allow their sustainable exploitation in respect of ecological balance. Since groundwater is endangered on all sides and it is ubiquitous, it must as far as possible respect the general related ecological objectives (P.Muet, et al., 2011). In addition, it is necessary to ensure their protection taking into account their use for the production of drinking water (K.Zeghid, 2013).

In the Maghreb countries, drinking water comes mainly from groundwater (sources and groundwater), and in most cases only disinfected, unlike water from the lake or dam, which requires treatment most important. Protective measures (norms, laws) were taken from the end of the 1970s, in order to protect groundwater from the risks caused by human activities (industry, agriculture, recreation,) and thus guarantee water from quality (A.El.Bennoury, 2002).

1.10 Regulation and rules of groundwater protection in Algeria

For several reasons, groundwater protection is a major priority requiring policies for the management, sustainable development and conservation of these water resources as a national community asset.

The main laws governing water protection are as follows:

Law n ° 83-17 of July 16, 1983 concerning the water code:

This law outlined the protection of groundwater resources. It addressed the protection of groundwater in Chapter 03 through Articles 109 up to Article 124. Article 110 defined the perimeter of protection as a contour delimiting the geographical area within which is forbidden or regulated any activity likely to undermine the qualitative conservation of water resources. Activities that may be subject to prohibition or regulation within the protection perimeters are mentioned in Article 111:

- The execution of wells and boreholes.
- Quarrying.
- The installation of pipelines, tanks and hydrocarbon deposits.
- The installation of sewage pipelines of all kinds.
- The establishment of all constructions.
- The spreading of manure, fertilizer and all products intended for the fertilization of soil and crop protection.

• Deposits of garbage, filth, radioactive detritus, in general, any product and material likely to alter the quality of the water.

The protection of groundwater must be the subject of a qualitative protection of dams, wells or boreholes and also a quantitative protection for over-exploited groundwater.

Immediate or close protection perimeters may be instituted around mobilization works, underground or semi-underground tanks, water treatment or pumping stations, intended for human consumption, where, in addition to all the activities mentioned, it is prohibited. In Article 111 and the following activities:

• The circulation of self-propelled vehicles,

• The installation of fuel dispensing service stations,

• Any other activity that may affect the quality of the water.

Subject to authorization, the replacement works of redevelopment of existing hydraulic facilities, without increasing the volumes of water withdrawn. In areas where groundwater resources are overexploited and in order to conserve operating flows or decommission a number of sampling points, water metering is mandatory.

Any establishment of activity within close or remote protection perimeters is subject to the prior agreement of the administration (J.O.R.A. N ° 30,1983).

Executive Decree No. 04-196 of July 15, 2004:

This law will demonstrate the need for pollution protection perimeters as follows:

There is a perimeter around each point of natural mineral water or spring water qualitative protection.

If new circumstances make it necessary to recognize this, these protection areas for natural mineral waters or spring waters may be modified and extended according to the procedures and procedures that prevailed for their initial delimitation.

No survey or underground work of any kind may be carried out without the information and approval of the Standing Committee (OJ No 45,2004).

The law n ° 05-12 of 4 August 2005 relating to water:

Its purpose is to set the principles and rules for the use, management and sustainable development of water resources as a national community asset, and to ensure and regulate resource protection by:

• Quantitative protection perimeters;

• Qualitative protection perimeters; Quantitative protection perimeters: For aquifers that are over-exploited or threatened with extinction, quantitative protection perimeters are instituted to ensure the preservation of their water resources.

Qualitative protection perimeters: It is established around structures and installations for the mobilization, treatment and storage of groundwater or surface water as well as certain vulnerable parts of aquifers and stream, a qualitative protection zone comprising, according to the pollution prevention needs:

• An immediate protection perimeter: the land of which must be acquired by the State and protected by a natural or legal person responsible for the operation of the structures and installations concerned;

• A close protection perimeter: inside which are prohibited or regulated deposits, activities or installations likely to pollute the water, chronically or accidentally; • A remote protection perimeter: within which are regulated the depots, activities or installations referred to in the previous paragraph (J.O.R.A. N ° 60,2005).

Executive Decree No. 07-399 of 23 December 2007:

The purpose of this decree is to set the terms and conditions for the recreation and demarcation of perimeters for the qualitative protection of water resources, as well as the de regulation of activities in each perimeter of qualitative protection.

Therefore, according to the needs of prevention of the risks of pollution, the qualitative protection of the water resources is ensured by three types of perimeters of protection:

• The immediate protection perimeter: this perimeter has the function of preventing the deterioration of the catchment works and of avoiding the discharge or the infiltration of polluting substances inside or in an immediate proximity of catchment works. Its extent is constituted by the lands of right of works and installations of mobilization, treatment and storage of water.

• Close Protection Perimeter: aims to prevent the degradation of water quality by underground or surface migration of toxic or undesirable hazardous substances. It extends from the boundary of the first protection perimeter to a distance determined on the basis of the underground or surface migration time of hazardous, toxic or undesirable substances. Its extent is determined by the migration time between the place of emission of the pollution and the point of sampling of the water resource. For groundwater this is the calling zone.

• The remote protection perimeter: which aims to extend the perimeter of close protection to reinforce the protection against the risks of chronic, diffuse or accidental pollution? It extends from the boundary of Zone 2 to the watershed boundary for surface or groundwater resources (J.O.R.A. # 80,2007).

Executive Decree No. 07-399 set the conditions and procedures for the creation and delimitation of protection perimeters in two sections:

• Fields of application

• The procedure for establishing qualitative protection perimeters. Chapter II of the same executive decree set out the measures for regulating activities within the scope of qualitative protection.

Around vulnerable parts of groundwater or stream, protection is provided exclusively through the establishment of a close protection perimeter or a remote protection perimeter.

The executive decree defined the procedures for the establishment of perimeters for the qualitative protection of groundwater resources, as well as all parties or persons responsible for the creation and monitoring of these perimeters.

The executive decree required a technical study to delimit the perimeters of qualitative protection around:

• Works and groundwater mobilization facility as well as some vulnerable parts of groundwater.

• Works and installations for the mobilization of surface water as well as some vulnerable parts of stream.

• Water treatment plants, seawater desalination plants, brackish water demineralization stations and water storage tanks (J.O.R.A. # 80,2007).

Executive Decree No. 10-73 of February 6, 2010

The purpose of this decree is to set the terms and conditions for the delimitation of the quantitative protection zones for aquifers and the specific conditions for the use of their water resources. Therefore on this basis any aquifer, whose hydrogeological assessment shows a chronic imbalance between water withdrawals and the renewable capacity of the aquifer, reflecting either a situation of overexploitation, or an evolution that could lead to a situation of overexploitation, is the subject of a quantitative protection device (JORA N ° 11,2010).

1.8 How the protection can be done?

The protection of groundwater resources must also ensure the qualitative protection of all catchments of springs, wells or cracks as well as all the vulnerable

parts of groundwater from the quantitative protection of over-exploited or threatened groundwater resources being inside which are:

*Prohibit any work carried out on shaft sinking or drilling or any modification of existing installations intended to increase the flow rates

*Subject to authorization the work of replacement of redevelopment of the existing hydraulic installations without increase of the sampled water volumes (K.Zeghid, 2013).

Following to decree No 07-399 of 23 December 2007, the government of Algeria established this law which is relative to the protection of different water resource.

Executive Decree No. 07-399 of 23 December 2007:

The purpose of this decree is to set the terms and conditions for the recreation and demarcation of perimeters for the qualitative protection of water resources, as well as the deregulation of activities in each perimeter of qualitative protection.

Executive Decree No. 07-399

Set the conditions and procedures for the creation and delimitation of protection perimeters in two sections:

• Fields of application

• The procedure for establishing qualitative protection perimeters. Chapter II of the same executive decree set out the measures for regulating activities within the scope of qualitative protection.

Around vulnerable parts of groundwater or streams, protection is provided exclusively through the establishment of a close protection perimeter or a remote protection perimeter.

The executive decree defined the procedures for the establishment of perimeters for the qualitative protection of groundwater resources, as well as all parties or persons responsible for the creation and monitoring of these perimeters.

The executive decree required a technical study to delimit the perimeters of qualitative protection around:

• Works and groundwater mobilization facility as well as some vulnerable parts of groundwater.

• Works and installations for the mobilization of surface water as well as some vulnerable parts of stream

• Water treatment plants, seawater desalination plants, brackish water demineralization stations and water storage tanks (J.O.R.A. # 80,2007).

Conclusion

Aquifers with its different forms is considered as one of the good source of drinking water, however it's also exposed to the risk of pollution.

The laws that are given by the Algerian government show the importance of the groundwater and how much it should be protected. The various laws and decrees established above gave the outline of the protection of water resources without giving any details on the vulnerable parts.

Chapter two: description of the study area

Introduction:

2.1 General presentation

Ghar Boumaza, karst area, is located on a hill covered with sparse vegetation. On the left side of the national road 22, connecting Tlemcen to Sebdou, one can observe its entrance, a large opening carved in the rock which gives, outwards, on a stream and, inwards, where the outflow finishes on the Tafna River.

Ghar Boumaza is bounded on the north by Djebel Nador 1579 m high and Oued Essafssaf, on the west by the forest of Daher El Berhal, on the east by the Merchiche forest and on the south by El Hebalet and Sebdou.

2.2 Location of Ghar Boumaza and its presentation

Administratively, the karst system of Ghar Boumaza, with an area of 11300ha, belongs to the commune of Terny and A.Ghoraba in the daïra of Mansourah.

All the establishments that exist on the system are: Tal Terny, Sehb, Oulad Bounouar, Merchiche, is characterized by its southern exposure, in contact with the agro-pastoral communes. The common element is the alignment of agglomerated centers along the road (RN 22), where we find successively Tal Terny, Sehb, Ouled Bounouar, Merchiche. Only Dar Maamar escapes this organization (11).

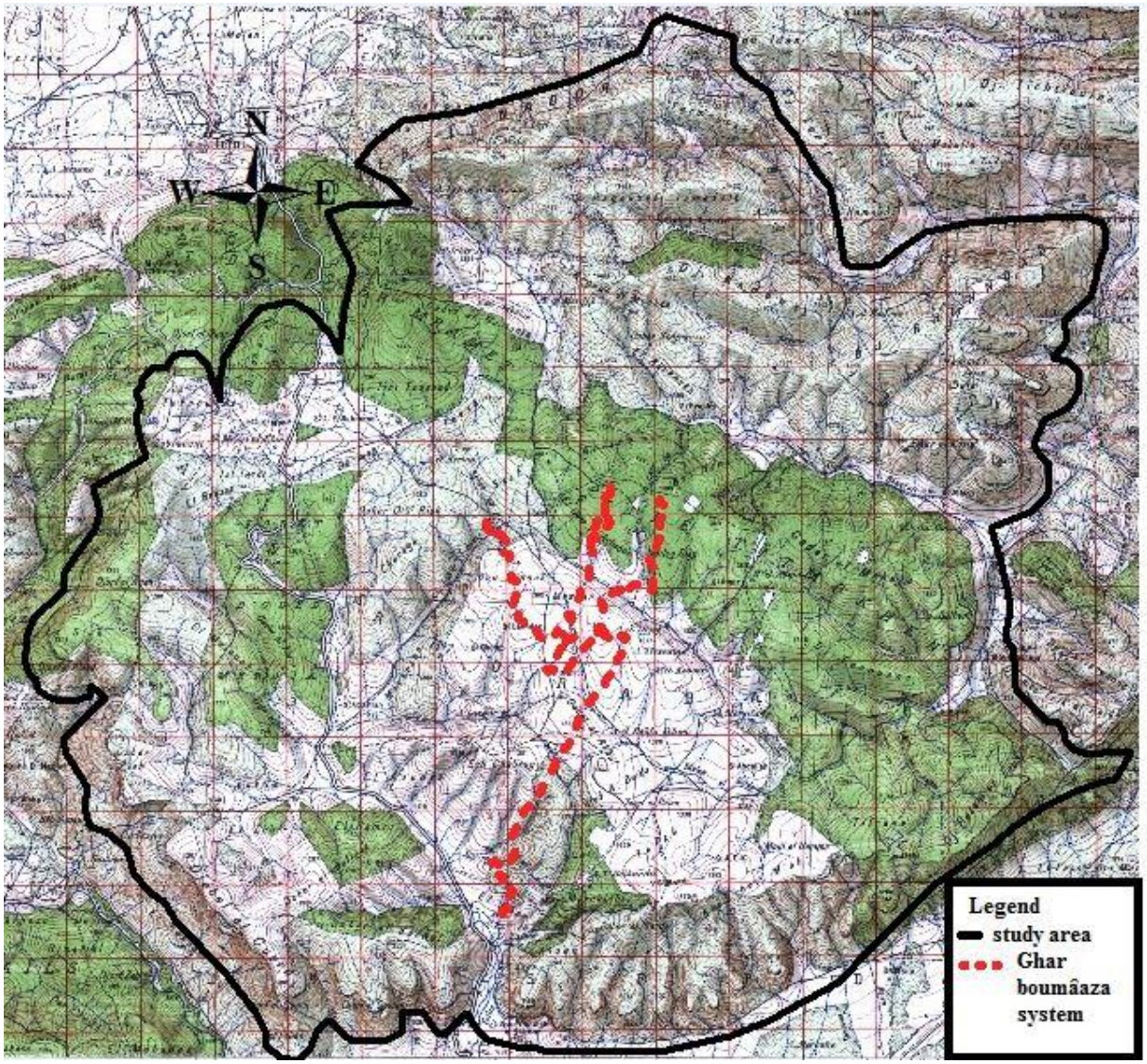

Figure II 1 : perimeter of the karstic system of Ghar Boumaza (from the topographic map 1/50000)

2.2.1 Geological context

General framework

The Tlemcen Mountains consist mainly of Upper Jurassic and Lower Cretaceous formations. Kimmeridgian and Tithonian limestones and dolomites make up more than 80% of the summit parts of the plateaus. In the South and North, these formations are masked by a thick tertiary sedimentation represented by fluvial deposits Eocene on the southern lapel and by Miocene marls and continental deposits of the Quaternary in the North, (see extract of the geological map of Algeria at 1/500000) in figure, below: (F.Bensaoula, 2006)

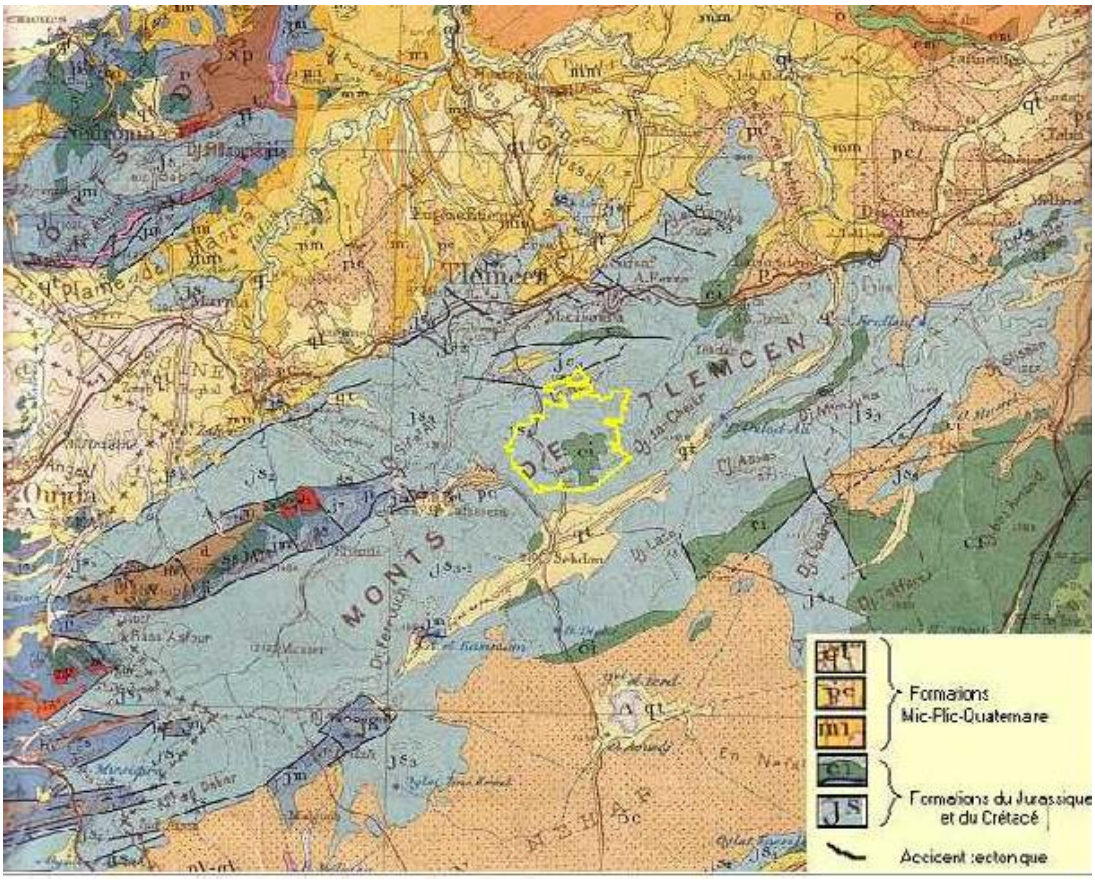

Figure II 2 :Geological map of the all region of Ghar Boumaza (from the geological map 1/500.000) (O.Khatir, et al., 2016)

Geological context of the studied sector:

Ghar Boumaza is a karst system with the particularity of being limited entirely by impermeable soils (F.Bensaoula, 2006).

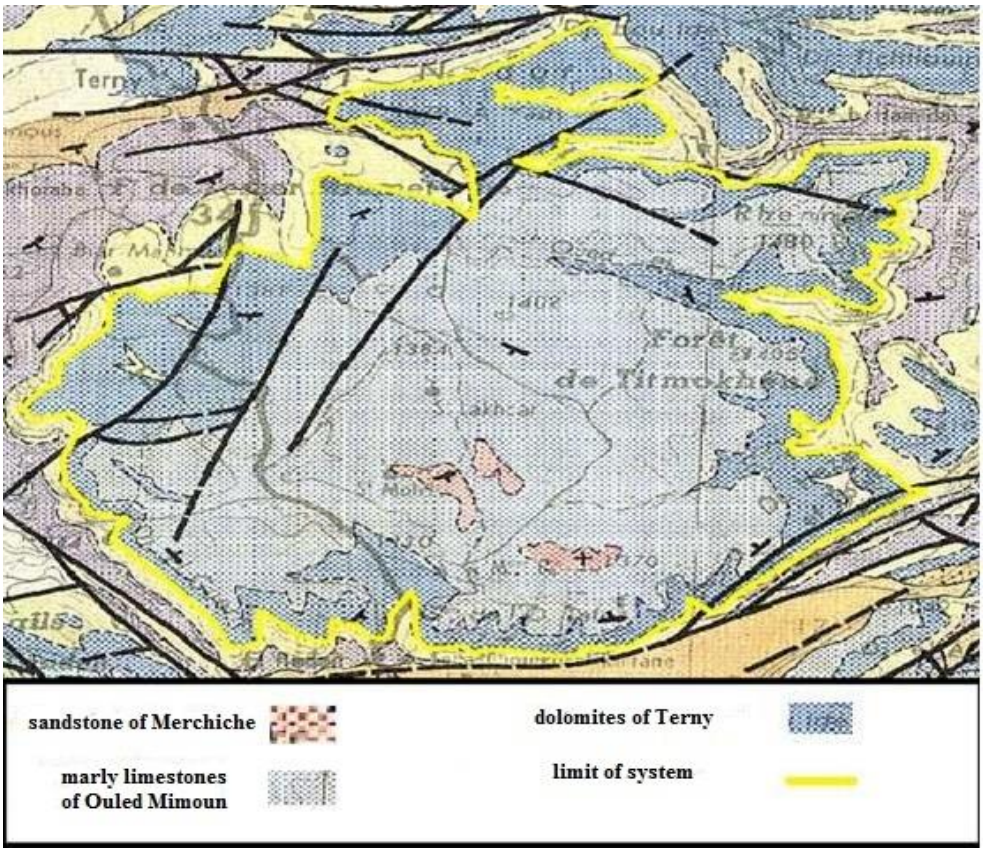

Figure II 3 :Geological map of the study area (O.Khatir, et al., 2016)

Lithostratigraphy

'The litho-stratigraphic succession, shows the series of formations in our study area, the Terny Dolomites and part of the Hariga marly limestone (which could be sometimes dolomitized) constitute the calcareo-dolomitic superior' (F.Bensaoula, 2006).

These formations show a lateral facies change, a variation of thickness as well as a very irregular dolomitization, through the Tlemcen Mountains according to the work of Benest M (1983)., Collignon B (1986), and Bensaoula, (2006). The description of the formations which follows is mainly inspired by the works of Benest, in 1985 (F.Bensaoula, 2006).

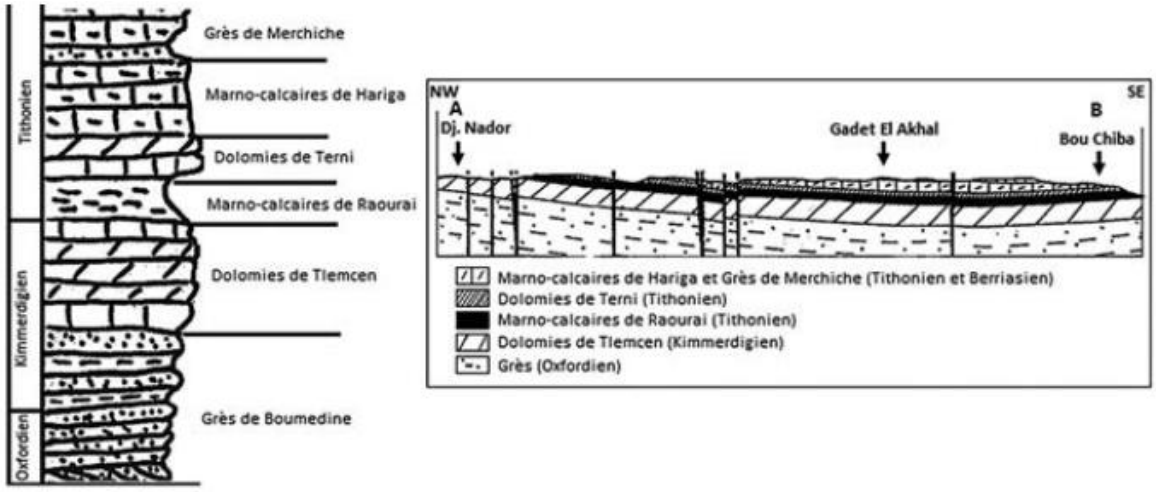

Figure II 4 : Litho-stratigraphic Log (F.Bensaoula, et al., 2018)

The Dolomies of Terny

Correspond to the cornice above the limestone of the Lato, their thickness is about 50m in the area of Sebdou. In much of the Tlemcen Mountains, the Little Fossiliferous Terny Dolomies show a constant facies. We observe at the base a horizon rich in flint and recrystallized columnar stromatolites. On the border southern Tlemcen and Daia Mountains, as well as the high plains of Oran. This dolomite formation cannot be separated from the dolomitized Lato limestones (F.Bensaoula, 2006).

The marly limestones of Hariga

The limit of these marl-limestones is difficult to determine when the first courses of the formation are calcareous and completely affected by dolomitization. The upper limit is easy to specify. It corresponds to the sole of the first sandstone bench of Merchiche sandstone (F.Bensaoula, 2006).

The sandstone of Merchiche:

In their typical localities, admitting micritic and marly intercalations rather poor in dasycladaceae but rich in lituolids, among these, one distinguishes forms quite comparable to that which L, Hottinger has described and figured in Eastern

Morocco under the name of Pseudocyclammia. (Streptocyclammia) gr, pravula-muluchensis (F.Bensaoula, 2006)

Geological synthesis:

The geological section carried out in the Merchiche syncline by Benest shows that the Terny Dolomies (100 m) are based on the marl-limestones of Raourai andare overcome by the formation of marl-limestone Hariga (about 195 m, Benest 1985). The latter is very micritic and very marly. It is surmounted in turn by the marl-limestones of Ouled Mimoun which begins with sandstone Merchiche (52 m). In all, a series of layers 347 m thick rests on the calcareo-dolomitic series of Terny and Hariga. Benest, 1985, measured a dip of 5 ° to the north.

The galleries have been excavated in the upper calcareo-dolomitic or Ternian dolomite of Tithonian and Hariga limestone marl (with very little marl) difficult to separate due to dolomitization (F.Bensaoula, 2006).

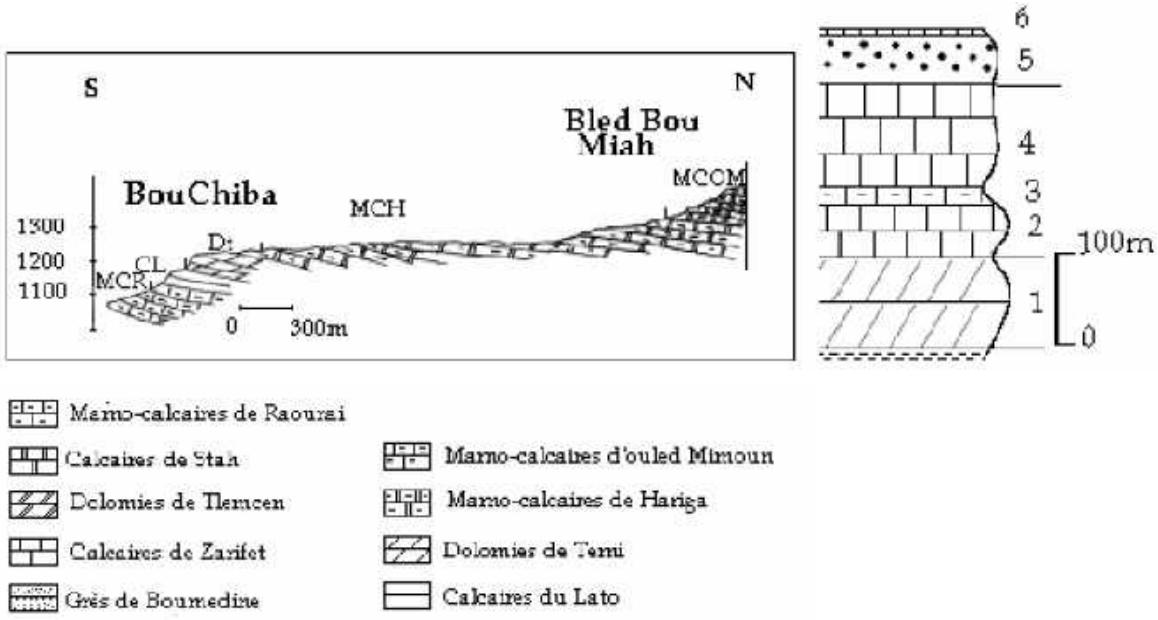

Figure II 5 : Geological context near to Merchiche Mountain (F.Bensaoula, 2006)

The study of geology is an essential step to map the vulnerability.

2.2.2 Hydrological context

With an underground network of around 18Km, the karst system of Ghar Boumaza is considered as the source of the Tafna stream. It occupies a large part of

the southern territory of the commune of Terny. The source of Ain Taga considered as an outlet of this system, feeds the gardens of Hebalat (figure II-7), then it moves to the upper Tafna stream (F.Bensaoula, 2006).

Figure II 6 : Falls of Hbalat (M.E.Bouabdallah,2018)

The Tafna stream is the main stream in the catchment of Tafna which has an area of 7245km^2, the stream receives almost all affluent of Tlemcen wilaya's that reach the sea at Rachgoun beach.

The hydrographic network of Ghar Boumaza has the form of gullies concealed where the flow is intermittent, and for that all rain and snow that fall on the mountains infiltrates through fissures.

« After each period of rainfall especially on the wet season, a stream will be created at the entrance of the cave, where this water will flow to the cascades of Hbalat then it reaches the river of Tafna. However, the source of Ain Taga (500m downstream from the cave) is considered as the permanent outlet of Ghar Boumaza where the outflow can reach 45L/s" (F.Bensaoula, et al., 2018).

2.2.3 Soil

The soil is the key element for the distribution of the vegetation; it depends on the geological and topographic and climatic factors.

Determining the agro-soil value of soils through our study area is very though, due to the unavailable of studies in our study area. For this fact we based this part of study on the distribution of the vegetation, the geology of the region and the analogy of the pedological work done in the surrounding region of the studied area.

So it should be noted that the soils are almost in the Mediterranean climatic conditions, under the dependence of the bedrock that gave them birth because of their inability to radically alter the geological substratum (O.Khatir, et al., 2016).

2.3 Climatic context

The knowledge of the rainfall and thermal evolution are important for a better interpretation of the hydrological and hydro-geological behaviors of the study area, and for this purpose, a study of the climate (temperature and rainfall) is done on the basis of the climatic conditions of Mefrouche meteorological station, spread over 53 years(1963-2017) for precipitation.

“The climate of the region is considered as a cool semi-arid Mediterranean, nuanced by continental influences. The climate is considered as quite harsh in winter, where it could snow for 21 days” (O.Khatir, et al., 2016)

2.3.1 Rainfall

The study of the rainfall is very important for the next step of this work, but also to know the weather of the region. The only one station that registers the precipitation in the region is the one situated in Mefrouche dam, which is situated approximately 21Km as the crow flies to our study area. There was another station in Merchich but, it has been turned off few years ago.

The characteristics of the pluviometric station are mentioned in the following table:

Station	Altitude (m)	Latitude	Longitude
Meffrouche	1110	34°50’50.2’’N	01°17’14.5’’W

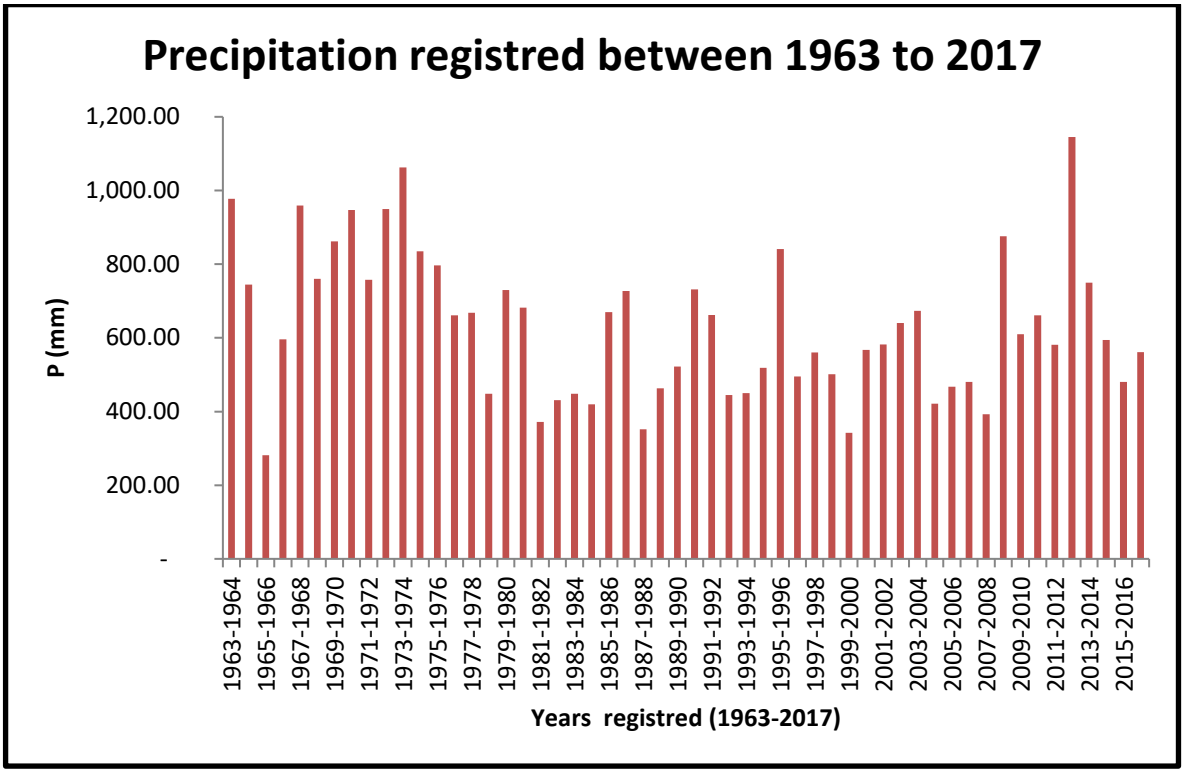

Figure II 7 : Annual rainfall evolution in Mefrouche Station

The above graph represents the precipitation registered for the period of (1963-2017) in Mefrouche station, and we can observe the irregularity on the precipitation during the period, the average precipitation is 632.5mm /year, and the rainy year was 2013 with 1144mm.

2.3.2 Temperature

Temperature parameter has a key role on vegetal life, mostly on biological processes because it controls the percentage of evaporation which could impact the flow and infiltration.

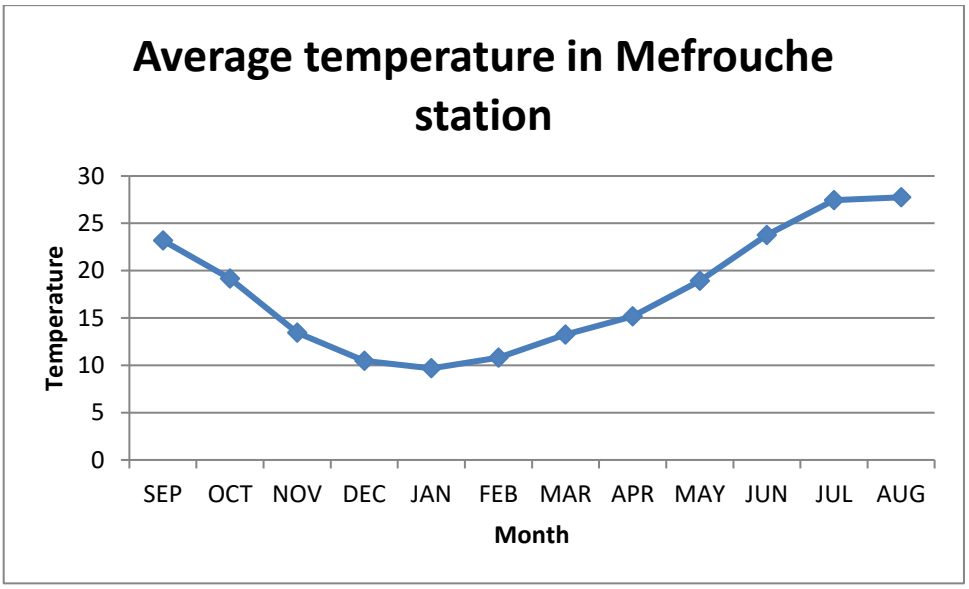

Figure II 8 : Average monthly temperature in Mefrouche station for the period (1990-2017)

The above graph represents the monthly average variation of the temperature from 1990 to 2017" registered in Mefrouche station, where the hottest temperature registred was on July 1994 "29.8°C", and the coldest temperature was on February 2012 "6.6°C".

2.4 land use of the region:

Our study area has an important number of agglomerations that don't respect any standard of urbanization, with a degraded vegetation. The abundance of water has favored the installation of some hamlets which use it for irrigation.

2.4.1 Population

The typology of housing parks is dominated by traditional housing (Haouch), precarious and strongly influenced by the pastoral activity of the owners. It results from self-construction, often uncontrolled, designed in light masonry (stone, breeze block, sheet metal, etc.). However, there are some constructions of the modern type (rural housing program), with an extroverted façade. There is a number of social amenities that are insufficient to meet the needs of demand (A.Taamir, 2013).

The following table shows the repartition of population in our study area:

Table II 1 : Repartition of the population in different villages on the study area (O.Khatir, et al., 2016)

Hamlets	Population	Lodgment
AS-Sehb	782	155
Tal Terny	127	53
Merchiche	115	33
OuledBounouar	178	45
Dar Maamar	88	45

2.4.2 Drinking system

The region of Sehb is alimented by a drilling with a flow rate of 8 L/s.

Water is stored into two tanks with a capacity of 120 and 50 m^3. The water supply network is a simple network with the principal pipe and some of taps which are allocated in different places; the network is in a bad shape.

Table II 2 : Summary of requirements and storage capacity (O.Khatir, et al., 2016)

Year projected	Population	$Q_{moy.j}$ m^3/j	$Q_{max.j}$ l/s	Tanks installed (m^3)	Theorical capacity (m^3)	Storage deficit (m^3)
2013	864	182	2,5	170	230	60
2018	955	200	2,8	170	240	70
2028	1 163	245	3,4	170	267	97

The water supply network does not reach all villages, or if it reaches the major problem is the quality of water (problem of turbidity observed in situ).

2.4.3 Sewage system

The sewage system of the region presents a real concern where the network of the central region has registered a real delay; this comes back to the nature of the landform but also the vulnerability of groundwater. No wastewater treatment plant

does exist in the region and the network of sewage system differs from one point to another (T.Medjdoub, 2014).

The following table shows the situation of the sewage system.

Table II 3 : State of sanitation network (O.Khatir, et al., 2016)

Village	Network connection	Observations
Merchiche	No sanitezed (limited to septic tank)	Study achieved and the work is in progress
OuledBounouar	Sanitized with rejection towards RN22	Extension of rejection in progress study
Tal Terny	Sanitized with rejection towards RN22	Extension of rejection in progress study
Dar Maamar	No sanitezed (limited to septic tank)	Septic tanks
Seheb	Sanitized with rejection towards RN22	Extension of rejection in progress study

2.4.4 Infrastructures

Roads:

The road network is characterized by the principal national road RN 22, considered as the gate of the south because it connects the west north to the south, it length is around 25km. A second local road (CW111) connects the RN 22 to the locality of Dar Maamar, where it's found on a bad condition.

Quarries :

Our study area has two private quarries which are:

Table II 4 :Mining exploitation (O.Khatir, et al., 2016)

Name of quarry	Nature of activity	Place	Surface	Activity of the quarry
SARL SEDOUKI	Career aggregates	Tal Terny	05 Ha	Non
SARL UNION MILOUDI	Career aggregates	Tafza Merchiche	07 Ha	Non

The exploitation of a quarry may have a negatif impacts to the groundwater

Military barracks:

The study area contains two military barracks, the first one in the region of Tel Terny (considered as the northern limit of our study are), and the second one in the locality of Ouled Bounouar.

This type of infrastructure presents a real harm if we compare them to the normal infrastructures, due to the activity of explosives and shooting fields, so we can have a rest of heavy metals (mercury, lead) which can pollute easily the resource and affect the health (F.Alonso, et al., 2004).

Conclusion

In order to make a mapping of the vulnerability of the groundwater pollution, it's very important to collect all required data geographic, geologic, and also climatic. Sometimes the data are missed due to the lack of update or not registered on the responsible administration

Chapter three: methodology and application

Introduction:

In this chapter, we'll review the different methods for mapping the vulnerability of groundwater. The Intrinsic vulnerability mapping deals with the assessment of contaminant and layer properties that determine and influence the previously described processes. It is important that all properties that are relevant for the processes are considered. Each layer offers different conditions for the transport and fate of contaminants due to its own characteristics (J.M.Vias, et al., 2006).

This method is applied to the system of Ghar Boumaaza, located in Tlemcen Mountains, with an average rainfall of 630mm/year, and the geology of the region is composed by sandstone, marly limestone and karstic dolomite.

The quality of water which is used for drinking or to household has to be monitored. Two analysis campaigns are done in some places where the water is used for different purposes to determine the quality of groundwater and to find out the polluted sources.

3.1 Literature reviews of vulnerability mapping:

Classification of methods for mapping groundwater vulnerability is done in many ways, it depends on:

- Type of vulnerability studied (intrinsic or specific)
- The case of study (source or resource)
- The geological formation (porous, karstic or fissurated)
- The location of study area (Country, natural environment, climate)
- Expected results: general vulnerability map, source protection area, or an estimation of the vulnerability on one point.
- The technical support used: emperical methods, mathematic methods or numerical modeling or methods also ome forcasting

methods (T.Lorienne, 2014).

The European Approach uses four factors in assessing intrinsic vulnerability: Overlying layers (O), Concentration of flow (C), Precipitation regime (P) and Karst network development (K). The factors O, C and K represent the internal characteristics of the system, while the P factor is an external stress applied to the system. The O factor may comprise up to four layers – soil, subsoil, non-karst rock and unsaturated karst rock. The C factor recognizes that in karst areas the overlying protective layers may be bypassed by runoff, which is concentrated at or near the surface of the ground and which then enters the groundwater system via a doline or a stream sink. For resource vulnerability mapping, where the target is the top of the saturated zone, the factors O, C and P should be taken into consideration, while, in addition, the K factor should be taken into account for source vulnerability mapping where the target is a karst water supply such as a borehole or a spring (F.Zwahlen, 2003).

The following table resumes the main methods used for mapping the vulnerability:

Table II 5 : Recapitulatif of different methods for mapping the vulnerability (O.Khatir, et al., 2016)

Name of method	References	Type of aquifer	Interpretations of the criteria of the European approach taken into account	Target
«AVI»	Van Stempvoort D. et al., 1993	Porous	O	Resource
«COP »	Vías J.M. et al., 2002	Karst	0, C & P	Resource
« DRASTIC »	Aller et al., 1987	Porous	C, O & P	Resource
« EPIK »	Doerfliger N., 1996 Doerfliger N. et Zwahlen F., 1996	Karst	C, O & K	Resource/Source
« GOD»	Foster S.D.D., 1987	Porous	O & K	Resource

« GLA method »	**Hölting B. et al., 1995**	**Porous**	**O**	**Resource**
« LEA »	**Dunne S., 2003**	**Karst**	**O & C**	**Resource**
« PI-méthode »	**Goldsheider N. et al., 2002**	**Karst**	**O, P & C**	**Resource**
« REKS »	**Malik P. et Svasta J., 1999**	**Karst**	**O & K**	**Resource/Source**
« RISKE »	**Petelet-Giraud E. et al., 2000**	**Karst**	**O, C & K**	**Resource/Source**
« RISKE 2 »	**Plagnes V. et al., 2006**	**Karst**	**O, C & K**	**Resource/Source**
« SINTACS »	**Civita M. et De Maio M., 1998-2000**	**Porous**	**C, O & P**	**Resource**
« SINTACS Pro Karst »	**Cucchi F. et al., 2007**	**Karst**	**C, O, P & K**	**Resource/Source**
« VULK »	**Jeannin P.Y. et al., 2001**	**Karst**	**O & K**	**Resource/Source**

3.1.1 Methods for porous media:

DRASTIC:

DRASTIC is a weighting and rating system developed by the United States Geological Survey in the mid 1980's. The method uses seven parameters: depth to groundwater table (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of the vadose zone media (I), hydraulic conductivity of the aquifer (C). The depth to water table and vadose zone media are given the highest weighting. DRASTIC would seem to be best suited to regional assessments (1:50 000 and 1:100 000 scales) and has been applied in a large number of countries worldwide (F.Zwahlen, 2003).

SINTACS:

The SINTACS method is similar to DRASTIC. The method utilises the same parameters, but has four different weighting systems depending on the hydrogeological setting. The weighting system has been designed to illustrate the

relative importance of the parameters within different settings, which are known as Normal, Severe, Seepage, Karst and Fissured. Normal and Severe reflect the density of human settlement and the intensity of landuse. Other factors are also considered e.g. irrigation. Seepage is used to describe areas that are frequently flooded or swampy i.e. where there is seepage from the surface network to the groundwater (F.Zwahlen, 2003).

AVI:

The AVI method uses two variables to formulate a vulnerability index, these being; the thickness of each sedimentary layer above the uppermost saturated aquifer (d) and the estimated hydraulic conductivity of each of these layers (k). The "hydraulic resistance" (c) of each layer is then calculated as the quotient of thickness and conductivity (c = d/h).

The total hydraulic resistance for several sedimentary layers is established by summing the values for each layer. The hydraulic resistance describes the resistance of the layers to vertical flow (lateral spread of contaminants is taken to be insignificant). The hydraulic resistance has an aspect of time, as it indicates the approximate time of travel for water to move by advection downward through the sedimentary layers under a hydraulic gradient of one. The AVI index does not however take into account other factors, e.g. climate, hydraulic gradient, porosity, diffusion etc. It is perhaps most suitable at a large regional scale.

GOD:

This method considers three parameters:

- The nature of groundwater occurrence (ranging from none to unconfined).
- Overall Aquifer Class which considers the degree of consolidation and lithological character.
- Depth to groundwater which takes into consideration the confined or unconfined nature of the aquifer.

A numerical value is attached to each parameter division and the three values are then multiplied together to form an aquifer vulnerability index (Gogu &

Dassargues, 2000). This method includes the need to assess potential risks to the aquifer and as a result may be said to approach the rigor of a general risk assessment (21).

3.1.2 Specific methods for karst:

EPIK:

EPIK was developed at CHYN in the University of Neuchatel in the early 1990's to address particular risks posed to groundwater quality in the mountainous Alpine Karst of Switzerland.

The method uses four parameters that are empirically combined and have been "weighted" by the consensus of experts working in the region. EPIK can only be used on karst aquifers and is typically applied at a scale of 1:10,000.

EPIK uses four parameters; epikarst (E), protective cover (P), infiltration conditions (I) and karst development. These parameters are combined using a weighting system which is the basis of the final intrinsic vulnerability map on which four vulnerability classes are recognized.

EPIK has been applied in many karst areas of Europe, mostly as a result of work carried out by COST 620. EPIK is thought to have been the first method that included "flow concentration" as a parameter. The method is based on a clearly defined conceptual model of a karst

RISKE:

The RISKE method is a multi-criteria method of the Point Count System Models (PCSM) or index method with criteria weighting. It aims to assess the intrinsic vulnerability of karstic aquifers. This approach is derived from the EPIK method developed in Switzerland by Doerfliger (28) to "assess the sensitivity of karstic groundwater to natural and anthropogenic influences in a comprehensive and rigorous manner".

The RISKE method takes into account 5 criteria that define the aquifer architecture and flow organization in the karst environment: aquifer rock, infiltration, soil, karstification and epikarst (21).

3.2 Presentation of COP method

The COP acronym comes from the three initials of the factors used: flow Concentration, Overlying layers and Precipitation.The conceptual basis of this method, according to the European Approach (Daly et al. 2002; Goldscheider and Popescu 2004), is to assess the natural protection of groundwater (*O* factor) determined by the properties of overlying soils and the unsaturated zone, and also to estimate how this protection can be modified by the infiltration process – diffuse or concentrated – (*C* factor) and the climatic conditions (*P* factor – precipitation) (16).

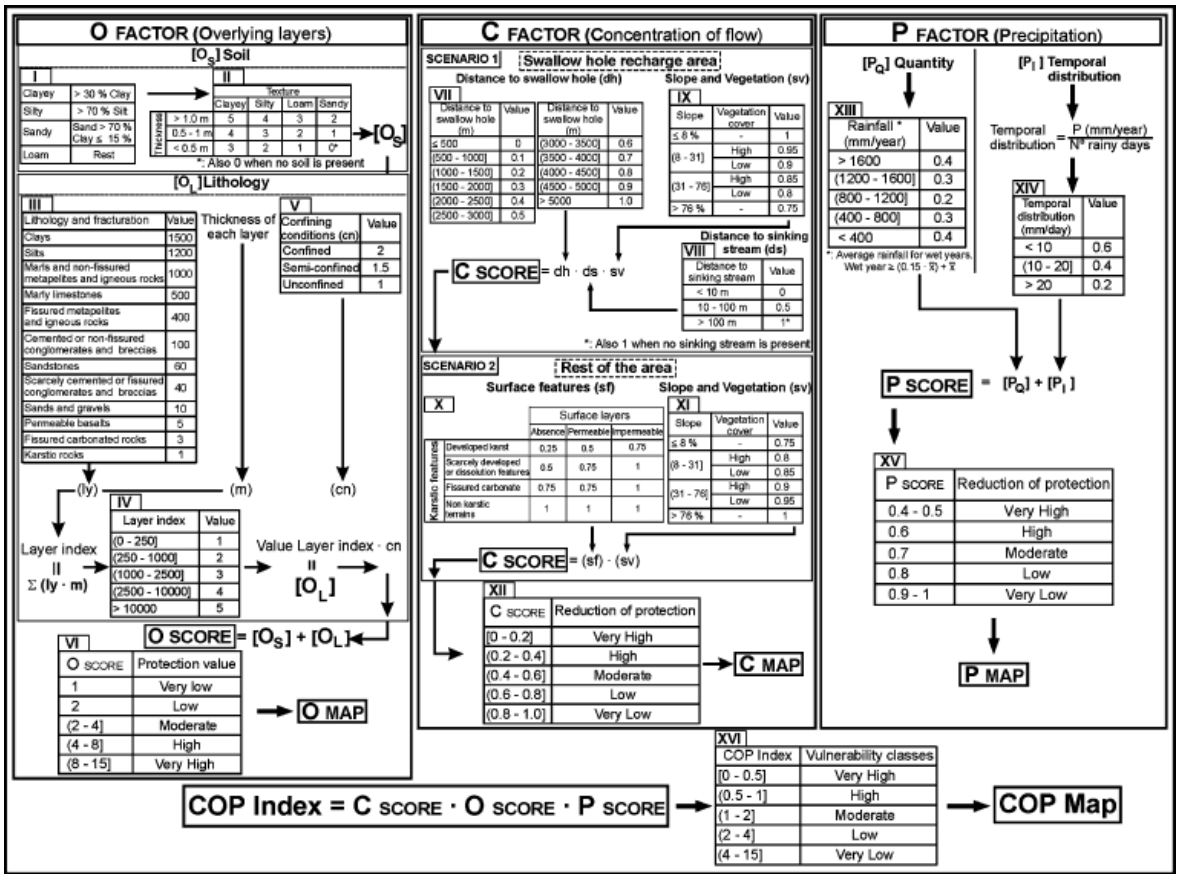

Figure III 1 : Flowchart of the COP method: showing the different steps for the evaluation of the C, O, P factors an the COP index (F.Zwahlen, 2003)

3.2.1 Parameters of the method

O factor:

The *O* factor considers the protection provided to the aquifer by the physical properties and thickness of the layers above the saturated zone. Daly et al. (2002) proposed subdivision into four layers: topsoil, subsoil, non-karstic rocks and unsaturated karstic rocks. In the proposed COP method only two layers with important hydrogeological roles are used in order to evaluate the *O* factor: Soils [*O*S] and the lithological layers of the unsaturated zone [*O*L] (J.M.Vias, et al., 2006).

C factor:

The *C* factor is a modifier of the *O* factor (overlying layers) and represents the potential for water to bypass the protection provided by the overlying layers (D.Daly, et al., 2002). The *C* factor represents the degree to which precipitation at or near aquifer outcrop is concentrated into a swallow hole, bypassing the unsaturated zone. This is based on the PI method (N.Goldscheider, et al., 2000)and the EPIK method (N.Dorfliger, et al., 1998). Two scenarios are distinguished for this factor (J.M.Vias, et al., 2006).

P factor:

The *P* factor is evaluated by two subfactors: *Quantity* of precipitation [*P*Q] and *temporal distribution* of precipitation [*P*I]. The [*P*Q] subfactor describes the effect of rainfall quantity and the annual recharge on groundwater vulnerability. It corresponds to the mean annual rainfall of a historical series of wet years. Several vulnerability mapping methods (PI, DRASTIC) consider groundwater protection to decrease (or vulnerability to increase) with increasing recharge as infiltration occurs more rapidly (J.M.Vias, et al., 2006).

The [P_I] subfactor concerns the temporal distribution of precipitation in a certain period of time and thus is indicative of the intensity of precipitation. This subfactor

enables a comparison to be made between zones within Europe, where rainfall and intensity conditions are highly variable (J.M.Vias, et al., 2006).

3.3Application in the field

Our study area is the karst system of Ghar Boumaaza, which is constituted by carbonated rocks like dolomites of Terny, so to map the vulnerability we selected COP method which corresponds perfectly to our zone. Apply this method to a karst aquifer can be very useful to establish protecting perimeter.

The method is based on three criteria, which are C (concentration of flow), O (layers) and P (precipitation).

3.4 O mapping

To establish this first map, we need to make two different carte which are Os and Ol, where both need data of geology and soil.

3.4.1 Os map

"The *soil subfactor* [*OS*] deals with the biologically active part of the subsurface, where attenuation processes occur and as a consequence, when present, should be taken into account in vulnerability mapping. Several parameters are considered in the evaluation of the soil subfactor: texture, grain size distribution and thickness, the last being highly variable in Mediterranean areas" (J.M.Vias, et al., 2006).

Following to the COP method, we need to find out the type of our soil but unfortunately; due to leak of pedological background we couldn't determine easily the soils properties. So for this, we estimated Os map from the vegetation map and also an investigation in the field. The vegetation map was digitized under "Mapinfo" (1/20000).

In our case, we distinguish three types of vegetation:

1. 42% of Scrub, where it dominates the region. The thickness of the soil is about 0.2m, and from the study of the soil (in the field) we found out that the soil of this area is silty, where there is more than 70% of silt.
2. 32% of the area is covered by forest, and the thickness of the soil is more than 1m. Following to geological study and from the field we classify this part as clayey soil.
3. 26% of the rest is cultivated, by dry crops. The thickness of the soil is around of 0.6m, and the types of these crops can be found mostly when soil is composed by different element, also from the study of the geology, we classify this soil as loam.

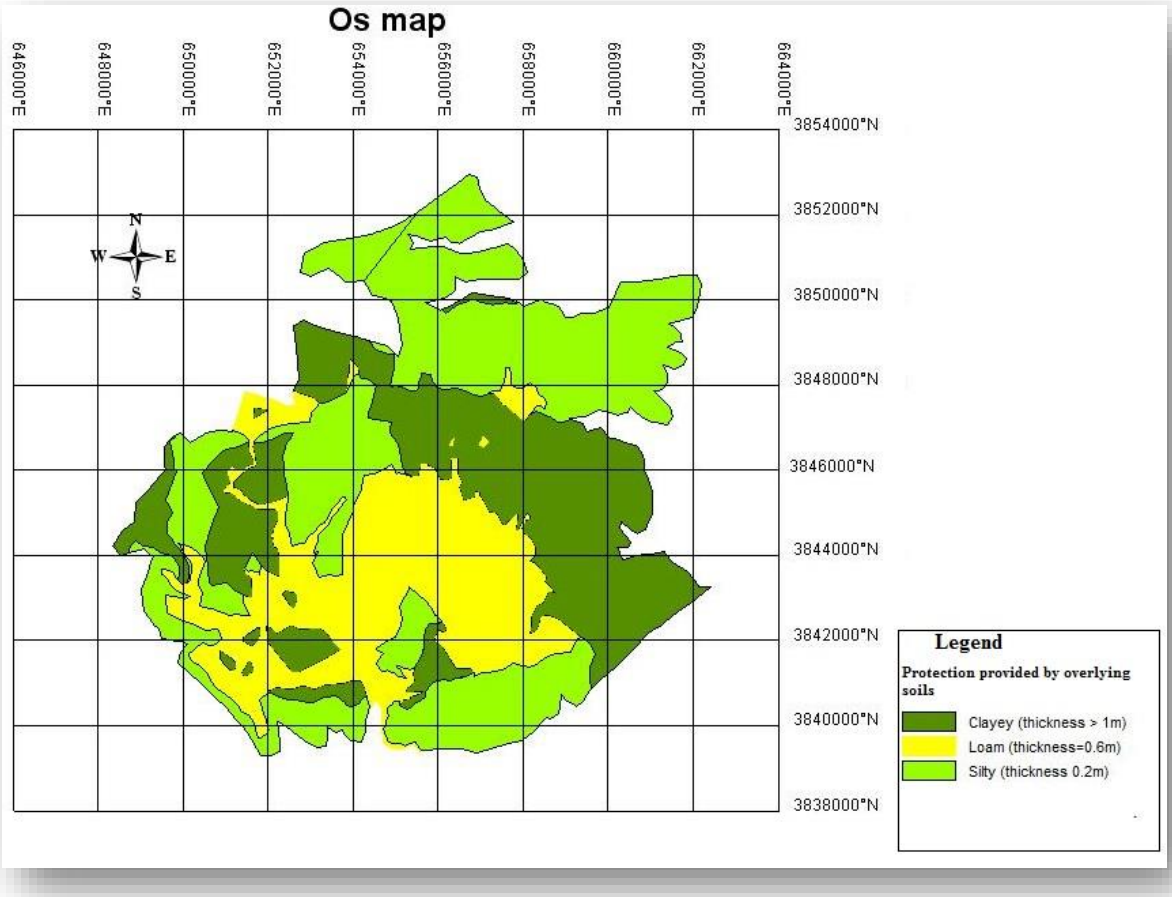

Figure III 2 : Os map

3.4.2 OL map

"The *lithology subfactor* [*O*L] reflects the attenuation capacity of each layer within the unsaturated zone. The assessment criteria for its quantification are the

type of rock (which determines its hydrogeological characteristics, mainly effective porosity and hydraulic conductivity) and the degree of fracturing (ly), the thickness of each layer (*m*) and any confining conditions (cn)" (J.M.Vias, et al., 2006).

All required data for this step are found in the geological map, so for that we digitized it (1/20000) under mapinfo.

Following to the lithology of our region, the aquifer is among three layers, which are:

1) Dolomites of Terny: it's a layer which is considered as karstic rock, "massive limestone and dolomite with a high intensity of fracturing which gives an easy and fast flow, but also a high risk of contamination" (O.Khatir, et al., 2016). Its thickness is about 100m.
2) Limestone of Hariga: with 35 to 65% of limestone minerals, limestone of Hariga is the second layer, and it's considered as marly limestone. The thickness of this layer is around 195m.
3) Sandstone of merchiche: with a thickness of 52m, it's the third and last layer of our aquifer; we consider this layer as sandstones.

The confining condition of our aquifer is considered as unconfined, so we take the value of Cn equal to 1.

Os value is equal to: Ol=Iy*m*cn

With:

Iy: value of lithology; m: thickness of layer, cn: confining value

Table III 1 : Ol factor depending on the lithology, thickness and confining condition

Parameter / Layer	Lithology and fracturation (Iy)	Thickness of soil (m)	Confining condition (cn)	Ol value
Dolomites of Terny	Karstic rock	100	1	1

Limestone of Hariga	Marly Limestone	195	1	5
Sandstone of merchiche	Sandstones	52	1	5

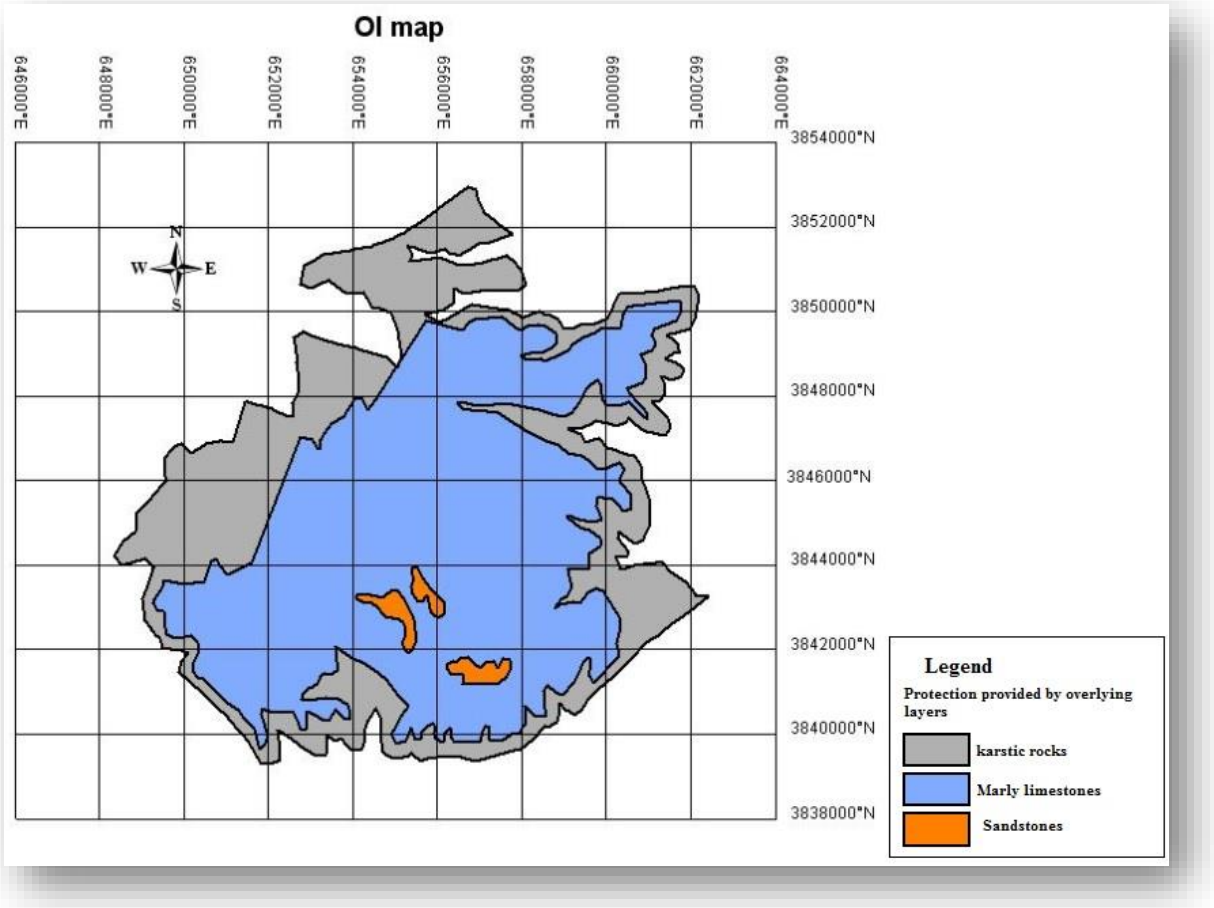

Figure III 3 : Ol map

3.4.3 O map

We get the O map by adding the two maps OL and OS, and it's done by the software Vertical mapper:

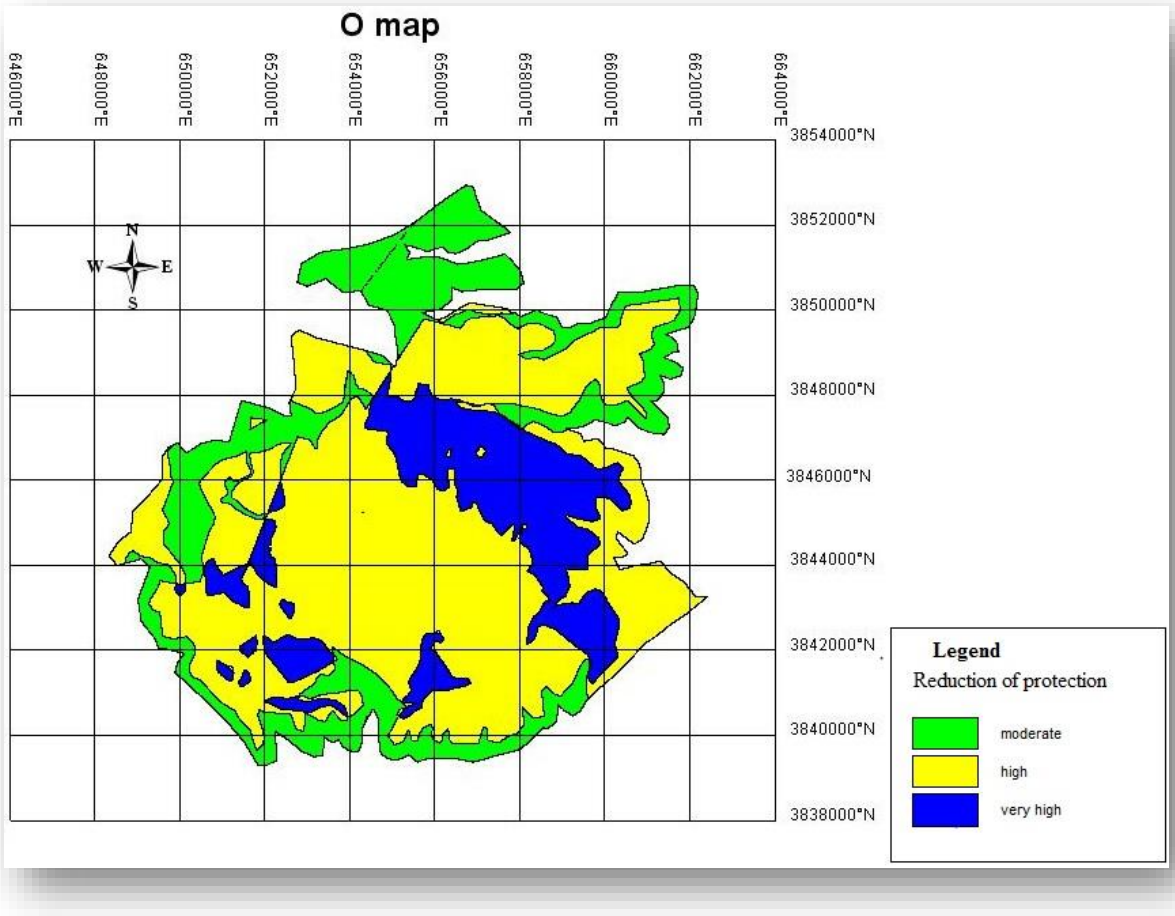

Table III 2 : Distribution on Km^2 of "O" Map in classes.

3.5 C mapping

Concentration of flow is the second parameter of this method and it depends on different criteria, this parameter is evaluated by two scenarios where both belong to the slope and vegetation and each one depends on different parameter.

3.5.1 First scenario

The evaluation of the *C* factor in this scenario considers four variables: the distance from the recharge area to the swallow hole (*dh*) and to the sinking stream (*ds*), and the influence of slope (*s*) and vegetation (*v*) (16).

- *Dh map:*

Distance to swallow hole is the recharge area which will increase the vulnerability if the distance to swallow hole increase. The following table represent all swallow hole present in the study area.

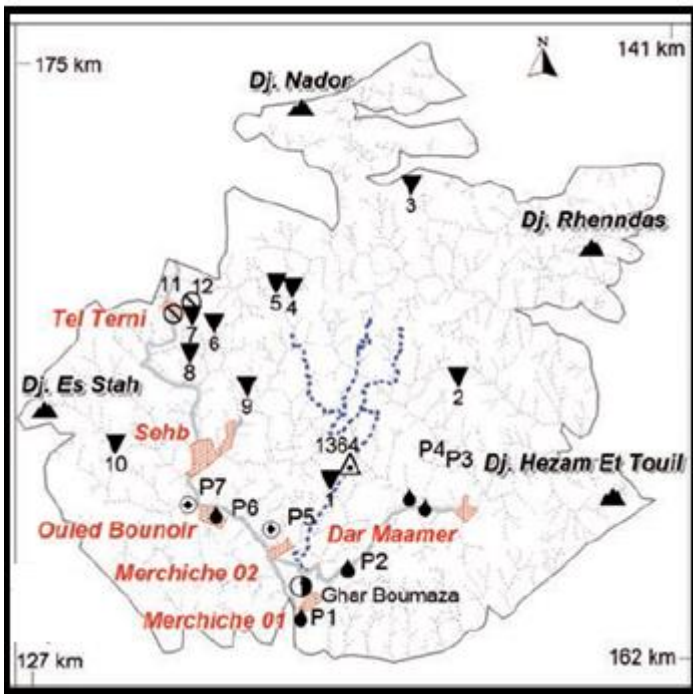

Figure III 4 : Location of different swallow hole in the study area (F.Bensaoula, et al., 2018).

After drawing catchment of each swallow hole, we could estimate the distance of each one and we have had only two categories of distance, less than 500m and distance between 500 to 1000m.

:

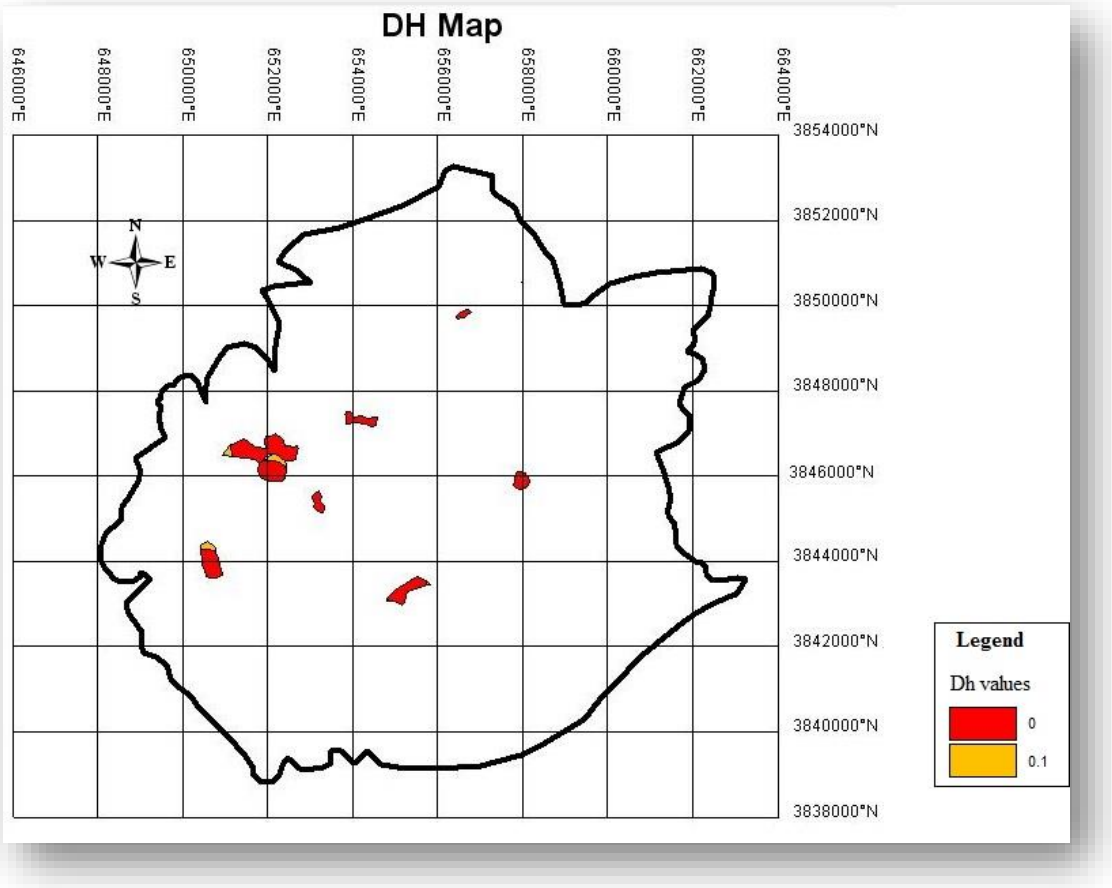

Figure III 5 : Dh values obtained for swallow hole

- *Ds value:*

  This value is defined as the distance to sinking stram.Since there is no sinking stream in our study area, the value is 1.

- *Sv map:*

Sv map required two elements; vegetation and slope.

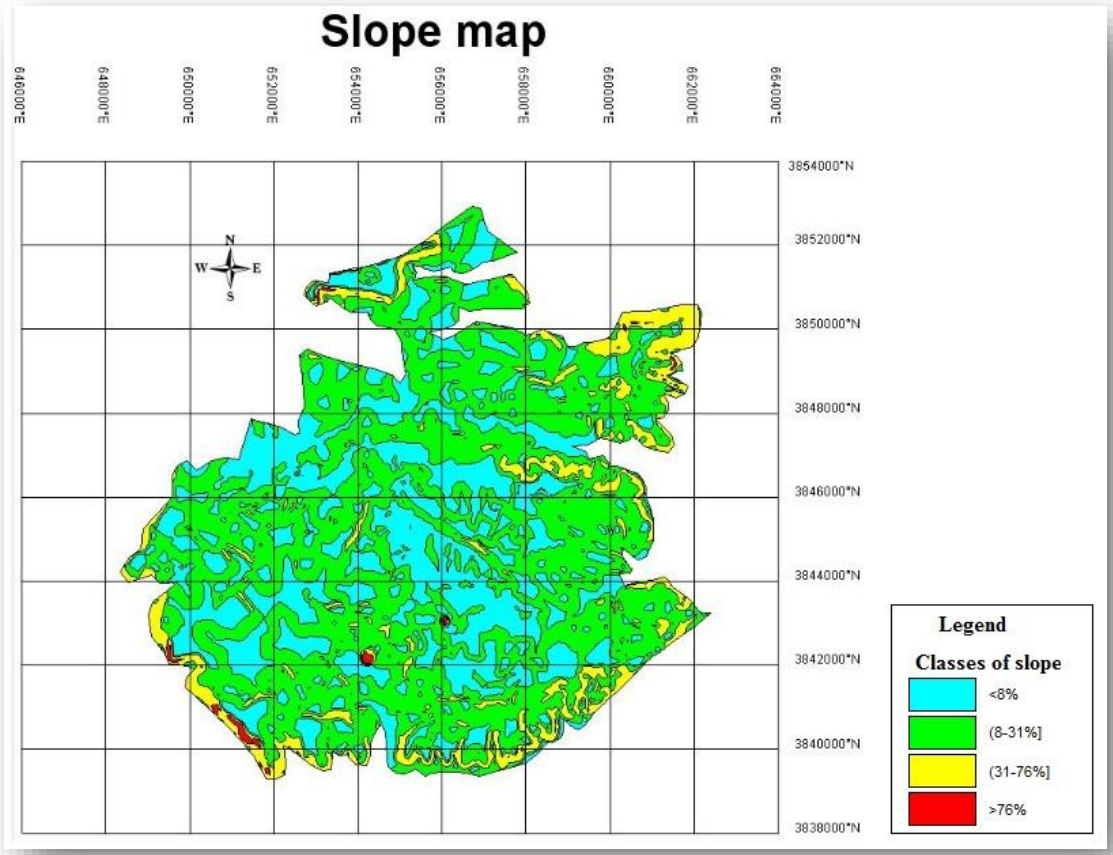

Figure III 6 : Classified slope obtained from the topographic map

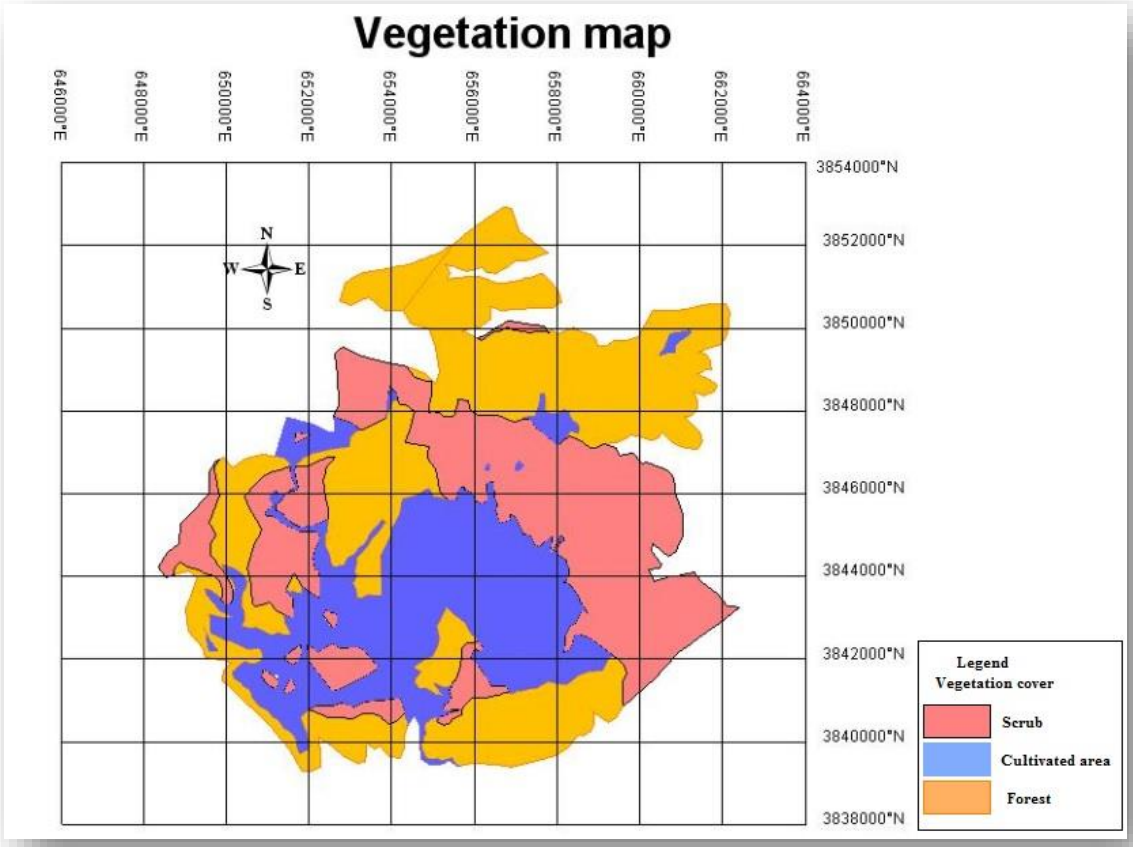

Figure III 7 : Vegetation map

As a first scenario we've got this final map for the scenario 1, where the vulnerability is located near to the different swallow hole of our study area.

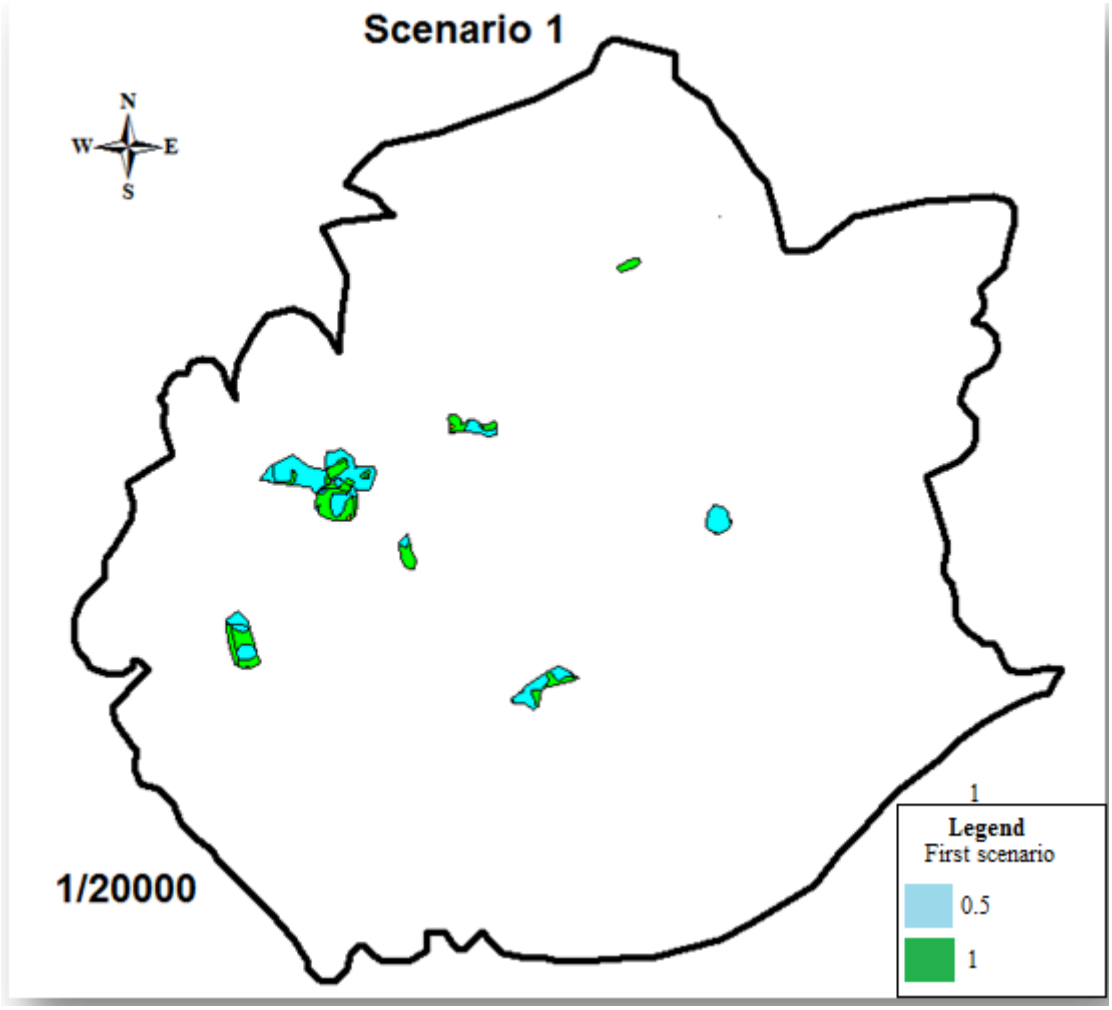

Figure III 8 : Result obtained from the first scenario Result of the first scenario

3.4.2Second scenario

The *C* score under this situation is evaluated by the combination of only three variables: surface features (*sf*), slope (*s*) and vegetation (*v*).

- *Surface features:*

  This parameter takes on consideration properties of the aquifer, the permeability of it, but also development of the karst. To achieve this step we took geological map, and from the characteristics of each layer, so finally we've got two features:

  - Developed karst where the surface layer is absent (sf=0.25)
  - Developed karst where the surface is permeable (sf=0.5)

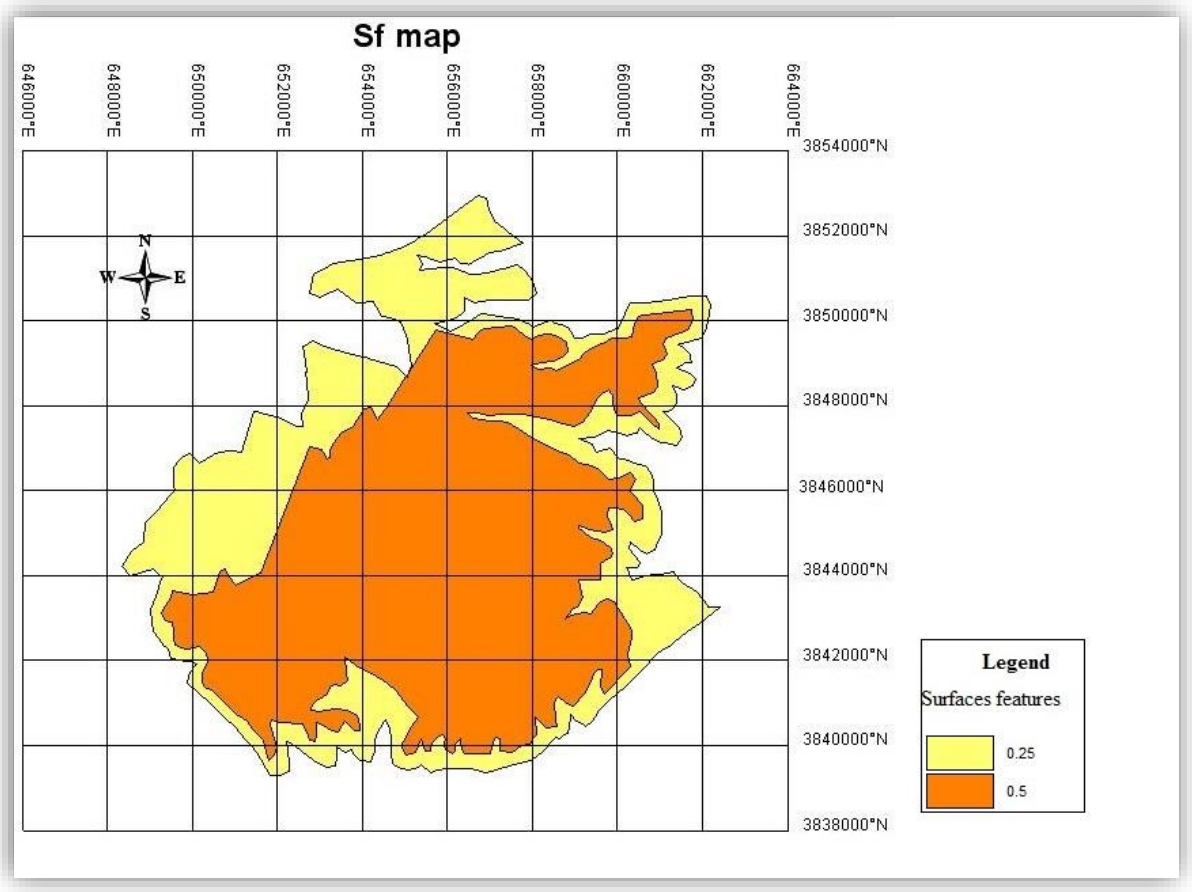

Figure III 9 : Sf factor « Surface map »

- Sv: it's the same parameter like in the first scenario, but the results are different, so the new map become:

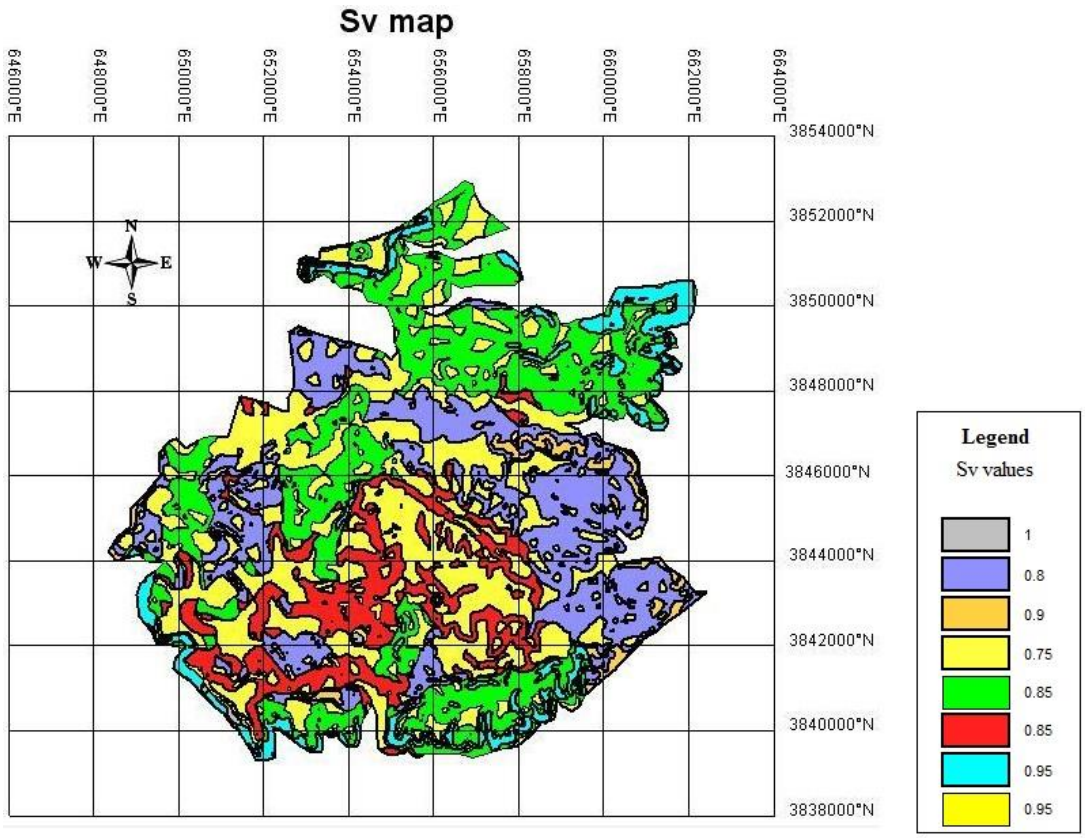

Figure III 10 :Sv map for the second scenario

3.5 P mapping

According to Daly et al. (2002) this factor includes the quantity of precipitation and factors which influence the rate of infiltration, i.e. frequency, temporal distribution, duration and intensity of extreme rainfall events. This factor depends on two sub factor which are PI and PQ (16).

In our region, the only station that records precipitation and temperature is located in Mefrouche, the nearest station to our study area.

The [*P*I] subfactor concerns the temporal distribution of precipitation in a certain period of time and thus is indicative of the intensity of precipitation (16). This temporal distribution is equal to:

$$PI = \frac{p\ (mm/year\ )}{N°\ of\ rainy\ days}$$

The precipitation that we take it is the rainy year, where it registred the maximum value, and it was in 2013 with a value of 1144mm, and rainy days is equal to 70.

Following to COP method we have to determine PI value, and for that and due to the lack of data, we took the rainy year as reference (because we consider it as a catastrophic scenario).

Nevertheless, the PQ subfactor depends on quantity of precipitation, and it takes on consideration certain values, values of wet years. A wet year is defined as the following equation:

$$\boldsymbol{wet\ year \geq (0.15 * \overline{x}) + \overline{x}}$$

$\overline{\boldsymbol{x}}$***:*** *Average precipitation.*

Our series of data are from 1936 to 2017, and the average rainfall of this period is 632.5mm/year, and the wet years are those with a value higher than 727.35mm/year. From this value, we've only 18 years which exceed it. So we take the values of these years which are considered as yet year, and we calculate the average which is equal to: 858.47mm/year.

At the end, the value of P score is equal to:

P= PI+PQ

Table III 3 : P score with all parameters

Parameter	Wet year (mm/year)	Average (mm/year)	PQ value	Rainy year (mm/year)	Rainy days	Temporal distrubution	PI value	P value
P	≥727.35	858.47	0.2	1144	70	16.36	0.4	0.6

P score is 0.6 and from the table (…), the reduction of protection is considered as high.

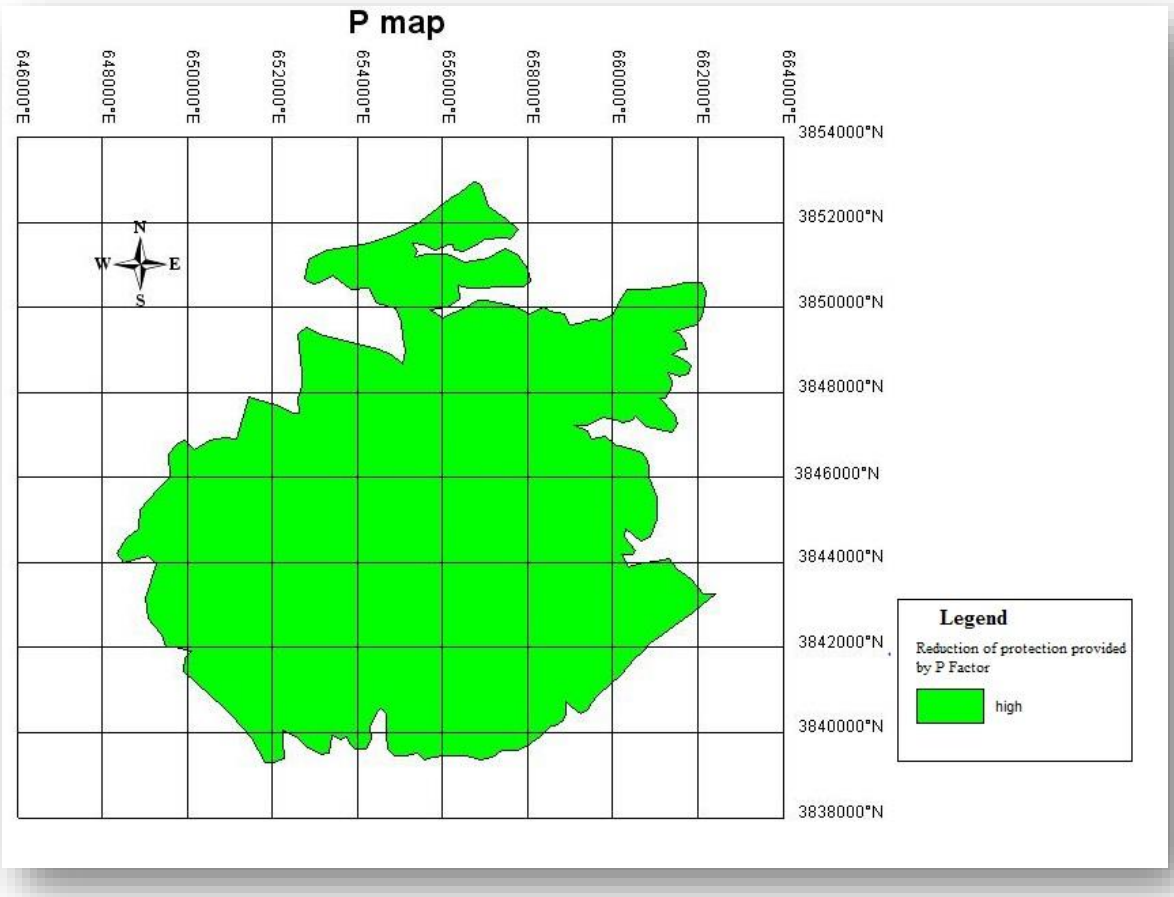

Figure III 11 : P map

3.6 COP map

The factors of COP method are combined to estimate the intrinsic vulnerability for a resource on a karstic aquifer following to this equation:

COP index= C.O.P

The final numerical presentation of the factors (C,O and P) are multiplied, because each factor is considered as a factor which influences the evolution of the karstic aquifer vulnerability.

On COP method, the indices of vulnerability vary among 0 and 15 following to the proposition made by Vrba and Zaporozec (1994), and values are grouped on five classes of vulnerability (K.Zeghid, 2013).

Table III 4 : classes of vulnerability following to COP method

Area	O factor	Protection value
	1	Very low
	2	Low
	(2 – 4)	Moderate
	(4 – 8)	High
	(8 – 15)	Very high

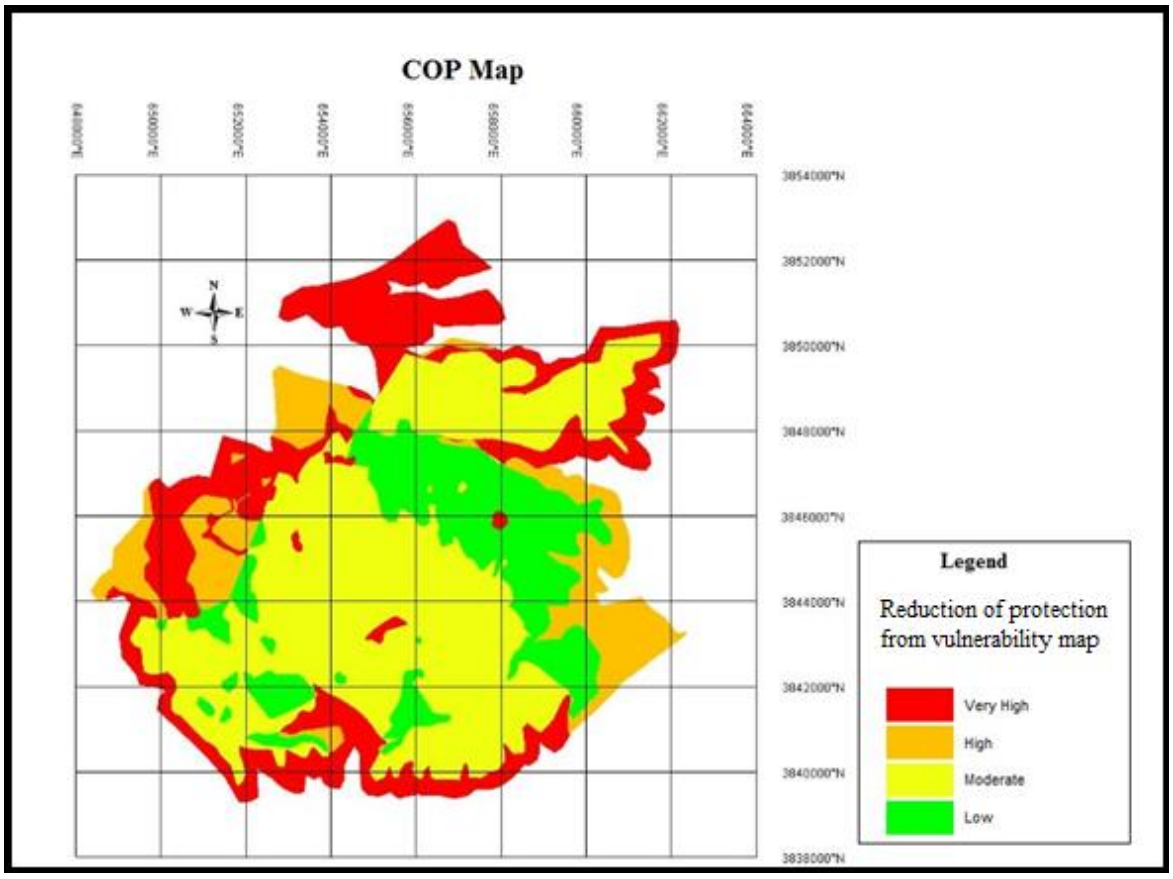

Figure III 12 : COP map

The intrinsic vulnerability of the karstic system of Ghar Boumaza is classified into 4 categories. The surfaces of the classes are presented on the following table:

Table III 5 : Repartition of the vulnerability following to COP method

Vulnerability	**Surface (Km^2)**	**Proportion**
Very high	28.3465	25.04
High	15.1575	13.39
Moderate	49.9476	44.12
Low	19.7622	17.45

- 25% of the total area is under a very high vulnerability, and 13% the vulnerability is high, and this vulnerability is found where the layer is a karstic rock but also where a swallow hole is present, and it comes back to the high permeability of the soil but also where there's a high slope(between 8-76%).

-44% of the area is under a moderate vulnerability, which depends mainly on loam soil, and the geology is marly limestone, the main slope of this part is under to 8%.

-The rest of our study area (17%) the vulnerability is low, and the soil of this part is clayey which considered as impermeable soil.

3.7 Hazard map

The evaluation of risk is an important step in the process of groundwater protection; the risk can have several forms which may contaminate this resource.

This is why it's considerable to asses all types of activities in our study area, and this can be done by the land use map.

It's also important to know main activities in the region, and that's why we should classify them following to COST620, where it's done an inventory of different hazards which are relevant to the vulnerability of our aquifer.

Table III 6 : Categories of risk according to COST 620 (O.Khatir, et al., 2016)

number	**level I categories of hazards**	**level II categories of hazards**
1	infrastructural development	
1.1		waste water
1.2		municipal waste

1.3		fuels
1.4		transport and traffic
1.5		recreational facilities
1.6		diverse hazards
2	industrial activities	
2.1		mining (in operation and abandoned)
2.2		excavation sites
2.3		oil and gas expolaration
2.4		industrial plantss (non-mining)
2.5		power plants
2.6		industrial storage
2.7		diverting and treatment if waste water
3	livestock and agriculture	
3.1		livestock
3.2		agriculture

We obtain from the land use map the following table which resumes different hazardous in our study area with their weight:

Table III 7 : Weight of hazardous in the study area

No.	Dangers	Weighting value
1	**infrastructural development**	
1.1	Wastewater	
1.1.3	Houses without sanitation system	**45**
1.1.4	Septic tanks	**45**
1.1.9	Reject of used water in the stream	**45**
1.4	**Transport and traffic**	
1.4.1	Roads unsecured	**40**
1.6	**Divers risks**	
1.6.1	Cemetery	**25**
1.6.5	Active or abondanded military activities	**35**
2	**Industrial activities**	
2.2	Excavation site	

2.2.3	Quarry	**25**
3	**Livestock and agricultur**	
3.1	**Livestock**	
3.1.1	Animal barn (sheds, shelter, barn)	**30**
3.1.3	Breeding in battery, or intensive	**30**
3.1.4	Spreading of organic fertilizers	**45**
3.1.6	Intensive grazing area	**25**

The above table shows the weight of all type of hazarus on groundwater; the weight varies among 10 to 100. To obtain the classes of hazardous which describes the values of hazardous (from 0 to 120) and which gives us five degrees of hazardous, we use the following equation (O.Khatir, et al., 2016):

$$Hi=H*Qn*Rf$$

With**:**

Hi: Hazardous classe

H: Weight of the hazardous

Qn: Ranking factor which varies between 0.8 to 1.2

Rf: Reduction factor which varies between 0 to 1.

Table III 8 : Hazardous index and it classes

Classification of the hazard	Classes of hazard	Vulnerability
0 – 24	**1**	**Very low**
>24 – 48	**2**	**Low**
>48 – 72	**3**	**Moderate**

> 72 – 96	4	High
>96 - 120	5	Very high

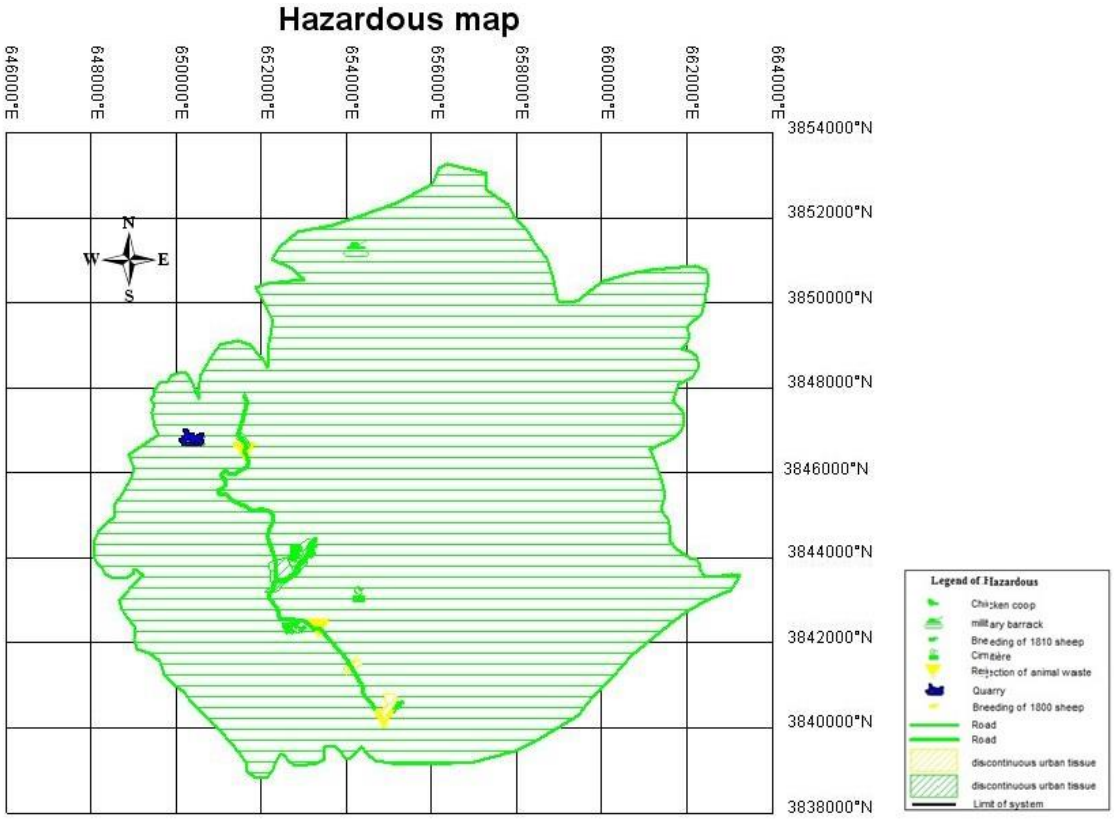

Figure III 13 : Classified hazards map of the study area.

In our case we found out only three classes of vulnerability from the different hazardous, and these classes are: low, very low and moderate.

3.8 Risk map

3.8.1 Risk definition:

Risk assessment and risk management techniques are increasingly used in a broad range of hydrogeological activities, including groundwater resource and quality management, or prioritisation of groundwater remediation (26). In particular, groundwater protection schemes are usually based on the concepts of contamination risk and risk management (27).

Mapping of risk in our case needs different information and data which are:

- Vulnerability map.
- Identification and assessment of potential hazards.

Following to the report of COST620, risk map is acquired by crossing hazardous map (classified), and vulnerability map (J.M.Vias, et al., 2006).

3.8.2 The map:

The Risk map which is obtained from hazardous map and vulnerability map; the bellow table represents the classes of pollution related to the vulnerability and the hazardous.

Table III 9 : Repartition of the pollution risk related to groundwater

Value	Risk Class	Risk level
>0.167	1	no or very low
0.042-0.167	2	Low
0.014-0.042	3	moderate
0.005-0.014	4	high
<0.005	5	very high

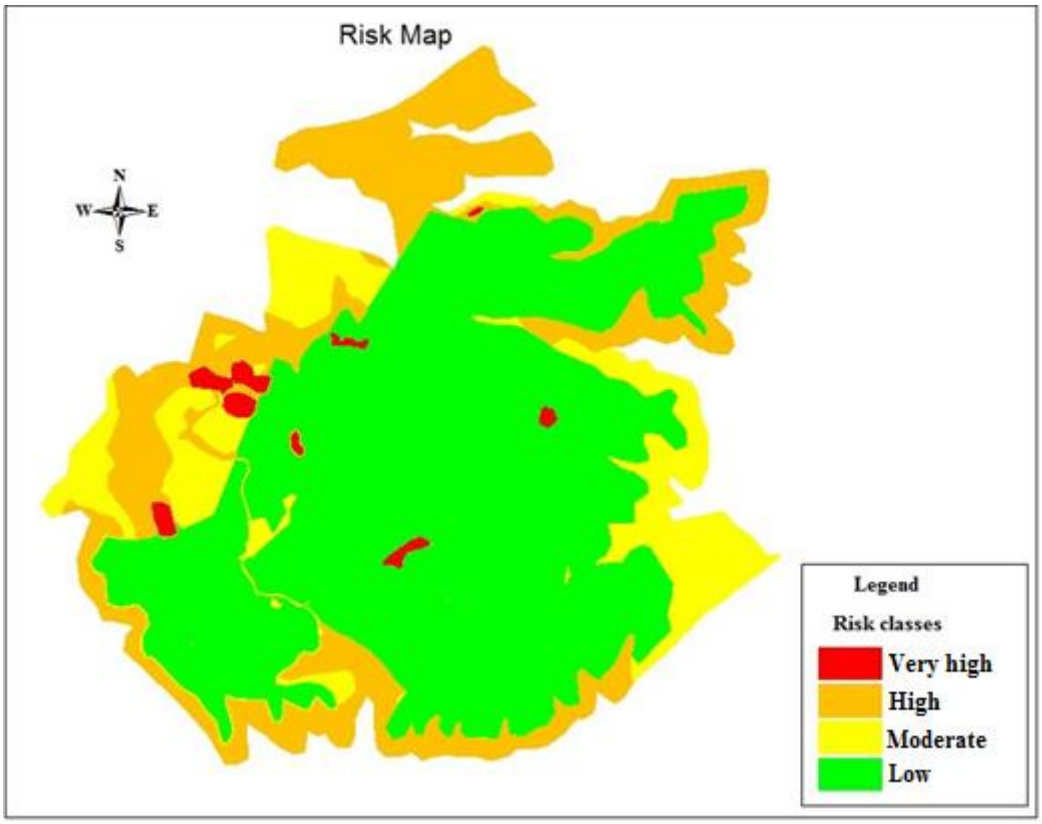

Figure III 14 : Risk map of pollution related to groundwater of the karsit system of Ghar Boumaza

Fourth classes are distinguished on our risk map with surfaces of:

Table III 10 : Repartition of risk pollution on the karstic system of Ghar Boumaza

Value	Area (km^2)	Proportion (%)
Low	68.8854	60.95
Moderate	15.9998	14.13
High	26.6196	23.51
Very high	1.70758	1.41

3.8.4 Interpretation of risk map:

The combination of the intrinsic vulnerability and hazardous map has carried out four classes of risk: Low, moderate, high and very high

This map is very important where it lets us to find out all risks related to the pollutants factors like (the wastewater reject, septic tank and the human activities).

To confirm that there's a real risk of pollution, we've made two analyses of water in different places where water is directly used from the underground, as well

as sources or wells. These analyses will carry out a real investigation of the study area and to give a real vision to the actual situation of the groundwater.

3.9 Confirmation of the results "Water analysis"

The analyses of water for a well or a source should be done at least three times by year to have a correct estimation of the results.

Drink water which is contaminated can seriously impact the human health. The diseases may differ from stomach cramps, nausea and diarrhea with vomiting and fever, and all of them are back to the presence of bacteria.

The physic-chemical and microbiological analyses of groundwater refer to all actions of sampling, whether they're analyzed, measurements or observations (made in a laboratory or on the site the measuring station.

The information related to the analysis results should be provided by the body responsible of analysis, and communicate the results under a responsibility with regard to a standards.

For the parameters, we selected three categories of parameter

Physical parameters:

- Temperature
- Turbidity
- Conductivity
- Odor and color.

For the chemical parameters, we'll find different types (ions, cation). However, the microbiological is considered as the part of the water quality where we must monitor it as much as possible, because for the physical and chemical parameters can be distinguished easily. The diseases caused by the bacteria and germs are the most common like (malaria, typhoid and diarrhea).

The water provided by our aquifer is used for the household, irrigation but also for drinking, and for this reason two analyses were done. The analyses concern different parameters which are:

Physical: Temperature and conductivity.

Chemical: calcium, magnesium, chloride, sulphates, sodium, potassium, bicarbonates, carbonates and nitrates.

Microbiological: Aerobic germs, Coliforms, Fecal coliforms, fecal streptococci, clostridium sulphito-reducers 46°C, E. coli and Salmonella.

The first one was in a wet season, and it was realized just after a rainy period. The index of rainy period has an importance which may help us to see the behavior of the aquifer which answers quickly after each rainy period.

3.10.1 First analysis (done)

First analyze:

The first analyze was done after a high period of rainfall, that was on 28/03/2018, we wanted to know the impact that could have the rainfall on the quality of the water, because as we know, the karst system has an important permeability so it can carry different things to our aquifer.

Table III 11 : phisicochemical analysis of the four points for the 28/03/2018

Results of first analysis done 28/03/2018					
Parameter	**Source of Ain TAGA**	**Source of Ain ElKbira**	**Drilling of Sehb**	**Source of Ouled Bounouar**	**standards from the article n°11-219 of the 11-06-2011**
Calcium mg/L	219.9	139.5	101.95	183.67	-
Magnesium mg/L	***6.42***	***0***	***6.04***	***5.96***	**-**
Chloride mg/L	***81.65***	***28.4***	***37.27***	***40.23***	***500***
Sulphates mg/L	***30.07***	***53.4***	***19.56***	***163.7***	***400***

Sodium mg/L	*48.92*	*17.24*	*22.86*	*24.42*	-
Potassium mg/L	*1.95*	*4.9*	*3.32*	*18.36*	-
Bicarbonates m/L	*549*	*610*	*315*	*219.6*	-
Carbonates mg/L	*0*	*0*	*0*	*0*	
Nitrates mg/L	*9.3*	*15.3*	*10.3*	*11.5*	*50*
Temperature (°C)	*13.9*	*14.7*	*13.8*	*14.2*	-
Conductivity (ms/cm)	*4.62*	*4.8*	*4.86*	*4.32*	-

Table III 12 : Microbiological analysis for the points monitored on 28/03/2018

Results of first analysis established 28/03/2018						
Parameter	**Source of Ain TAGA**	**Source of Ain ElKbira**	**Drilling of Sehb**	**Source of Ouled Bounouar**	**Standards**	**References and methods**
Aerobic germs (ufc/ml)	**26**	*7*	*15*	*8*	*20*	*NA 763*
Coliforms (ufc/100ml)	**460**	**240**	**210**	**1100**	*<10*	*NA 764*
Fecal Coliforms (ufc/100ml)	*missed*	*missed*	*missed*	*missed*	*Missed*	*NA 764*
Fecal streptococci (ufc/50ml)	**positif**	**positif**	**positif**	**positif**	*Missed*	*NA 765*
Clostridium sulphito-reducers 46 ° C	*missed*	*missed*	*missed*	*missed*	*Missed*	*Official paper n°36-2013(MAO*)*
E. coli (ufc/100ml)	*Missed*	*Missed*	*Missed*	*Missed*	*Missed*	*Official paper n°31-2013(MAO*)*
Salmonella (ufc/50ml)	*Missed*	*Missed*	*Missed*	*Missed*	*Missed*	*Official paper n°31-2013(MAO*)*

Interpretation:

The presence of coliforms in our samples can indicate the contamination of a source. The coliforms birth naturally on the soil and vegetation which is in decomposing, but they can be associated to a fecal contamination for human of animal. Considering the fact that the vulnerability of groundwater is impacted by external influences as the human activities, environmental or agricol.

Aerobic germs are found on only one sample and in many cases this infection is mixed by aerobic and anaerobic

However, in our analyses there's no presence of E.Coli which is found in the fecal matter of human and animal. Salmonella is bacteria classified as pathogens, the infection of humans by transmission of Salmonella can cause severe disease, it's not found in our samples.

From the results obtained by the laboratory of analyses that the four points assessed should not be drunk due to the presence of coliform and fecal streptococci, following to the standards of drinking established by the Algerian government.

3.10.2 Second analysis

The second analyze was done in the dry season on 15/07/2018, we wanted to know the impact that could have the rainfall on the quality of the water. The dry season could impact on the mineralization and the presence of bacteria.

Table III 13 : Second Physicochemical analyses of the four points done on 15/07/2018

Results of second analysis established 15/07/2018					
Parameter	**Source of Ain TAGA**	**Source of Ain ElKbira**	**Drilling of Sehb**	**Source of Ouled Bounouar**	**standards from the article n°11-219 of the 11-06-2011**
Calcium mg/L	***119.79***	***90.91***	***154.92***	***53.62***	**-**

Magnesium mg/L	*3.8*	*2.14*	*2.32*	*2.4*	*-*
Chloride mg/L	*3.87*	*2.14*	*4.32*	*2.2*	*500*
Sulphates mg/L	*34.2*	*130.3*	*23.2*	*48.4*	*400*
Sodium mg/L	*2.3*	*1.3*	*2.62*	*1.33*	*-*
Potassium mg/L	*0.48*	*0.65*	*0.99*	*0.346*	*-*
Bicarbonates mg/L	*361.12*	*266.57*	*244.48*	*298.9*	*-*
Carbonates mg/L	*0*	*0*	*0*	*0*	
Nitrates mg/L	*11.2*	*10.05*	*12.2*	*13.5*	*50*
Temperature (°C)	*13.9*	*14.7*	*13.8*	*14.2*	

Table III 14 : Second microbiological analyses of the points done on 15/07/2018

Results of second analysis established 15/07/2018						
Parameter	**Source of Ain TAGA**	**Source of Ain ElKbira**	**Drilling of Sehb**	**Source of Ouled Bounouar**	**Standards**	**References and methods**
Aerobic germs (ufc/ml)	*15*	*25*	*8*	*10*	*20*	*NA 763*
Coliforms (ufc/100ml)	*28*	*1100*	*3*	*15*	*<10*	*NA 764*
Fecal Coliforms (ufc/100ml)	*missed*	*missed*	*missed*	*missed*	*Missed*	*NA 764*
Fecal streptococci (ufc/50ml)	*positif*	*positif*	*positif*	*positif*	*Missed*	*NA 765*
Clostridium sulphito-reducers 46 ° C	*missed*	*missed*	*missed*	*missed*	*Missed*	*Official paper n°36-2013(MAO*)*
E. coli (ufc/100ml)	*Missed*	*Missed*	*Missed*	*Missed*	*Missed*	*Official paper n°31-2013(MAO*)*
Salmonella (ufc/50ml)	*Missed*	*Missed*	*Missed*	*Missed*	*Missed*	*Official paper n°31-2013(MAO*)*

Interpretation:

Water that flows underground does not keep the same mineralization but it varies depending on the geological context of the aquifer and climatic.

In our case, the karstic aquifer has a quick answer to rainfall where it carries more minerals after a rainy period. In this second analyze we observed a big decreasing of the minerals present on a drinking water and this comes back to the nature of our aquifer.

For the microbiological part we observed that the presence of fecal streptococci is still in our samples, but also the presence of coliforms in two other samples

Conclusion

The COP method has been developed to estimate the intrinsic vulnerability of the groundwater on the region with a Mediterranean climate, so this method can be applied by the availability of some data (geological, climatic) but only with a real knowledge of GIS (K.Zeghid, 2013).

The results obtained carried out that the vulnerability is very high when the karstic rocks are present but also when there’s a presence of swallow hole and the potential hazards.

The contamination of water has proved the high vulnerability of our resrouce which should be highly monitored.

Chapter four: conclusion and recommendations

Conclusion

In Algeria and mainly in Tlmecen, the karstic water contributes to the socio-economic development of the population (K.Zeghid, 2013).This water has a key role and they're vulnerable to the pollution. This pollution causes a real degradation on the water quality, and this degradation threat more the environment and human health.

Different policies concerns the groundwater protection have been developed in Algeria, but they're not applied, so mapping the vulnerability to pollution is a key tool to the protection.

The literature review of the different method for mapping the vulnerability published by different authors on the world allowed us to that these methods are available for all types of aquifer and for different climate, however not all of them can be applied in our region.

The COP method has been selected after a bibliographic review of the methods for mapping the vulnerability, this method can be applied on the Mediterranean climate and for intrinsic vulnerability of Ghar Boumaza.

Based on map of the intrinsic vulnerability COP, we've observed that more that 38% of the total area is under high and very high vulnerability, and 44% is under a moderated vulnerability.

The superposition of this map and hazardous map carried out the risk map with four classes, and from this map we distinguished some pollutants points like:

- Septic tank.
- Reject of wastewater.
- Human activities.

Finally, these maps of vulnerability constitute a key tool on what the delimitation of protection perimeter. The results of COP method are very useful to elaborate some landscaping plan for urban and rural on the study area, but also for the policy makers.

Recommendations

To eliminate all potential risk of pollution, it's highly recommended to the government to apply all laws published, by setting the perimeter of protection following to the decrees published from the Algerian government.

From the population which live in this region to set out each on any changes of the parameter of water which can be distinguished by the first contact (color, odor or a bad taste) to the first responsible.

As an example the source of ouled bounour:

The trough which is used for the animals (cows and sheep) should be closed for the other uses to raft any source of pollution.

Figure IV 1 : Source of ouled Bounouar (M .E. Bouabdallah, 2018)

Creating a protected perimeter for sources.

We recommend also other analyses in the other sources of Ghar boumaza to see the degree of pollution at the global scale.

How these results can be used in practice

The results can be very useful for different purposes and by different users who are:

To the local citizens who drink directly this water which is considered as contaminated and presents a real risk to their health.

As a second application of the COP method on north of Algeria, we can consider this method as a good one for mapping the intrinsic vulnerability mainly when we're faced to a karstic aquifer.

A real background for the next work on the region.

An alarm to the local responsible where they should monitor and to find a real solutions to the contamination of the sources.

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For the research grant, it was used for the following tasks:

1/ Water analyses: the analyses were done for two times first in the wet season and in the dry season and each one I spent 78064DA and the same amount for the second analyses 78064DA so a total of 156128DA .

2/ Internship: The internship was in Italy and the fly ticket was of :

- Visa fees: 7900DA
- Tlemcen to Algiers :4935DA
- Algiers to Milan: 35137DA
- Local transport in Italy:
- Airport to metro station : 8Euro
- Metro station to train station: 4,5 Euro
- Train ticket: 10,60Euro one way and 11,50Euro for coming back.
- Algiers to Tlemcen: 4935DA

2/ Data collection

- Temperature data: 35224DA
- Rainfall data: 38556DAwith a total of

A total of 282815DA has been spent and a total of 34,60Euro and the total is about of 2829Dollar.

From PAUWES I received an amount of 2462USD so I was obliged to spend more from my stipend.