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# Sensitivity analysis approach for groundwater vulnerability assessment using DRASTIC-LU model, application to Khemis Miliana alluvial aquifer


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And To all my fellow students of Hydrogeology Class of 2022

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# *Dedication*

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# List of Abbreviations :

| Abbreviation | Description |
|---|---|
| **USEPA** | United States Environmental Protection Agency |
| **GIS** | Geographic information system |
| **DEM** | Digital Elevation Model |
| **DTM** | Digital Terrain Model |
| **NOM** | National Office of Meteorology |
| **NAHR** | National Agency of Hydraulic Resources |
| **GGC** | General Geophysical Campaign |
| **CMB** | Chloride Mass Balance |
| **IDW** | Inverse Distance Weight |
| **LU** | Land Use |

## Abstract :

This study aims at the vulnerability assessment of groundwater in Khemis Miliana plain, Algeria, and to identify areas where vulnerability of groundwater to contamination is the most. A vulnerability map has been developed using DRASTIC-LU model in order to identify areas where vulnerability of groundwater to contamination is the most as well as using sensitivity analysis to evaluate the effect of each parameter on the final vulnerability map. In this analysis, vulnerability index is calculated by considering different hydrogeological parameters such as water table depth, net recharge, unsaturated conditions, soil media, aquifer media, hydraulic conductivity, topographic slope and Land Use. The parameters used in this study have been prepared, treated, weighted and integrated in a Geographic Information System (GIS) platform. The value of vulnerability index estimated lies between 96 to 195 Further, result shows that out of total area, 20 % of the area indicates low vulnerability, 56 % indicates medium and moderate vulnerability 19 % indicates high vulnerability and 6 % of area indicates very high vulnerability. It means majority of the study area exhibit moderate vulnerability. The sensitivity analysis applied in this study suggests that land use media and depth of groundwater are the key factors determining vulnerability. The study produces an effective tool for local authorities who manage and monitor the ground water resources.

## Résumé :

Cette étude vise l'évaluation de la vulnérabilité des eaux souterraines dans la plaine de Khemis Miliana, en Algérie, et à identifier les zones où la vulnérabilité des eaux souterraines à la contamination est la plus élevée. Une carte de vulnérabilité a été développée à l'aide du modèle DRASTIC-LU afin d'identifier les zones où la vulnérabilité des eaux souterraines à la contamination est la plus élevée ainsi qu'une d'une analyse de sensibilité pour évaluer l'effet de chaque paramètre sur la carte de vulnérabilité finale. Dans cette analyse, l'indice de vulnérabilité est calculé en tenant compte de différents paramètres hydrogéologiques tels que la profondeur de la nappe, la recharge nette, la zone non saturée, les sols, le milieu aquifère, la conductivité hydraulique, la pente topographique et l'utilisation du sol. Les paramètres utilisés dans cette étude ont été préparés, traités, pondérés et intégrés dans une plateforme de Système d'Information Géographique (SIG).La valeur de l'indice de vulnérabilité estimée se situe entre

96 et 195. En outre, les résultats montrent que sur la superficie totale, 20 % de la superficie indique une faible vulnérabilité, 56 % indiquent une vulnérabilité moyenne et modérée, 19 % indiquent une vulnérabilité élevée et 6 % de la superficie indiquent une vulnérabilité très élevée. Cela signifie que la majorité de la zone d'étude présente une vulnérabilité modérée. L'analyse de sensibilité appliquée dans cette étude suggère que d'utilisation des terres et la profondeur des eaux souterraines sont les principaux facteurs déterminant la vulnérabilité. Cette étude produit un outil efficace pour les autorités locales qui gèrent et surveillent les ressources en eaux souterraines.

# ملخص

تهدف هذه الدراسة إلى تقييم قابلية تأثر المياه الجوفية في سهل خميس مليانةبالجزائر ، وتحديد المناطق التي تكون فيها المياه الجوفية أكثر عرضة للتلوث. تم تطوير خريطة قابلية التمرض باستخدام نموذج DRASTIC-LU من أجل تحديد المناطق التي يكون فيها تعرض المياه الجوفية للتلوث هو الأكثر أهمية وكذلك استخدام تحليل الحساسية لتقييم تأثير كل متغير على خريطة قابلية التمرض النهائية. في هذا التحليل ، يتم حساب مؤشر التمرض من خلال النظر في المعلمات الهيدروجيولوجية المختلفة مثل عمق منسوب المياه ، صافي التغذية ، الطبقة غير المشبعة ، وسط التربة ، طبيعة الخزان الجوفي ، التوصيل الهيدروليكيالمنحدر الطبوغرافي و خريطة استخدام الاراضي. تم تحضير المعلمات المستخدمة في هذه الدراسة تقسيمها و دمجها و وزنها في بيئة نظام المعلومات الجغرافية .قيمة مؤشر قابليةالتمرض المحسوبة تقع بين خمسة و تسعون و مائة و خمسة و تسعون علاوة على ذلك ، تُظهر النتيجة أنه من إجمالي المساحة ، تشير 20٪ من المنطقة إلى ضعف منخفض لقابلية التمرض، و 56٪ تشير إلى ضعف متوسط ومتوسط ، 19٪ تشير إلى ضعف شديد و 6٪ من المنطقة تشير إلى مستوى مرتفع للغاية. وهذا يعني أن غالبية منطقة الدراسة تظهر ضعفًا معتدلًا لقابلية التمرض. يشير تحليل الحساسية المطبق في هذه الدراسة إلى أن وسائط استخدام الأراضي وعمق المياه الجوفية هي العوامل الرئيسية التي تحدد قابلية التأثر، وتنتج الدراسة أداة فعالة للسلطات المحلية التي تدير وتراقب موارد المياه الجوفية

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# General introduction

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## General Introduction:

Groundwater vulnerability refers to intrinsic characteristics that determine the sensitivity of the water to be adversely affected by an imposed contaminant load. The anthropogenic and agricultural activities are responsible for deterioration of groundwater level and increasing vulnerability. Due to the deterioration of groundwater level, sustainable development plans are needed to protect these resources (Nageswara and Narendra 2006).

Groundwater has a major contribution to agricultural, industrial, drinking, and other municipal uses, particularly in the region where other sources of water are lacking as in the Upper Cheliff Plain named Khemis Miliana alluvial plain. To get continuous supply of water and mitigate adverse effects, it is urgent to define definite strategies and guidelines for quality control, monitoring and management of groundwater. An assessment of groundwater vulnerability is the most feasible step regarding these purposes.

Mapping to identify the groundwater vulnerability to contamination corresponds to a type of specialized hydrogeological map meeting a particular need and targeting a varied audience. These are schematic maps produced with the aim of assisting decision-making for land use planning. They can meet inventory needs and guide regulatory bodies to ensure comprehensive management of all groundwater resources in a territory. Stakeholders in the water sector and their partners can therefore use them to provide themselves with the means to better understand ecological dynamics and consequently ensure the groundwater protection.

Vulnerability assessments must be objective, scientific and based on accurate evidence (Mohammadi *et al*. 2009). Different methods have been introduced to estimate groundwater vulnerability. These assessment methods maybe divided into three general categories: process-based simulation models; statistical methods and overlay; and index methods.

In semi-arid regions, as Khemis Miliana plain, groundwater is the major natural resource, since it is used to satisfy most of the water needs. In the last decades, the groundwater use has strongly increased; In the study region, many problems of groundwater are related to environmental conditions: salinization, over-exploitation, pollution, and contamination. The groundwater status in the alluvial Khemis Miliana plain is becoming more and more critical due to the over-exploitation, the increase of the urbanization and the continuous development of agricultural activity. The quality of groundwater has been degraded due to farming activities and other land uses using fertilizers and pesticides in huge quantities. Several studies take attention to the evaluation of the groundwater quality to assess its use possibility (Ghouili et al. 2018; Hamzaoui-Azaza et al. 2020; Aouiti et al. 2021). The prediction of the behavior of aquifer systems following contamination is recommended in order to ensure the development and management of the territories which allow the preservation of the resource's quality and therefore the human health.

So, the first objective of this study is to evaluate the vulnerability of the shallow aquifer of the alluvial Khemis Miliana plain using the DRASTIC-LU model. The second objective is to determine the influence of each single parameter on the aquifer vulnerability assessment for each DRASTIC parameter using the sensitivity analysis method.

Groundwater vulnerability in our study defines the sensitivity/possibility of groundwater to contamination under natural/anthropogenic factors. The vulnerability mapping can help to identify the areas that are more sensitive to be polluted than others. Aquifer vulnerability assessments in Khemis Miliana plain are standard tools for protecting groundwater from potential sources of pollution; they are valuable for any future decision.

# Chapter I

# Bibliographic Overview

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## I.1 Groundwater vulnerability:

There has been a lot of discussion in the past years about large-scale groundwater contamination, and the necessity for strategic aquifer preservation planning. Protection against contaminates such as inorganic pollutant (arsenic, aluminum, mercury, fluoride, iron and nitrate) and manmade organic pollutants (pesticides, plasticizes and chlorinated solvents).

The concept of aquifer vulnerability was first introduced by Marget. This concept refers to the sensitivity of an aquifer to deterioration due to an external action and is based on the assumption that physical environment may provide some degrees of protection to groundwater against contaminants entering the subsurface zone. Consequently, some land areas are more vulnerable to groundwater contamination than others (Baghapour, Fadaei Nobandegani et al. 2016). Frequently, aquifer vulnerability assessments are carried out in areas with water resources under stresses originating from industrial and agricultural activities (Sener et al. 2009). The vulnerability studies can provide valuable information for stakeholders working on preventing further deterioration of the environment (Mendoza and Barmen 2006). Several assessment methods have been developed to evaluate the groundwater vulnerability to contamination such as DRASTIC (Aller et al. 1987), GOD (Foster 1987), AVI (Van Stempvoort et al. 1993), SINTACS (Civita 1994), SI (Francés et al. 2001), and EPPNA (Artuso et al. 2002).(Chandoul, Bouaziz et al. 2015).

There are two main types of vulnerability assessment: intrinsic vulnerability and specific vulnerability. The first term refers to the intrinsic property of groundwater system to human or natural impacts. The most leading model of the intrinsic vulnerability is DRASTIC index. DRASTIC index was introduced by United States Environmental Protection Agency (USEPA) for the first time. It is an abbreviation for seven main parameters in hydro-geological system, which control groundwater contamination. These parameters are Depth to water table (D), net Recharge (R), Aquifer media (A), Soil media (S), Topography (T), Impact of the vadose zone (I), and hydraulic Conductivity (C).(Baghapour, Fadaei Nobandegani et al. 2016).

It is now more than forty years since the vulnerability concept was proposed, but there is not a perfect and complete definition of aquifer vulnerability. Foster in 1987 defined vulnerability as” the intrinsic characteristics which determine the sensitivity of various parts of an aquifer to being adversely affected by an imposed contamination load”. The best way to map aquifer vulnerability is the evaluation by a three dimensional model which takes into account all characteristics of aquifer and its variability with space and time. In practice, due to amount and quality of available data, budget and time constraints, the output of vulnerability assessment would be a two dimensional map where at each point different properties of aquifer be integrated to predict the potential pollution(Sartaj 2017).

## I.2 Types of vulnerability:

### I.2.1 Intrinsic vulnerability:

Intrinsic vulnerability is the term used to represent the characteristics of the natural environment that determine the sensitivity of groundwater to pollution by human activities. The intrinsic sensitivity of an aquifer is a function of the intrinsic geological and hydrogeological characteristics of the environment. The specific vulnerability or simply the vulnerability of an aquifer is defined by including land cover and the characteristics of a contaminant. In Europe the intrinsic vulnerability of an aquifer is defined as a function of hydrogeological parameters only.

### I.2.2 The specific vulnerability:

Specific vulnerability (area at risk) is the term used to define the vulnerability of groundwater to a particular pollutant or group of pollutants. It takes into account the properties of pollutants and their relationships with the various components of intrinsic vulnerability. Specific vulnerability as describing the potential impacts due to land use and the contaminants present. Sometimes the contaminant load on the ground is considered as a parameter in the evolution of vulnerability.

## I.3 Vulnerability mapping:

The first vulnerability maps were developed by French researchers in the early 1970s. (Albinet and Margat 1970).They were then tested in other countries of the world. The principle of their elaboration consisted in the synthesis of some parameters having a major influence in the vulnerability of aquifers. Over the last twenty years, several methods have been proposed and tested in order to achieve a simple and precise characterization of vulnerability.

Geographic information system (GIS) has emerged as a powerful tool for storing, analyzing, and displaying spatial data and using these data for decision making in several areas including engineering and environmental fields(e.g., Stafford 1991; Good child 1993;

Burrough and McDonnell 1998; Lo and Yeung 2003). It allows for swift organization, quantification, and interpretation of a large volume of spatial data, providing an efficient environment.(Machiwal, Jha et al. 2011), coupled with using indexing methods provides us with vulnerability mapping; this tool is commonly used to estimate the sensitivity of groundwater to contaminations alongside risks mapping.

Basically, there are three available techniques for creating vulnerability maps: overlay and index based techniques, process based simulation techniques ,and statistical techniques .Although, with respect to particular factors and under specific circumstances they have strengths and weaknesses.(Machiwal, Jha et al. 2011)

## I.4 Vulnerability assessment methods:

The first vulnerability maps were drawn up by French researchers in the early 1970s (Albinet and Margat, 1970). They were then tested in other countries around the world. The principle of their elaboration consisted in carrying out the synthesis of a few parameters having a major influence on the vulnerability of aquifers. For about twenty years, several methods have been proposed and tested in order to achieve a simple and precise characterization of vulnerability. The literature on the subject shows the existence of several methods for assessing and mapping the vulnerability of groundwater to pollution risks.

• Methods based on cartographic documents

• Methods based on a numerical rating system

**Table.1:** Different vulnerability assessment methods

| Method | Author | Year | Number of parameter | The parameters |
|---|---|---|---|---|
| DRASTIC | Alleret al | 1987 | 07 | D: Depth to water table / R: Recharge / A: aquifer media / S: soil type / T: Topography / I: Impact of the vadose zone / C: Hydraulic conductivity. |
| GOD | Fosteret al | 1991 | 04 | type of soil, geological formations, lithology of the trusty beds of the unsaturated zone, depth to the water table. |

| | | | | |
|---|---|---|---|---|
| SCAM3 | Vbra etZaporozec. | 1996 | 04 | Texture of the surface A horizon / Texture of the subsoil B horizon / pH of the surface horizon / Depth of weathered soil / Soil drainage class / Permeability of subsoil horizons / Organic matter content |
| EVARISK | Banton | 1997 | 03 | Texture of the surface A horizon / Texture of the subsoil B horizon / pH of the surface horizon / Depth of weathered soil / Soil drainage class / Permeability of subsoil horizons / Organic matter |
| EPIK | Zwahlen etal | 1996 | 04 | the development of the Epikarst, / the thickness of the protective cover, / the conditions of infiltration and the development of the Karstic network |
| RISKE | Petelet-Giraudetal | 2000 | 05 | Aquifer rock (R) infiltration conditions (I) Protective cover or soil (S) Karstification (K) Epikarst (E) |
| SINTACS | Civita | 1990 | 07 | Density of flow networks / Texture thickness / Aquifer/surface water connection / Recharge / Unsaturated zone / Hydraulic-topographic characteristics |

## I.5 Purpose of a vulnerability map:

The vulnerability map has been drawn up to show the possibilities of penetration and propagation of pollutants in the ground, depending on the terrain encountered on the surface (and more precisely, depending on the reservoirs in which the first groundwater tables are contained, which are generally free), the vulnerability of these tables, which are exploited by most of the wells and boreholes for the collection of drinking water and from which most of the springs in the area originate. The aim was not to make an inventory of pollution points or to indicate areas already polluted, nor was it to show how and by what type of pollutant the pollution will materialize and what the effects will be. From this map, it is therefore possible to define the sensitive areas in which pollution can seriously affect a water table and to have an idea of the means to be used if one wants to protect this water table.(Albinet and Margat 1970)

## I.6 Use of vulnerability maps:

### I.6.1 Land use planning (territorial activity planning):

Vulnerability maps can be used by different policy makers, government agencies or private companies as preliminary tools when planning projects on the territory, or to define temporal priorities for water resources management. In case of mandatory planning of polluting activities, the location of low vulnerability areas can be determined for these activities.

### I.6.2 Groundwater protection (estimation of potential contamination):

Vulnerability maps can be used by hydrogeologists and environmental agencies to determine the urgency and location of possible measures to protect groundwater.

### I.6.3 Educational/teaching (educational material):

Finally, vulnerability maps can be used as an explanatory tool for policy makers, educators, and the general public because of the synthetic way in which these maps present complex data.

## I.7 DRASTIC vulnerability mapping:

DRASTIC is one of the most well-known and widely used parametric vulnerability mapping techniques. DRASTIC can be used in extensive regions due to low cost of application and easy to collect data requirements. According to Panagopoulos (2006) ”the selection of many parameters and their interrelationship decreases the probability of ignoring some important parameters, restricts the effect of an incidental error in the calculation of a parameter and so enhances the statistical accuracy of the model”.(Sartaj 2017)

DRASTIC is an empirical model developed by the US Environmental Protection Agency (USEPA) for evaluating groundwater contamination potential on a regional basis (Aller et al. 1987). DRASTIC evaluates pollution potential based on weighted combination of seven hydrogeological settings: depth to water, net recharge, aquifer media, soil media, topography, impact of the vadose zone, and hydraulic conductivity of the aquifer (Aller et al.

1985). Each DRASTIC parameter is assigned a relative weight ranging from 1 to 5 based on their relative importance in influencing the flow of contaminants into groundwater system (Table 2) and a rating range from 1 to 10 for different ranges of the values (Engel et al. 1996). The DRASTIC index, a measure of the pollution potential, is computed by summation of the products of rating and weights of each factor as follow (Navulur and Engel 1996).

$$\mathbf{Di = Dr\,Dw + Rr\,Rw + Ar\,Aw + Sr\,Sw + Tr\,Tw + Ir\,Iw + Cr\,Cw} \qquad (\mathbf{I.1})$$

Where Di is the DRASTIC index, D, R, A, S, T, I, and C are the seven parameters, and the subscripts r and w are the corresponding rating and weights, respectively(Chandoul, Bouaziz et al. 2015).

### I.7.1 Depth of Water (D):

Depth to water is one of the most important parameters in DRASTIC technique which describes the distance that contaminant must travel from the surface to reach groundwater table(Sartaj 2017). Meaning, it represents in the aquifer the vertical distance from soil surface to water table in the saturated zone, it is calculated by subtracting levitation from groundwater level or determined by using topography and groundwater contour maps; this parameter represents in an indirect way the time that the pollutant takes to filter vertically in the non-saturated zone towards the aquifer, the deeper the water table is the longer the contaminant takes to filter , in other words the less chances for contamination.

### I.7.2 Net Recharge (R):

Groundwater net recharge is the amount of water that reaches the water table, it is the main factor for transferring contaminants, The more recharge shows more vulnerability to contamination (Sartaj 2017),meaning , the bigger the recharge is the faster the contaminant moves and in bigger amounts. Net recharge might be estimated from the rainfall infiltration, irrigation return flow, evapotranspiration and absorption wells in the study area.(Sartaj 2017)

### I.7.3 Aquifer Media (A):

Aller (1987) defined aquifer as a rock formation which yield sufficient amount of water for use. Aquifer media refers to consolidated and unconsolidated rocks (such as sand, gravel or limestone) which serve as an aquifer(Sartaj 2017). The circulation and path length of the contaminant in the saturated zone depends on the texture and lithology of the layers of the aquifer; which is always controlled by the granulometry, porosity, permeability and lithology of the geological formation.

In general terms, large sediment size, higher permeability and lower attenuation capacity can result more vulnerability to pollution. Aquifer media map could be prepared using geological information. (Sartaj 2017) .

### I.7.4 Soil Media (S):

The soil media represents the top weathered portion of unsaturated zone with significant biological activities(Sartaj 2017).

The nature of soil has a considerable impact on the phreatic napes by the pollutant coming from the surface; it can reduce, retard or accelerate the movement of the pollutant towards the aquifer. The richer the soil is with clay, the higher the absorption of the contaminant is, and the more the protection of groundwater is.

### I.7.5 Topography (T):

When speaking of topography we are basically referring to land slopes, this parameter translates the aptitude for runoff and infiltration of surface water towards the water table and thus reflects the capacity of this water to introduce polluting agents towards the water table. Indeed, the greater the slope of the land, the greater the water runoff and consequently the contamination of groundwater is low.

Digital Elevation Model could be used to prepare topography maps and slope is calculated by GIS tools.(Sartaj 2017) .

### I.7.6 Impact of Vadose Zone (I):

The vadose zone also termed unsaturated zone, extends from the top of the ground surface to water table at which groundwater is at atmospheric pressure.(Sartaj 2017) .It is essential to understand the time it takes the pollution to reach the aquifer, thus the possibility to treat it whilst being transferred.

The characteristic of unsaturated zone can determine attenuation properties of the media above water table. A vadose zone map is also prepared using sub-surface geology and lithology characteristics of drilling logs.(Sartaj 2017) .

### I.7.7 Hydraulic Conductivity (C):

The ability of an aquifer to transmit water and contaminants is defined as hydraulic conductivity. It describes the characteristics of the aquiferous terrain; it is the measurement of the speed of the pollutant displacement in the saturated area. Thus, the strong speeds of the underground flow are characterized by a high vulnerability.

The results of pumping test and lithology are used for creating a hydraulic conductivity distribution map(Sartaj 2017). The equation **k=T/b** might be used to calculate hydraulic conductivity of aquifer where the hydraulic conductivity of the aquifer is denoted by k (m/d), transmissivity is denoted by T (m2/d) and the thickness of the aquifer is denoted by

b (m).(Sartaj 2017) .

DRASTIC approach uses a deferent weight and rate for each of the parameters mentioned before to calculate the DRASTIC index, tables02 highlights them, and tables 03 and 04 highlight the ranges and colors of the DRASTIC index.

**Table.2:** Weight of parameters in the standard version of the DRASTIC method.

| Parameter | Standard DRASTIC Version (Wight) | Properties |
|---|---|---|
| **D**: depth of the water table | 5 | The higher this depth, the longer it takes for the contaminant to reach the piezometric surface. |
| **R**:Net Recharge | 4 | Main vehicle for the transport of the contaminant.<br>The greater this recharge, the higher the risk of contamination |
| **A**: Aquifer media | 3 | Characterized by the particle size of saturated land. The finer the particle size, the greater the trapping of the pollutant. |
| **S**: soil type | 2 | The richer the soil in clay, the greater the absorption of heavy metals, and the greater the protection of groundwater |
| **T**:topography | 1 | The greater the slope of the land, the greater the water runoff and therefore the lower the groundwater contamination |

| | | |
|---|---|---|
| **I**: impact of the vadose zone | 5 | Its impact is determined from the texture of the terrain. The percolation of the pollutant to the piezometric surface is all the greater the more favourable this texture (gravel, coarse sand) |
| **C** : hydraulic conductivity | 3 | (Amharref,Aassineetal. 2007) The larger this parameter, the faster the transfer of the pollutant. |
| **LU:** land use | 4 | Refers to what type of human activity is going on. The nature and level of contaminants depend on land use types |

**Table.3**: Criteria of the vulnerability assessment by using DRASTIC method(Sartaj 2017)

| Class vulnerability | low | Average | high | Very high |
|---|---|---|---|---|
| Calculated Index Value | <101 | 101-140 | 141-200 | >200 |

**Table.4**: Colour codes for DRASTIC Indices introduced by Aller (Sartaj 2017)

| Calculated Index Value | colour |
|---|---|
| Less than 79 | Violet |
| 79-99 | Indigo |
| 100-119 | Blue |
| 120-139 | Dark green |
| 140-159 | Light green |
| 160-179 | Yellow |
| 180-199 | Orange |
| 200 and above | Red |

**Table.5:** Standard DRASTIC weights and rating system

| Depth to water | | Net recharge | | Aquifer media | | Soil media | | Topography | | Impact of vadose zone | | Hydraulic conductivity | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Range (m) | Rating | Range (mm/year) | Rating | Range | Rating | Range | Rating | Range (%) | Rating | Range | Rating | Range (m/day) | Rating |
| 0-1.5 | 10 | <50 | 1 | Massive shale | 2 | Thin or absent, gravel | 10 | 0-2 | 10 | Confining layer | 1 | <4 | 1 |
| 1.5-4.5 | 9 | 50-100 | 3 | Metamorphic /igneous | 3 | Sand | 9 | 2-6 | 9 | Silty/clay | 3 | 4-12 | 2 |
| 4.5-9 | 7 | 100-175 | 6 | Weathered metamorphic /igneous | 4 | Peat | 8 | 6-12 | 5 | Shale | 3 | 12-30 | 4 |
| 9-15 | 5 | 175-250 | 8 | Glacial till | 5 | Shrinking and /or aggregated clay | 7 | 12-18 | 3 | Limestone | 6 | 30-40 | 6 |
| 15-22 | 3 | >250 | 9 | Bedded sandstone, limestone, shale | 6 | Sandy loam | 6 | >18 | 1 | Sandstone, bedded sandstone | 6 | 40-80 | 8 |
| 22-30 | 2 | | | Massive sandstone, Massive limestone | 6 | Loam | 5 | | | Sandstone, shale, sand and gravel | 6 | >80 | 10 |
| >30 | 1 | | | Sand and gravel | 8 | Silty loam | 4 | | | Metamorphic /igneous | 7 | | |
| | | | | Basalt | 9 | Clay loam | 3 | | | Sand and gravel | 8 | | |
| | | | | Karst limestone | 10 | Muck | 2 | | | Basalt | 9 | | |
| | | | | | | Non-shrinking and Non-aggregated clay | 1 | | | Karst limestone | 10 | | |
| DRASTIC weight 5 | | DRASTIC weight 4 | | DRASTIC weight 3 | | DRASTIC weight 2 | | DRASTIC weight 1 | | DRASTIC weight 5 | | DRASTIC weight 3 | |

The DRASTIC method assumes that any contaminant is introduced at the ground surface, (2) the contaminant is flushed into the groundwater by precipitation, the contaminant has the mobility of water, and the areas evaluated using DRASTIC are 0.4 km2 or larger (Rosen 1994).(Chandoul, Bouaziz et al. 2015)

This methodology uses seven hydrogeological parameters which considering various parameters decreases the probability of misjudging and enhances the reliability of vulnerability index. DRASTIC acronym stands for quantitative and categorical variables including: Depth of water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone and hydraulic Conductivity. Figure1 displays the schematic diagram of DRASTIC parameters.(Sartaj 2017)

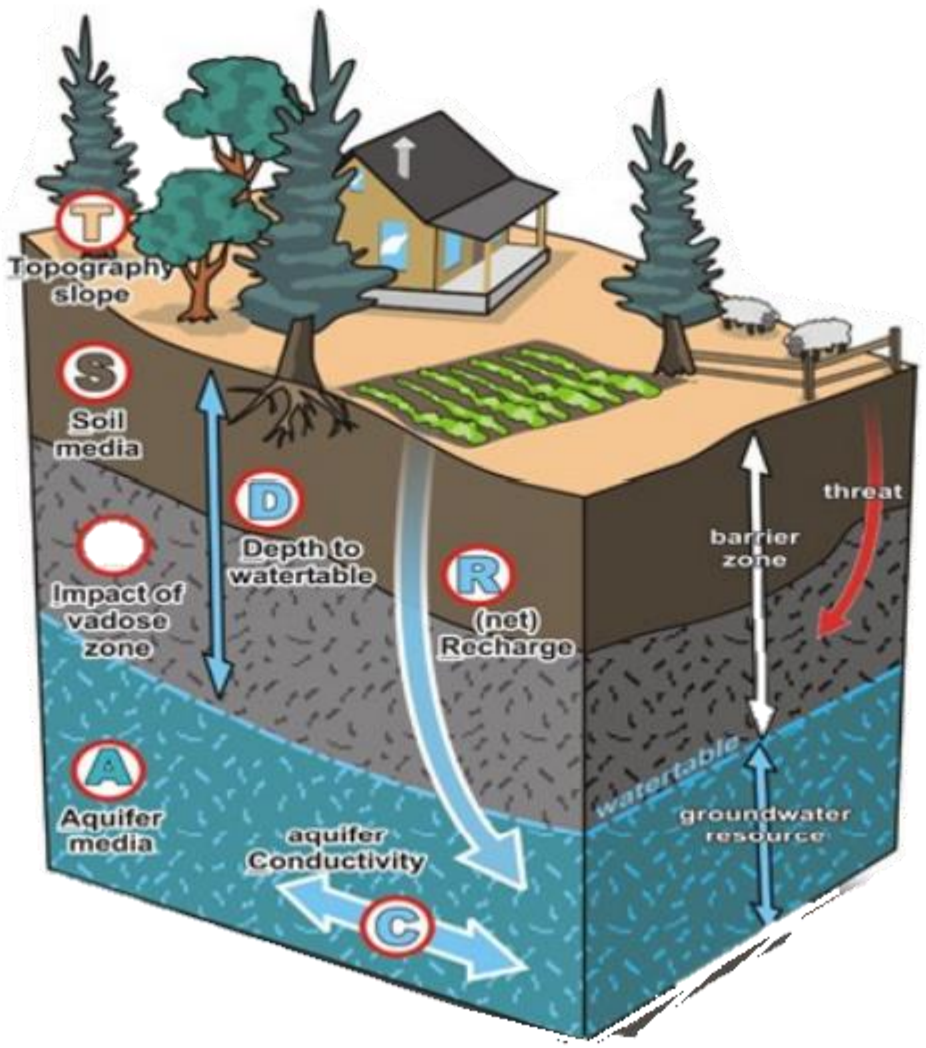


**Figure.1**: Definition of DRASTIC parameters, (Source:www.frakturmedia.net)(Sartaj 2017)

DRASTIC model is according to Delphi approach accomplished by a committee of experts so the weight and rates of parameters may not be changed. Groundwater vulnerability mapping using DRASTIC assumes some points which are :
The contaminant is released at the earth's surface (use of fertilizers, burning of coal and leaching of metals from coal-ash tailings etc.).

The contaminant flushes into the groundwater through precipitation.

The contaminant moves with the velocity of water.

The concerned area should be 100 acres (0.4 km2 ) or larger.(Sartaj 2017)

## I.8 DRASTIC-LU approach:

Many researchers have attempted to modify DRASTIC model in order to achieve a more accurate vulnerability assessment.(Sartaj 2017)McLay (2001) suggested that models such as DRASTIC with a land management index included, may be useful for predicting areas for more intensive monitoring of groundwater. It was also emphasized that there is a greater need to test the link between measurements of nitrate leaching from a variety of land use activities with measurements of groundwater nitrate concentrations below these activities. (McLay, Dragten et al. 2001)

DRASTIC-LU index:

$$\mathbf{Di} = \mathbf{Dr\,Dw} + \mathbf{Rr\,Rw} + \mathbf{Ar\,Aw} + \mathbf{Sr\,Sw} + \mathbf{Tr\,Tw} + \mathbf{Ir\,Iw} + \mathbf{Cr\,Cw} + \mathbf{LUw\,LUr} \qquad (\mathbf{I.2})$$

Where :

**LUw :** the Land Use weight.

**LUr :**the Land Use rate.

**Table.6:** Main land use classes and corresponding values.

| Land use according to the CORINE Land Cover | Value of the land use factor LU |
|---|---|
| Industrial landfill, garbage dump, mines | 10 |
| Irrigated perimeters, rice fields | 9 |
| Quarry, shipyard | 8 |
| Covered artificial areas, green areas | 7 |
| Permanent crops (vineyards, orchards, olive trees, etc.) | 7 |
| Discontinuous urban areas | 7 |
| Pastures and agro-forestry areas. | 5 |
| Aquatic environments (marshes, salt flats, etc.) | 5 |
| Forests and semi-natural areas | 0 |

## I.9 Definition of water pollution:

Water pollution is an alteration of the natural qualities (physical and chemical) of water. It is both the action and the processes of water quality degradation. The pollution of groundwater entails the permanent risk of limitation of this resource in the near future. It essentially results from human activity independently of the natural deterioration linked to geological factors. In this context, the study of the vulnerability to pollution of the aquifer system could prevent the risks of contamination and by the same guide the world of management and exploitation of groundwater.

## I.10 The origins of pollution:

### I.10.1 Domestic origin

This is the case, for example, of cesspools, individual sanitation systems with infiltration into the ground that are poorly designed or poorly dimensioned, overloaded urban wastewater treatment plants, etc.

## I.10.2 Industrial origin:

Pollutants of industrial origin are very varied depending on the type of activity: ordinary organic substances, synthetic organic products, hydrocarbons, mineral salts, heavy metals, etc.

## I.10.3 Agricultural origins:

Current crop and livestock practices strongly influence the regime and water quality (Charikh. 2015).

# Chapter II

# Presentation of the study area

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# II. Geographical location of the plain of Khemis Miliana:

## II.1 Regional context:

The study area is known as the plain of the upper Cheliff (according to the code 1 set by the NAHR), it is located 120km south-west of Algeria, it appears as a form of intra mountain depression in the north part of Algeria, which covers 10 communes: Arib, Ben Allal, Sidi Lakhdar, Khemis Miliana, Ain Soltane, Djendel, Ain Lechiakh, Bir Ould Khelifa, Djelida and Ain Defla.

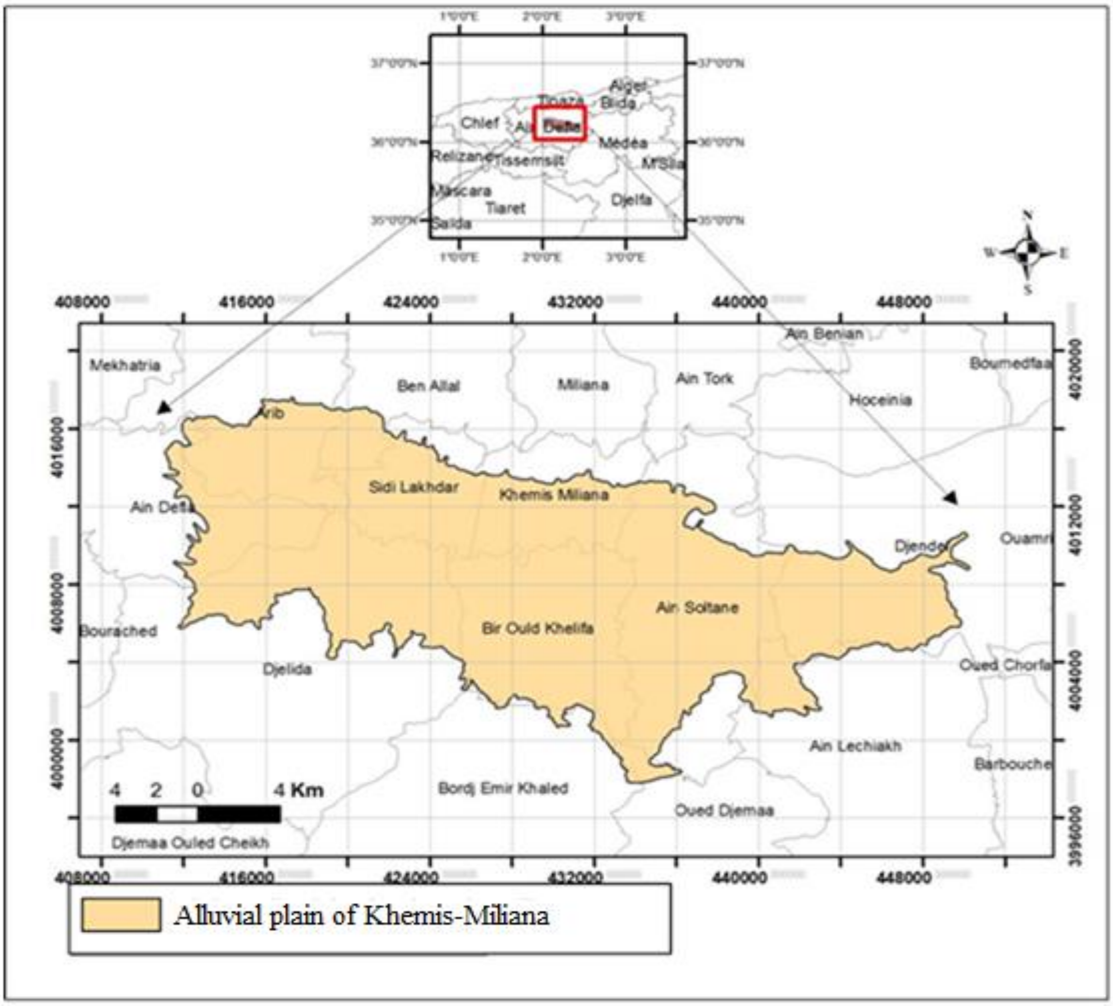


**Figure.02:** Geographic situation map of the study area (Alluvial plain of Khemis-Miliana)

## Local context:

The study area is called alluvial plain of Khemis-Miliana or ex. Affreville. It is part of the valley Oued Chelif N°: 01-15, 16 and 17(see Figure 03), with a surface of 359.5 km$^2$, a perimeter of 159 km and at an average altitude of 270 m. It’s known to be one of the very big reserves of groundwater of the region. Geographically it's in between the altitudes (36°18'-36°6') N and longitudes (2°-2°27') E. limited to the north by the massif of the Zaccar mount (1576m), foothills of the Dahra mounts, to the south by the massif of Ouarsenis, to the east by the Djebel Gontas and to the west by the Djebel Doui which separates it from the plain of El Abadia.

The plain of Khemis Miliana is indicated as an agricultural area requiring sprinkler irrigation due to a semi-arid continental climate with very dry summers and rainy episodes in winter sometimes causing flooding of the Oued Cheliff.

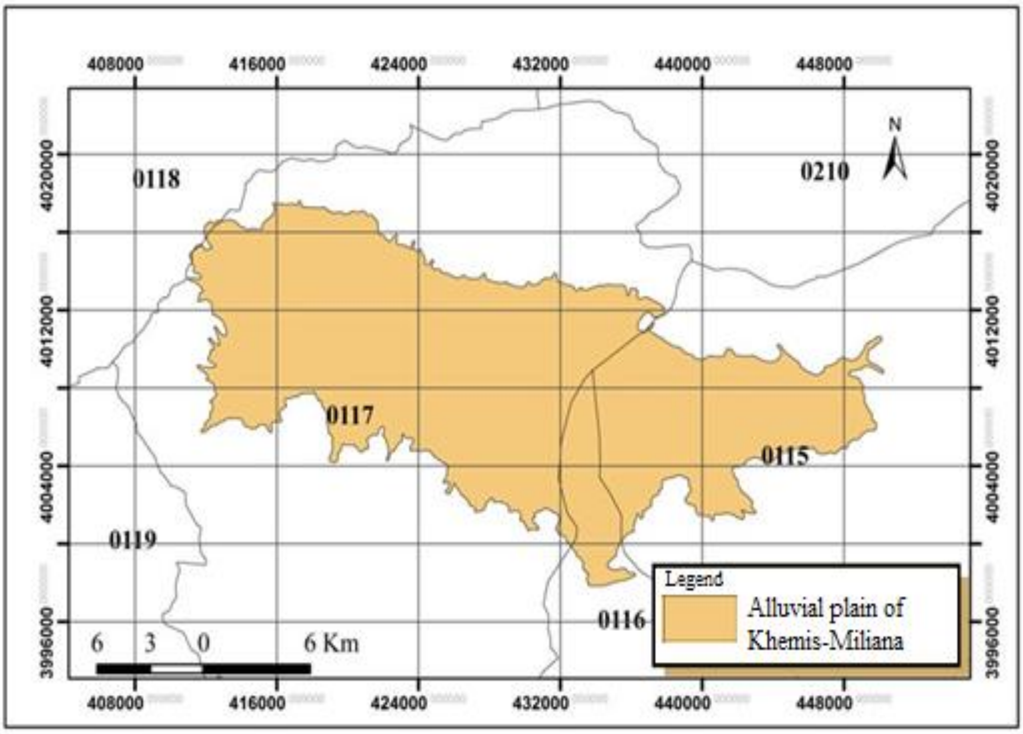


**Figure.03:** Geographical location map of the study areas to the sub-catchments.

## Habitat :

The population of the Haut Cheliff basin at the end of 2009 is 582,426 inhabitants with a growth rate of 1.3%, of which 82.55% are concentrated in urban areas and 17.45% only in rural areas.

This population is concentrated mainly in the towns located to the north of the plain, the most important of which are respectively from east to west: Djendel, Ain Sultan, Khemis Miliana, Sidi Lakhdar and the Aribs. while in the south of the plain the density of the most important agglomerations are Djelida and Bir Oueld Khalifa.**(KOUADRI.N and BENHARKAT.F, 2010) .**

Human activity is based on trade and agriculture irrigated by pumping and also by irrigation networks set up after the construction of the Harreza, Deurdeur, Ghrib and recently the Aribs dams.

## II.2 Geomorphologic context:

The hydrogeological unit of the Quaternary alluvium was delimited by vectorisation in order to define the geometric parameters (area and perimeter). The Upper Chelif plain has an area of 359.5 km² and a perimeter of 159.3 km. The following table summarises the main physiographic parameters:

**Table 07:** Physiographic catchment parameters(BONG.I ; MEZIANI.S, 2013)

| **Shape parameters** | | | | |
|---|---|---|---|---|
| code | Name of sub-basins | Kc | Equivalent rectangle (ROCK) | |
| | | | Length Lr (Km) | Width Lr(Km) |
| 0115 | W.Chelif Harbil | 1.66 | 71.60 | 11.18 |
| 0116 | Deurdeur | 1.72 | 78.92 | 10.75 |
| 0117 | W.Chelif Harreza | 1.45 | 58.13 | 13.18 |
| Geometric parameters Khemis Miliana plain | | | | |
| Surface of the plain (Km²) | | | Perimeter of the plain (Km) | |
| 359,5 | | | 159,3 | |

## Relief:

For a long time, the representation of hypsometric space or relief was materialized in two dimensions by paper maps. The arrival and powerful progress of computer technology have made it possible to move towards a three-dimensional description. This computerized cartographic document, known as a digital terrain model (DTM), is currently taking on a strategic role in digital cartography and in hydrogeological and hydrological studies. It is a digital representation of the relief of the study area, in the form of computer files containing altitudes.

In the plain of Khemis Miliana, the topography will therefore be represented by a digital terrain model DTM. In order to analyze the morphological characteristics of the study area, we built a digital terrain model DTM, based on the acquisition of elevation data by digitizing contour lines and points, this DTM was generated by digitizing and identifying contour lines from geo-referenced topographic maps at a scale of 1:25,000. Morphometric calculations, including slope calculation, as well as elevation classifications were extracted with ArcGIS modules via Raster spatial analysis (see Figure 04).

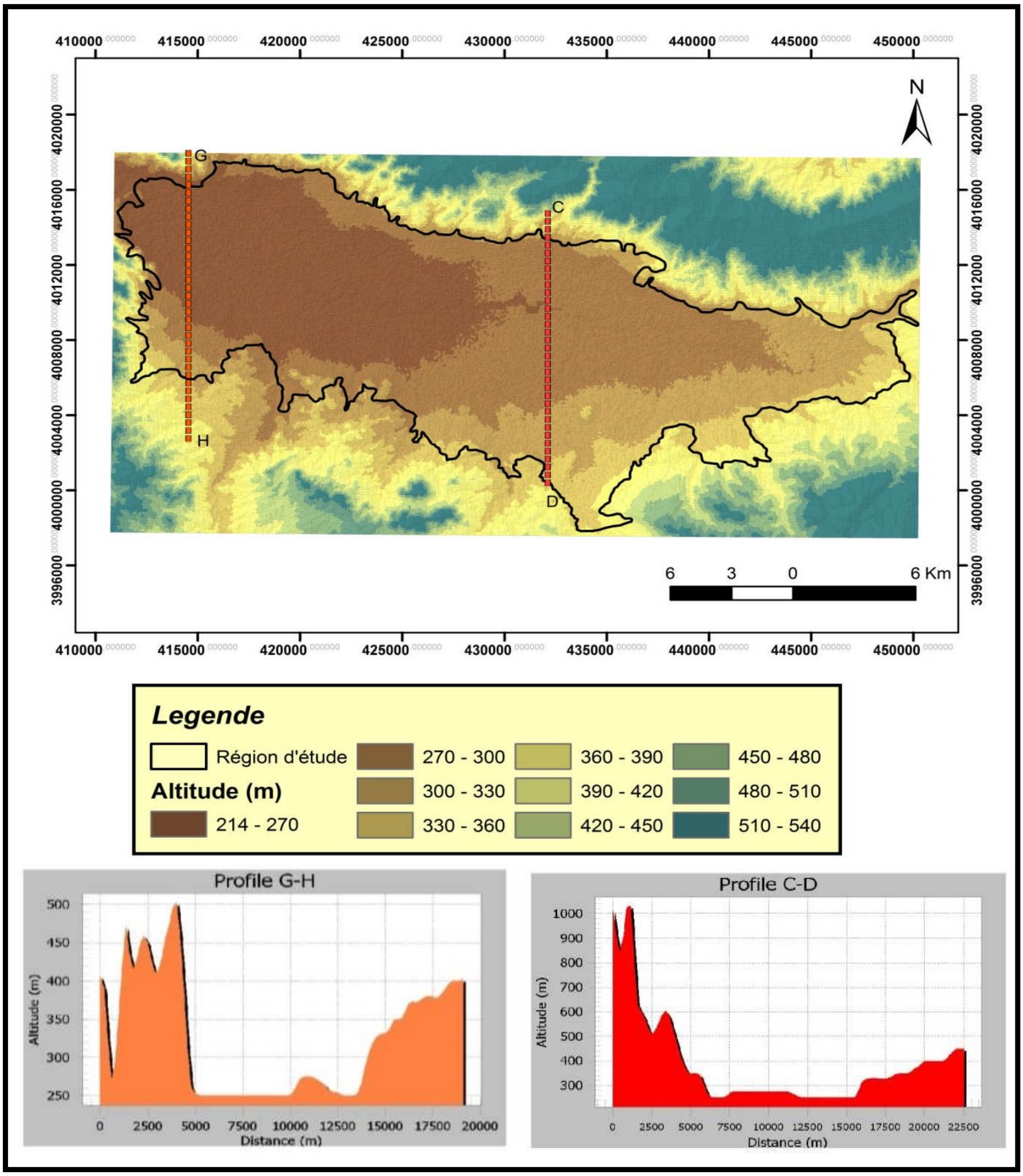


**Figure.04:** Topographical representation of the study area in digital form.

## II.3 Hydroclimatology:

The plain of Khemis Miliana is characterized by a semi-arid climate with Saharan influences in summer and Mediterranean influences in winter, characterized by the following climatic regime: a cold winter and a hot summer.**(DERBAL.S and BENALI. F, 2004), (TIMTAOUSSINE.H, 2003)**.

## II.4 Hydro-graphic network:

The Haut Cheliff plain is crossed from East to West by Oued Cheliff and its main tributaries which are Oued Souffay, Millet and Boutane to the North, Deurdeur, Massine and Harreza to the South (see Figure 05).

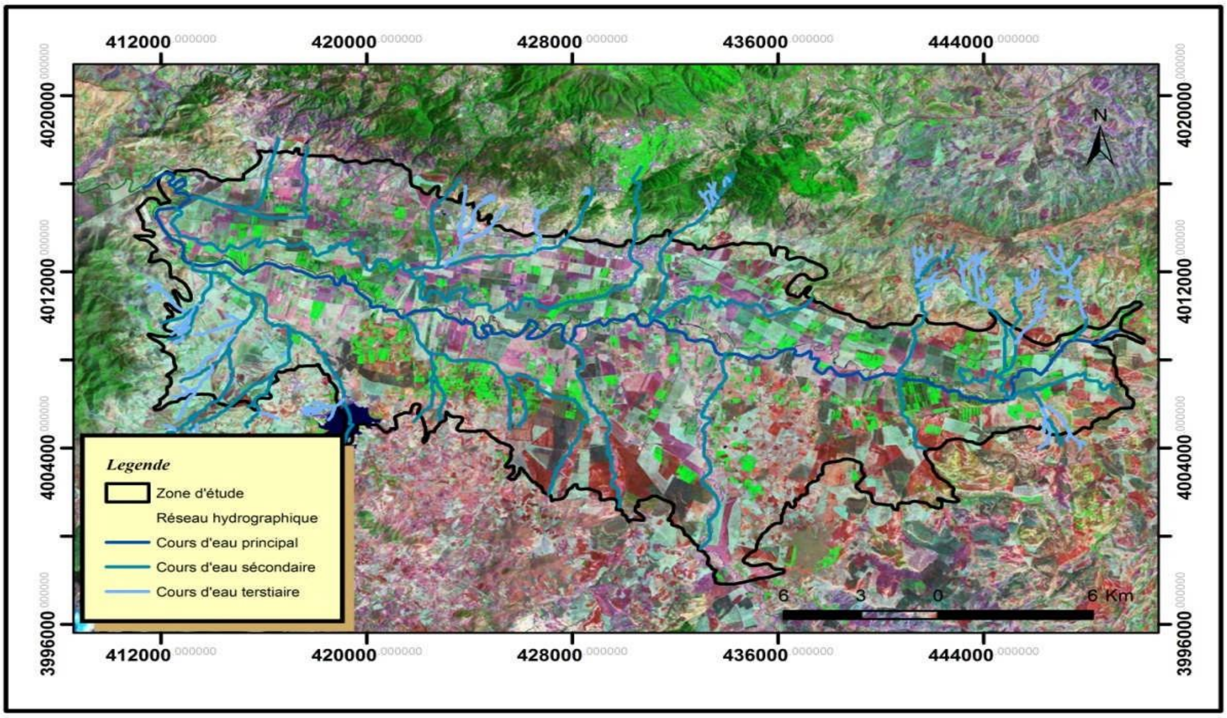


**Figure.05:** Hydrographic network on the satellite background.

The digitization process allows the reproduction of the hydrographic line with an accuracy of about 0.5 mm on the map, or 25m on the ground. The conventional statistics of the hydrographic tree obtained by statistical and geospatial analysis in ArcGIS are gathered in the following table.

**Table 08:** hydro-graphic network**(BONG.I ; MEZIANI.S, 2013)**

| **Wadi (watercourse)** | Cheliff | Souffay | Millet et Boutane | Deurdeur | Massine | Harreza | Djelida |
|---|---|---|---|---|---|---|---|
| **length (M)** | 59275.67 | 4305.85 | 30897 | 5171 | 6424 | 10273 | 5665 |
| **Direction of flow** | E-W | $N_{NE}$-$S_{SO}$ | E-W | $S_{SO}$-$N_{NE}$ | $S_{SE}$-$N_{NO}$ | $S_E$-$N_O$ | $E_{SE}$-$O_{NO}$ |

All the water from the main tributaries represented by the wadis of : Souffay, Boutane (in the North), Oued Deurdeur and Harreza (in the South), are collected in the direction of the centre of the Cheliff plain towards the main Oued in question, which drains all the waters of the Cheliff catchment area towards the outlet. The Oued Cheliff, which results from the meeting of these watercourses, crosses a cut between Boughari and Boughar and leaves the high plateaus to enter the tell. From Boughari Amoura (Dollfuss town), it flows in deep gorges and from the Djebels, follows the plain from East to West.

## II.5 Precipitations:

The total volume of precipitation that falls on the ground during a specified period is expressed as the height of water that would cover a horizontal plane. The essential aim of every measurement method in this field should be to obtain samples that are truly representative of the amount of precipitation over an area to which the measurements refer. In hydrology, the measurement of the exact value of the ideal precipitation is of great importance for the estimation of the recharge; it depends on the density and spatial distribution of the rainfall network. **(BONG. N et MEZIANI. S, 2013)**

### II.5.1 Rainfall network of the study area:

The study area is sheltered by 10 rain gauge stations whose management is simultaneously ensured by the service of the National Office of Meteorology and the National Agency of Hydraulic Resources, the distribution of these rain gauges in our study area is homogeneous and the rain gauge stations materialize in a more or less effective way in the plain, this distribution covers all its surface.

## II.5.2 Average annual precipitation:

The table below shows all the rainfall stations used in the calculation of the average annual rainfall or rainfall modulus, for the study area. According to the data analysis, the majority of the stations have been continuously observed for at least 26 years. For the present study, the characteristics of the hydro-meteorological stations selected are summarized in the table below.

**Table 09:** Characteristics of rainfall stations, according to A.N.R.H. Period(1981-2013)

| Stations | Code | X(m) | Y(m) | Z(m) | Pm (mm) |
|---|---|---|---|---|---|
| **Ababssa** | 01-17-15 | 414166,16 | 4002034,5 | 317 | 354,9 |
| **Arib Chellif** | 01-17-02 | 412561,16 | 4016440,25 | 230 | 410,5 |
| **Khemis Miliana** | 01-17-17 | 431848,16 | 4012029,25 | 285 | 418 |
| **Barrage de Harraza** | 01-17-18 | 428376,88 | 4005240,25 | 315 | 373,1 |
| **Ain Sultane** | 01-15-12 | 437142,94 | 4010312,5 | 295 | 412,1 |
| **Sidi Lakhdar** | 01-17-11 | 425052,56 | 4013500,5 | 250 | 384,9 |
| **Ain Defla** | 01-18-04 | 407652,56 | 4013805 | 270 | 424,8 |
| **Sidi Mokrifi** | 01-16-06 | 436173,91 | 3988065,25 | 540 | 375,3 |
| **Bordj Emir Khaled** | 01-17-03 | 428853,28 | 3997638,5 | 500 | 335,7 |
| **Gherib Cheliff** | 01-14-07 | 460267,69 | 4002141,5 | 460 | 459,6 |

The temporal analysis of rainfall at the Ain Soltane rainfall stations shows us that 1994 is the driest year, while 1995 is the wettest with an annual rainfall of 684.5 mm for a period that spans from 1980 to 2013. At the Khemis-Miliana station, 1994 is considered the driest year for the same station, while 1996 and 2009 are the wettest with annual rainfall of 590.5 mm and 612.9 mm respectively. The station of Aribs Chelif also revealed that the year 1993 is the driest; those of 1995 and 2010 are the wettest with rainfall of 602.5 mm and 612.9 mm. Finally, at the El Ababsa station, the year 2000 is considered the driest, while for the same station; the years 1987 and 1996 were identified as wet with annual rainfall of484.6 mm, 459.3 mm, respectively (See Figure 06).

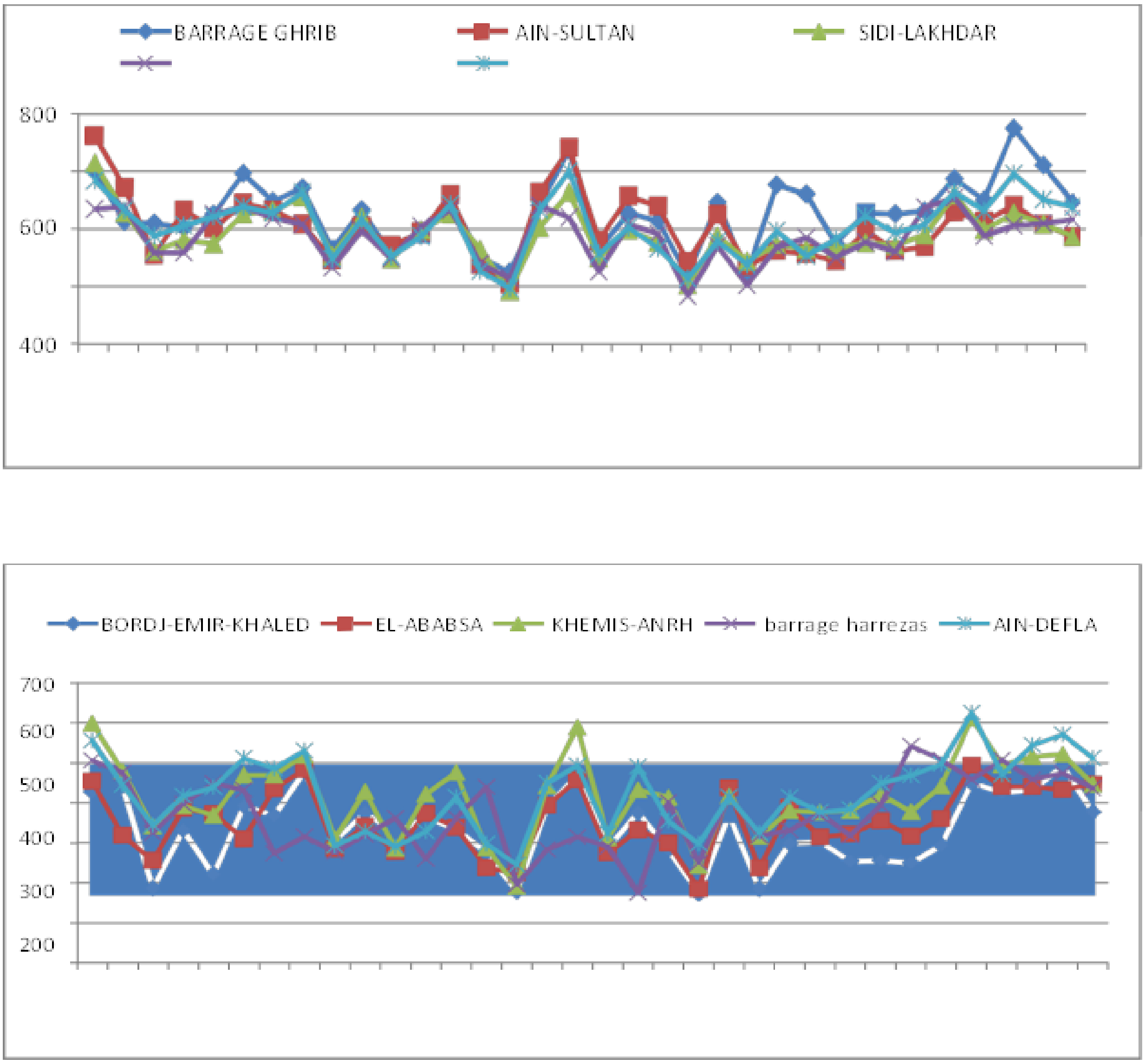


**Figure.06:** Temporal variation in average annual precipitation.

### II.5.3 Determination of the precipitated water level by the Thiessen method:

The Thiessen method is generally used, and its application generally gives reliable results. It is particularly suitable when the rainfall network is not spatially homogeneous (irregular spatial distribution of rain gauges).

This method allows for the estimation of weighted values by taking into consideration each rain gauge station. It assigns to each rain gauge a zone of influence whose area expressed in %, represents the weighting factors of the local value.

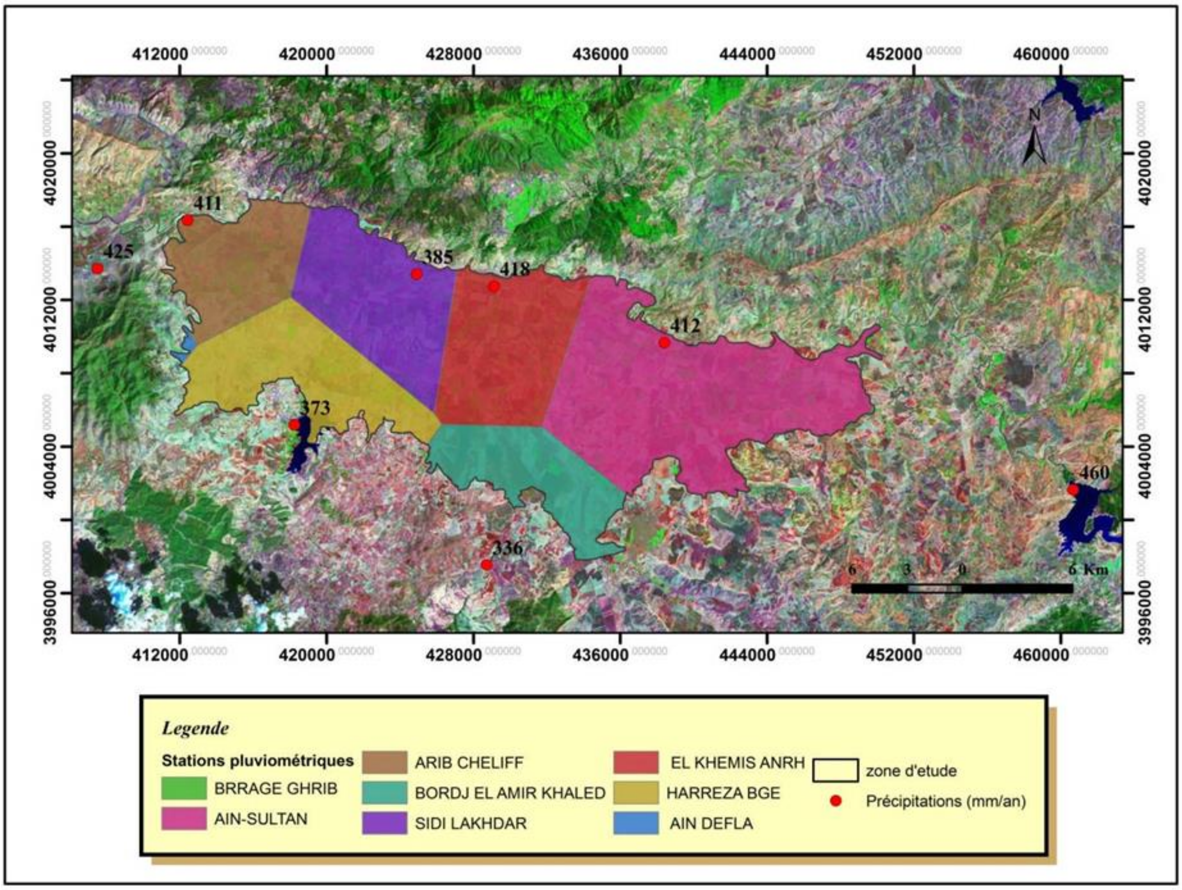


**Figure.07:** Spatial distribution map of mean annual precipitation by Thiessen polygons

### II.5.4 Temperatures:

Temperature measurements are carried out under a standardised shelter at 1.50 m above the ground, the temperatures are seasonal and their variations are regular over time, the only data we have been able to obtain are those from the Herraza dam and the Khemis Miliana rainfall station.

According to the analyses of the average monthly and annual temperatures of the period that ranges between 2003-2012**(BONG.N and MEZIANI. S, 2013)**, we can easily, distinguish four seasons of the year:

An autumn, spreading from September to November, with a seasonal average temperature of 23.16 C°;

A winter, which spreads from December to February, with an average monthly temperature of 12.41 C°;

A spring, which develops from March to May, with an average monthly temperature of 19, 12 C°;

And finally a hot summer, distributed from June to August, with an average monthly temperature that reaches 30, 91C°;

We can conclude that, the sector of study corresponds to a semi-arid zone or the annual average temperature varies in the vicinity of 21, 42°C.

## II.6 Geological setting:

The study area located in the Upper Cheliff (plain of Khemis-Miliana) corresponds to a subsidizing depression consisting mainly of Quaternary alluvium representing the terraces of the wadi Cheliff, surrounded to the north and south by the primary and Jurassic massifs of Zaccar and Doui East.

The High Cheliff, located north of the Ouarsenis, is roughly elongated from east to west, over 60 km long and an average of 25 km wide.**(BENMERIDJA AHMAD, 2004)**

The alluvial plain of Khemis-Miliana, is part of the Atlas Tellian, it corresponds to a Neogene synclinorium resting on the Cretaceous bedrock of the subsiding Tellian furrow, between the Boumaad massif and the foothills of Ouarsenis (See Figure 07).

This ensemble is due to the superposition of several phases of folding and deformation of Primary, Secondary and Tertiary age.

The grounds which form the heart of syncline are of the higher Miocene, they constitute a sandstone layer at the top and pass towards the bottom to more clayey grounds. The main Miocene outcrops are at the level of Jebel Gantas and east of Ain Sultan.

The quaternary lands that occupy the center of the plain, are mainly represented by alluvial deposits of the Oued Cheliff, whose upper part is represented by very clayey silts of about fifteen meters thick. These alluvial deposits extend over areas of 241.2 km ² in the plain of Upper Cheliff.**(BOUZIANE ERRAHMANI.A, 2005).**

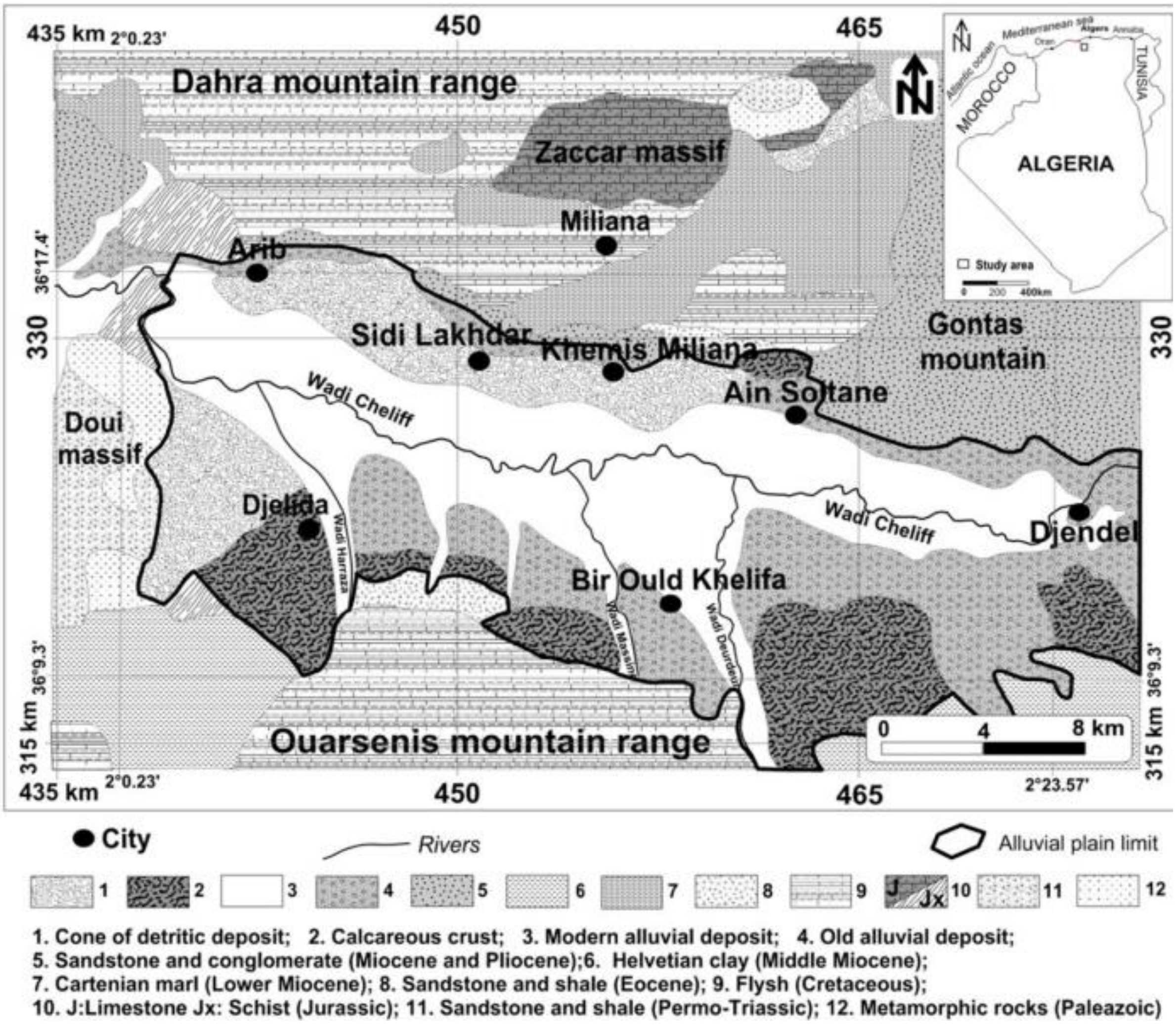


**Figure.08 :** Geological map of the Upper Chelif Plain

## II.6.1 Local geological context:

The plain of Khemis-Miliana, corresponds to a depressed area with recent sedimentation Mio-Plio-Quaternary. It is crossed from East to West by the Oued Cheliff which enters the plain by the threshold of Djendel and leaves it by that of Doui. The northern part of the plain is dominated by a line of reliefs that form the Djebel Gontas (871 m), the Zaccar massif (1579m) and the Aribs (Littré 1532 m). It belongs to the northern tell, the southern part is limited by the first buttresses of Ouersenis which belongs to the southern tell. **(BONG. N et MEZIANI. S, 2013).**

The Jurassic-Primary peaks of Zaccar, Doui and Aribs constitute the epi-metamorphic autochthonous with ante-nappe schistosity on which rests the allochthonous characterized by nappes of charriage with Cretaceous material. These nappes coming from the North were put in place during the lower Miocene.**(BONG. N et MEZIANI. S, 2013)**

The alluvial plain of Khemis-Miliana corresponds to an intra-mountainous furrow, in which the erosion of the surrounding reliefs and the successive transgressions allowed the deposits of strong thicknesses of sediments Neogene and Quaternary.

The Primary and Secondary terrains, due to their rigidity, have been deformed and raised by vertical movements, giving the Intra Tellian amygdala (Zaccar and Doui), while the Cretaceous terrains, due to their flexibility and plasticity, have been folded, giving the Subsidiary trench.

### II.6.2 Lithology of the plain of Khemis-Miliana:

The transverse lithological sections carried out in the plain of Khemis-Miliana makes appear the subsidient depression and the allure in synclinal of the various formations constituting the basement; one can observe from bottom to top:

- The lower Cretaceous, impermeable and spreading over the whole width of the plain; it served as a watertight bottom during the realization of the Ghrib dam;
- Surmounted by a Miocene, but not outcropping or very little on the surface;
- The alluvial deposits of Oued Cheliff; in the first place, being in contact with the clayey formation of the Miocene, form a layer of clayey alluvium, with an average thickness of 32 meters;
- The coarse alluvial deposits of the Cheliff itself, forming the most important aquifer of the region; their thickness can exceed 70 meters;
- At the edges of the Oued Cheliff, the contact between Miocene clay and alluvial deposits, form lenses of clay alluvium;
- Finally, a silty covering, surmounts the whole; observed essentially in the center of the plain, it makes the aquifer captive in some places.**(BONG. N et MEZIANI. S, 2013)**

The geophysical study established by the General Geophysical Campaign (G.G.C), and the drillings carried out have highlighted in the vicinity of the current watercourse of Cheliff a channel with coarse filling (large pebbles and gravels) which constitutes the main aquifer of the plain, its thickness varies between 5 to 150 m. The rest of the filling consists of sandy-clay alluvium, whose thickness decreases as one approaches the edges. The whole is covered by greyish silts from 10 to 20 m or it makes the aquifer semi-captive locally in some places.**(BENMERIDJA AHMAD, 2004)**

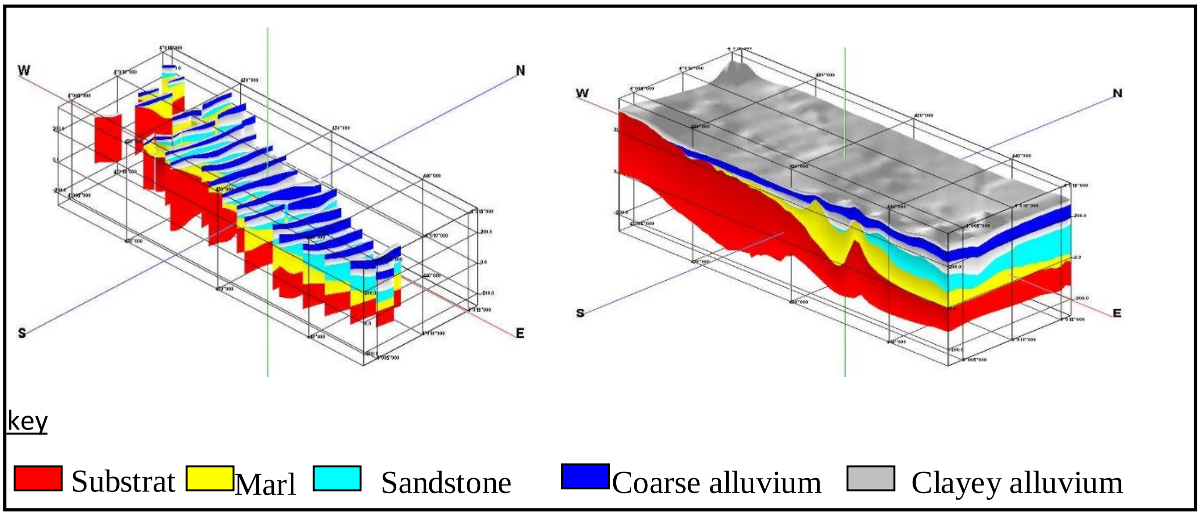


**Figure.09:** Diagram in diagonal panels, showing the spatial variation of geological units in the plain of Khemis-Miliana.

| | | |
|---|---|---|
| **Aquitard 1** | **Clayey alluvium** | |
| **Aquifer 1** | **Coarse alluvium** | |
| **Aquitard 2** | **Clayey alluvium** | |
| **Aquifer 2** | **sandstone** | |
| **Aquitard 3** | **marl formation** | |
| **Substrate** | **Substrate** | |

## II.6.3 Stratigraphy:

The stratigraphic series of the Upper Cheliff plain range from the Primary to the Quaternary age (see Figure 10).

- **The Primary**: consists of alternating black graphite schists and quartzite and clay banks.
- **The Triassic**: is generally constituted of dolomites and dolomitic limestones, it outcrops in the massif of Doui and Zaccar.

- **The Jurassic**: it is constituted in the Zaccar massif by massive, compacted, fractured and karsticlimestones, surmounted by sandstone shales and marno- limestones. The whole series reaches a thickness of about 700 m.

In the Jebel Doui, the Jurassic is represented essentially by levels of dolomitic limestones with a thickness close to 80 m.

- **The Cretaceous**: the Cretaceous outcrops on the lateral edges of the plain, it is represented from base to top by:

- Neocomian schistose clays, about 800 m thick in the north and west of Zaccar.

- Flyschfacies of the Albian which develop in the Boumaad massif.

- Marls with intercalations of limestone banks of Senonian age.

- **The Miocene**: The Miocene can reach 300 m thick, it is constituted from the base to the top by:

***The Lower Miocene (Burdigalian):*** rests on older Eocene and Cretaceous terrain, which begins with a conglomeratic formation about 220 m thick. This formation is essentially constituted by polygenic conglomerates with elements of very variable size, poorly sorted, with sandy or sandstone levels poorly stratified sometimes gypsiferous.

At the top, the conglomeratic levels become finer and gradually change to red to greenish brown sandstone marl.

***The upper Miocene (Vindobonian):*** is a series that represents from base to top: conglomeratic levels 1 to 2 m thick, with sandy-marl cement, surmounted by a marly level of blue color, about 50 m thick; white marlsalternating with some siliceous banks crowned by a deposit of sandstone and sand, about 100 m thick.

A marly formation of blue color, presenting a clayey facies, sometimes gypseous of about 90 m thickness.

***The Mio-Pliocene****:* the Mio-Pliocene is constituted by Quartzian pebbles, conglomerates, sandstones and detrital clays, as well as the ancient Travertine deposited at the level of the sources of Zaccar.

- **The Pliocene**: we distinguish a continental Pliocene and a marine Pliocene .

***The Lower Pliocene (Marine Pliocene):*** is represented by a Marneous series that begins with detrital sandstone or sandy and sometimes conglomeratic levels, then we have a progressive passage in the upper part to sandy marls and clayey sands, forming all the terms of passage to the Astian sandstones. The sandstones, with a thickness of a hundred meters, constitute a continuous band from the west of Abaddia to the southern slope of Dahra.

***The Astian***: is represented by a marine series finely sandy or sandstone of tawny yellow color. The sandstones are often with calcareous cement, locally changing to sandstone limestones.

***The upper Pliocene (Villafranchian):*** the continental Pliocene is formed of conglomerates with sandstone to sandstone-limestone elements and sands, unconsolidated.

The red sandy deposits with intersecting stratifications that follow the previous conglomerates belong to the Villafranchian. These deposits are mostly underlain by sandstone silts. Sometimes the conglomerates of the upper Pliocene do not exist, and the red Villafranchian formations are then in contact with Astian sandstones; moreover, south of Cheliff on the edge of the Ouarsenis, the Pliocene disappears completely. At this level, the Quaternary directly covers the Miocene sandstone.

- **The Quaternary:** the Quaternary deposits are continental; we distinguish an ancient Quaternary and a recent one.

***The ancient Quaternary:*** is represented essentially by conglomeratic alluvium: pebbles, gravels and sands. The alluvium of the ancient Quaternary is observed at the foot of theZaccar massif, and in particular to the east of Sidi- Lakhdar; they form the vast hills on the southern edge of the plain of Haut Cheliff.

***The recent Quaternar:*** the recent Quaternary is formed essentially of silt, whose thickness varies from 25 to 200 m, we distinguish from top to bottom:

* Brown to red silts, the oldest levels are discordant on the ancient Quaternary. These silts cover almost the entire depression in the form of sandy-sandstone alternation.

* Sandstones, visible especially on the banks of the wadis, form accumulations of very fine levels whose thicknesses can reach five meters, they are old dried out mud. These formations come from the erosion of the neighbouring reliefs.

* Current alluvium formed by silts, sands, pebbles and pebbles at the bottom of the talwegs and in the confluence zones of the wadis and abandoned meanders.**(KAHILA.A et ACHOUR.K, 2008)**

## II.7 Hydrogeological Setting:

In this section, we represent the different geological formations that may be of hydrogeological interest in the region.

### II.7.1 The main aquifers of the study area:

According to the study of the stratigraphic series and its lithological and structural characters, the following aquifer levels are distinguished:

- **Jurassic limestones**: constitute an important reservoir that is characterized by the presence of cracks that promote the circulation and storage of water.The density and poorly known distribution of its cracks pose enormous problems for the location of wells and boreholes.
- **Miocene aquifers:** are represented in the form of more or less clayey and sandy conglomerates. The Miocene limestones outcrop along the southern boundary of the valley, with the presence of voids and open internal cracks, due to the dissolution of carbonates under the influence of rainwater infiltration, especially along the contact surfaces.
- **Pliocene aquifers:** the Pliocene occurs in the form of yellowish Astian sandstones transitioning at their top to helix dune sands, with an average thickness of 100 m.
- **Quaternary alluvial aquifer subject of our study:** the Quaternary alluvial formations are the most important and most exploited aquifer in the alluvial plain of Khemis Miliana. The lithological descriptions of the drillings show that more than 20% of the materials crossed are sands, gravels or; and a range of depth of the drillings which varies from 5 to 150 m.**(BONG. N et MEZIANI. S, 2013)**

| Thickness (m) | Log | Lithology | Age | | | Hydrogeological behaviour |
|---|---|---|---|---|---|---|
| 10 à 20 | | Silt and clay | Quaternary recent | Quaternaire | C E N O Z O I Q U E (Mio -Plio-Quaternaire) | Semi - perméable |
| 100 | | Coarse alluvium (sandstone and pudding)<br>Clayey alluvium (sands, gravels, clays) | Ancient Quaternary | | | Perméable |
| 100 | | Clays<br>Sandstone and conglomerates | Pliocene | | | Imperméable<br>Perméable |
| 100 | | Sandstone and puddings | | | | Perméable |
| 200 | | Clays | Upper Miocene (Vindobonian) | Miocène | | Impermeable<br>Permeable |
| ? | | Sandstones and puddings<br>Limestones | | | | Permeable |
| 300 | | Marls | Lower Miocene (Burdigalian) | | | Impermeable |
| 1000 | | Sandstones and puddings | | | | Permeable |
| 20 | | Limestone | | | | Permeable |
| ? | | Sandstone and quartzite<br>Clays and shales | Eocene | | | Permeable<br>Impermeable |
| ? | | Marls and limestones marl | Senonien | Crètacé | M E Z O Z O I Q U E | Imperméable |
| 20à60 | | Limestone and marl limestone | Cenomanien | | | Impermeable |
| 1000 | | Schists and quartzite banks | Albien | | | Impermeable |
| 800 à 1000 | | Schistose clays | Neocomien | | | Impermeable |
| 1000 | | Limestone | Jurassique | | | Permeable |
| ? | | Gypsum and clay | Trias | | | Semi-permeable |
| 500 | | Schists and quartzites | Permo-Trias | | | Impermeable |

**Figure.10:** Litho-stratigraphic and hydrogeological log of the alluvial plain of Khemis Miliana (Mattauer 1958, Perrodon 1967)

According to the study of the stratigraphic series of the region (See Figure 07) and its lithological characteristics, we distinguished the presence of an alluvial aquifer with a double character locally a free water table with lithological passages and a presence of a silty-clay cover, which makes the water table of the coarse alluvium semi-captive locally. Another aquifer was interesting attributed to the Miocene and the aquifer of Zaccar limestones. We will focus our study only for the coarse alluvium of the Quaternary. This aquifer contains a much exploited water table in the plain. Its impermeable substratum is represented by the marls and clay of the Miocene.

## II.8 Conclusion:

The alluvial plain of Khemis-Miliana has an area of 359.5 km ², is located between the massif of Zaccar, the reliefs of Ouarsenis in the South, Djebel Gontas in the East and the threshold of Doui in the West. It belongs to the catchment area of the high Cheliff and it is crossed from East to West by Oued Cheliff, the geomorphology of the plain shows that the basin of the high Cheliff has an elongated shape with a semi-arid climate.

The geological and hydrogeological synthesis of the region, supported by a lithological and structural description, shows that the lower and upper Miocene forms a complete sedimentary cycle materialized by important deposits of marl-dominated sediments (higher than 2000 m) in parallel with an intense subsidence. The plastic sediments subsequently facilitate the formation of regular folds. The intensity of these folds increases from West to East with the increase in power of the Miocene formations (the perched syncline of the Gontas massif).

The whole region of the North-East of El Khemis is cut by important faults of NE-SW directions which bring up the deep substratum of the basin and bring back the schistose Cretaceous (forest of Oued Souffay). The bordering massifs in surrection along the vertical faults limit the basin in the North and in the West (Zaccar and Doui). The plain of Khemis-Miliana behaves as an intra-mountainous basin during the Neogene.

The Quaternary is characterized by a negative phase of filling materialized by the accumulation of coarse alluvium. The alluvial plain is limited to the East at the level of the Djendel threshold, this threshold with flexible tectonics is represented by the outcrops of sandstone, sand and marl of the upper Miocene. To the West, on the other hand, the threshold of Aribs, Doui is characterized by its brittle tectonics and by its ancient Jurassic-Primary age.

These two thresholds give the alluvial plain a certain hydrological interest, since the Oued Cheliff enters it through the first threshold and leaves it through the second. It descends from the Djendel towards the Aribs-Doui threshold.

The coarse alluvium is surmounted by a silty-clay cover which is considered as aquitard, which gives the local character of a semi-captivism to the water table, the formations of the Mio-Plio-Quaternary are formed of a multilayer water table with interstice porosity

# Chapter III

# Materials and methods

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## III.1 The objective of the study:

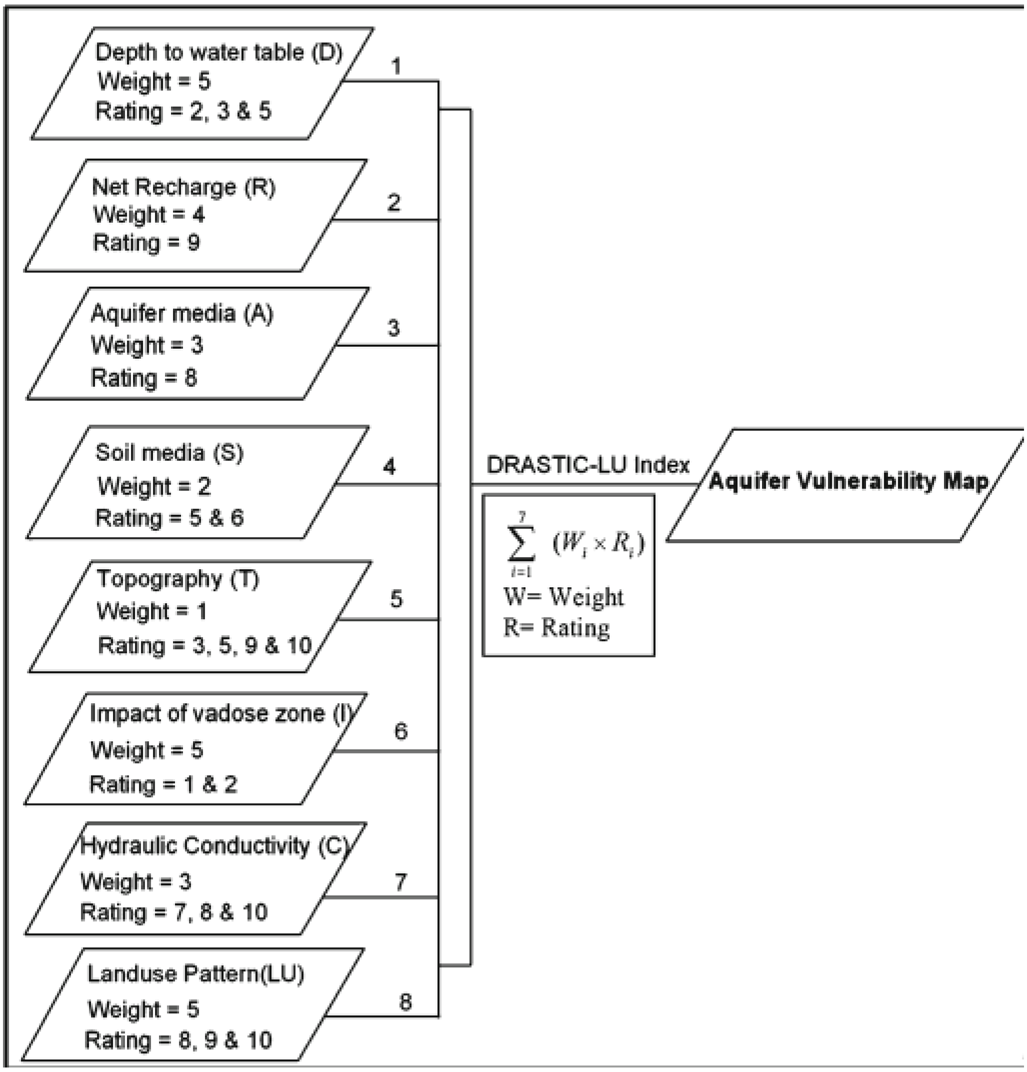
The objective of this study is to evaluate the vulnerability and the risk of pollution of groundwater resources of the alluvial plain of Khemis Miliana aquifer. It is thus possible to define the sensitive zones in which pollution can seriously affect a water table and to have an idea of the means to be used, to protect this water table.

## III.2 Data and DRASTIC method:

The DRASTIC method, which belongs to the group of weighted classes, is a system that was developed as a means to evaluate the intrinsic vertical groundwater vulnerability to pollution by parametric systems; the common principle of these systems is to first select the parameters on which to base the assessment of vulnerability. Each parameter is divided into intervals of significant value and is assigned a numerical rating increasing, according to its importance in vulnerability.(Elfarrak, Hakdaoui et al. 2014)

Groundwater resources have the potential to be contaminated from non-point sources or distributed point sources of pollution, such as pesticides or nitrates from fertilizers in agricultural areas. Groundwater vulnerability index describes the level of vulnerability which is a dimensionless index and function of hydrogeological factors, contamination sources, and anthropogenic effects.(Plymale and Angle 2002)

The vulnerability of groundwater to contamination was assessed using the modified DRASTIC-LU model. The parameters like depth to water, net recharge, aquifer media, soil media, topography, impact of vadose zone, hydraulic conductivity of the aquifer, and land use pattern were considered for the preparation of the aquifer vulnerability map. The DRASTIC-LU index is computed as the sum of the products of weights and rating assigned to each of the input parameters. However, the higher the DRASTIC-LU index, the greater the chance of groundwater contamination.(Alam, Umar et al. 2014)




**Figuer.11**: Flow chart of the methodology (Alam, Umar et al. 2014)

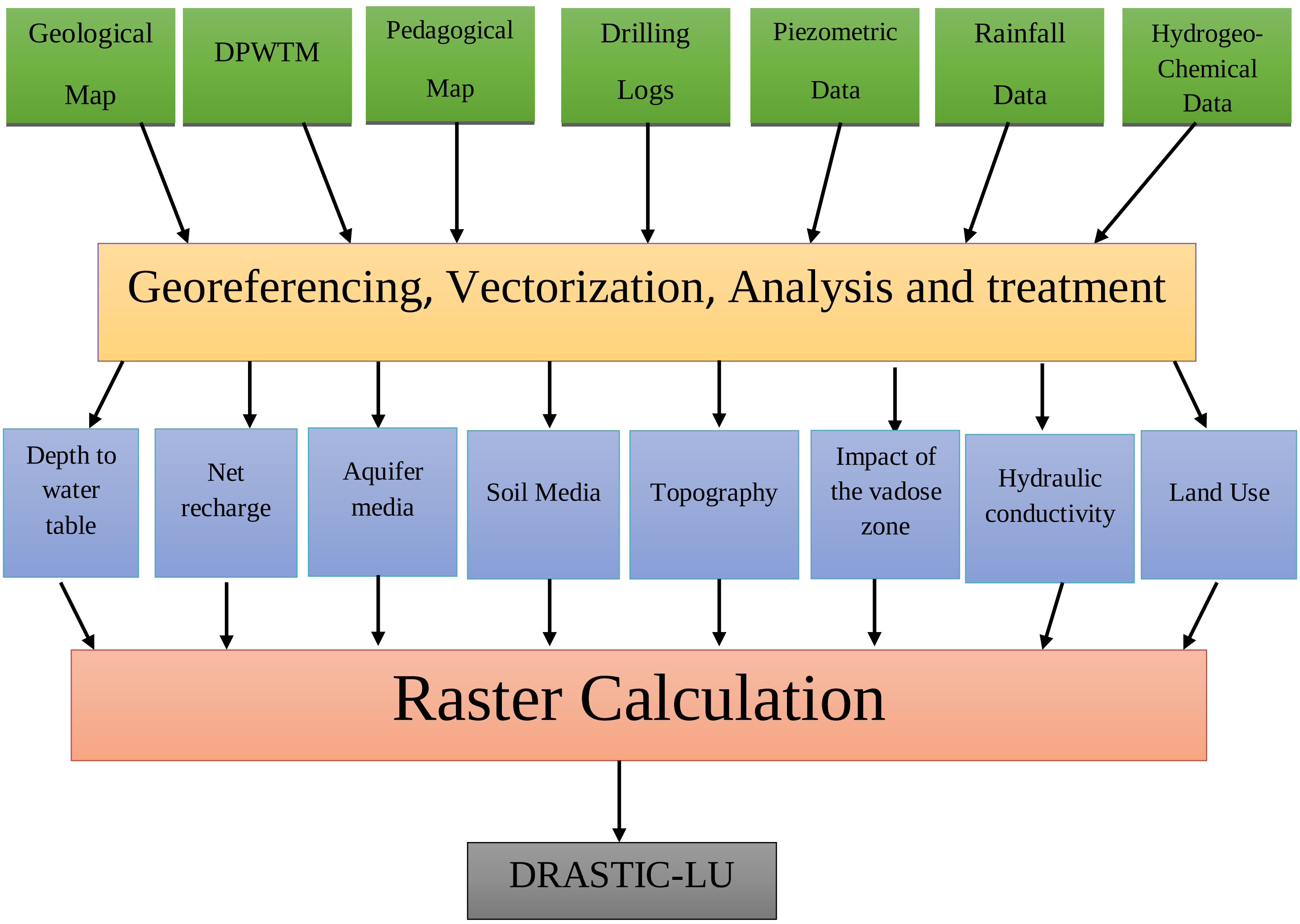



**Figure.12**: Organogram of the approach used to achieve the vulnerability of groundwater to pollution maps

**Table 10.** Notations granted to the parameter of the DRASTIC model (Lallemand Barrès 1994)

| **D : Groundwater depth** | | **R : Net recharge** | |
|---|---|---|---|
| **Value in (m)** | **Rate** | **Value in (mm/year)** | **Rate** |
| 0 - 1.5 | 10 | >25.5 | 9 |
| 1.5 - 4.5 | 9 | 17.5 - 25.5 | 8 |
| 4.5 - 9 | 7 | 10 - 17.5 | 6 |
| 9 - 15 | 5 | 5 - 10 | 3 |
| 15 - 21 | 3 | 0 - 5 | 1 |
| 22 - 30 | 2 | | |
| >30 | 1 | | |
| **A : Aquifer media** | | **S : Soil media** | |
| Karst limestone | 10 | Thin or absent | 10 |
| Basalt | 9 | Gravel | 10 |
| sand and gravel | 8 | Sand | 9 |
| Massive limestone | 6 | Clay aggregates or slopes | 7 |
| Solid sandstone | 6 | sandy loam | 6 |
| Shale in sequence | 6 | Loam | 5 |
| Metamorphic Altered, sandstone | 4 | silty loam | 4 |
| Metamorphic | 3 | clayey loam | 3 |
| Shale massif | 2 | Unaggregated and uncracked clay | 1 |
| **T : Topography** | | **I : Impact of the vadose zone** | |
| **Value in (%)** | **Rate** | karst limestone | 10 |
| 0 - 2 | 10 | Basalt | 9 |
| 2 - 6 | 9 | sand and gravel | 8 |
| 6 - 12 | 5 | Sand and gravel with silt and clay | 6 |
| 12 - 18 | 3 | Bedded limestone,sandstone and Shale | 6 |
| >18 | 1 | Sandstone | 6 |
| | | Limestone | 6 |
| | | Shale | 3 |
| | | Silt/clay | 1 |

| **C : Hydraulic conductivity** | |
|---|---|
| **Value in (m/s)** | **Rate** |
| >9.4 $10^{-4}$ | 10 |
| 4.7 10-$^{4}$ - 9.4 $10^{-4}$ | 8 |
| 32.9 $10^{-5}$ - 4.7 $10^{-4}$ | 6 |
| 14.7 10-5 - 32.9 $10^{-5}$ | 4 |
| 4.7 $10^{-5}$ - 14.7 $10^{-5}$ | 2 |
| 4.7 $10^{-7}$ - 4.7 $10^{-5}$ | 1 |

**Table 11.** Weighting factors for the different criteria of the DRASTIC method (Lallemand-Barrès, 1994)

| Criteria | Weighting factor | |
|---|---|---|
| | Normal | Phyto products |
| D : profondeur | 5 | 5 |
| R : recharge | 4 | 4 |
| A : milieu aquifère | 3 | 3 |
| S : type du sol | 2 | 5 |
| T : topographie | 1 | 3 |
| I : zone non saturée | 5 | 4 |
| C : conductivité hydraulique | 3 | 2 |

## III.3 Choice of method:

The DRASTIC method is an empirical approach and is based on the following assumptions: the territory of application covers more than 0.4 km2, the contaminant spreads in the environment from the ground surface by infiltration of precipitation and the type of contaminant does not affect the degree of vulnerability.

The values of the weights of the parameters of the DRASTIC method used (Table 1) are those defined by Aller et al. (1987). The reference values of the DRASTIC index used are those provided by Engel et al. (1996) and represent the measure of the hydrogeological vulnerability of the aquifer

**Table 12.** Weighting factor of the different criteria of the DRASTIC method (Lallemand-Barrès, 1994)

| Vulnerability degree | Vulnerability Index |
|---|---|
| Very weak | <80 |
| Weak | 80 - 120 |
| Medium | 120 - 160 |
| High | 160 - 200 |
| Very high | >200 |

## III.4 DRASTIC Parameter Mapping :

The data collected in the alluvial plain were processed using several geoinformatics platforms (ESRI ArcGISR, MapInfoR, RockWorksR, DiagramR…etc). These data were recorded in the database from which the information layers of the parameters such as (the hydrogeological unit, soil map, geomorphological objects, boundaries, spatial distribution of precipitation, etc.) were generated in the mode vector, while features such as Digital Elevation Model, groundwater depth…etc) were themselves processed separately in Raster mode and completed with spatial overlays with their necessary attributes. It is obvious to remind you that all the information layers of the DRASTIC model parameters have been converted to Raster mode with a pixel spatial resolution of
30 m for each separate parameter. The final result will be obtained by the algebra mapping using the Raster-calculator included in the Spatial Analyst module based on mathematical queries (Addition of Rasters for each parameter).

For the purpose of interpretation, the possible values of the DRASTIC index are subdivided into seven intervals or classes Table 08. All data relevant to groundwater vulnerability have been collected, including, for example, topography, geology, land use, hydrology, hydrogeology and precipitation. ArcGIS® software was used to compile the geospatial data, to calculate the drastic indices and to generate the vulnerability map.

The quality of vulnerability maps depends, among other things, on the data and the processing to which they have been subjected. Thus, a careful examination of the data must be carried out in order to highlight the information available and its quality. In the case of this study, the integration of the results of the field surveys carried out during the winter of 2014 completed the knowledge of the territory made possible by the compilation of existing data.

### III.4.1 Groundwater depth (D):

The evaluation of the depth parameter of the water table was developed by the water level measured during the piezometric survey carried out as part of this study in 2014.
A classification of each pixel is then carried out according to the systems of quotation of the DRASTIC method we had taken average annual values of the depth of groundwater of the water points, distributed in a homogeneous way in the plain for the period from 2010 until 2014, it was necessary for us to take into account the minimum groundwater depth that was taken during the previous piezometric campaign.

In order to be in the most precise conditions possible during the evaluation of the vulnerability under principle; as long as the depth is great in the aquifer, the better the aquifer is well protected and vise versa.

We carried out a method of interpolation of the depth values of 17 water points by interpolation, under the Spatial Analyst platform, the map resulting from the depths of underground water was generated in rasterized form with a pixel of 30 m of spatial resolution.

## III.4.2 Efficient aquifer recharge (R) :

The effective infiltration (Recharge) in our study area was calculated using the so-called C.M.B (Chloride Mass Balance) method (WOOD and SANFORD, 1995) according to the following equation:

$$\mathbf{I} = (\mathbf{P})\ \mathbf{X}\ (\mathbf{CLP})/\mathbf{CLES} \qquad (\mathbf{III.1})$$

Where :

**I** : is the recharge flux in mm/year.

**P** : in mm is the average annual precipitation for the period stretching from (1980-2014).

**$CL_P$** : the chloride concentration of precipitation in mg/L.

**$CL_{ES}$** : represents the concentration of chlorides in groundwater in mg/L for the 2014 low water hydrogeochemical campaign.

For the establishment of the map of the spatial distribution in the study region of this parameter, we proceeded to the realization of three maps which are :

- Map of the spatial distribution of average annual precipitation using the Thiessen method by triangulation algorithm for the precipitation values of the nine rainfall stations distributed in the study area
- Map of the spatial distribution of chloride concentrations in groundwater from 17 water points sampled by an interpolation method known as IDW.
- Map of the spatial distribution of chloride concentrations in the precipitation that fell in our study area, for the establishment of this map, we used the analysis results of a

hydrogeochemical analysis campaign to determine the chloride concentrations in precipitation, 13 rainfall points were analyzed in the Chemistry laboratory of the A.N.R.H of Blida during the months of March and April of the years 2014 and that of 2013.

- The precipitation chloride concentration values were interpolated by the IDW method and themselves converted into Raster mode.

Mathematical queries under Spatial Analyst Tools and Raster Calculator were executed (multiplication and division of Rasters) to obtain the final map of the spatial distribution of the recharge in mm/year.

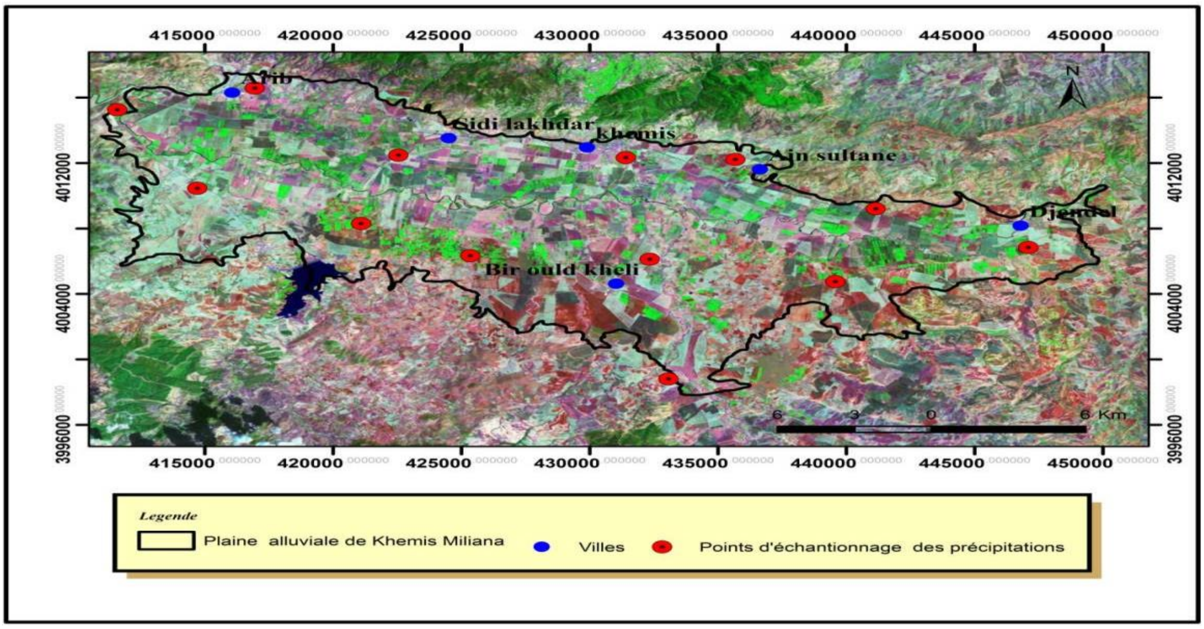



**Figure.13:** Spatial distribution of precipitation sampling points intended for chloride analysis in the study area.

In total, a number of 13 samples was fixed and later carried out, taking into account the good spatial distribution in the sector studied, the geographical location of the sampling points covers the upstream, downstream and central parts of the plain to at the end have a good result on the targeted objective.

The precipitation chloride concentration values were interpolated by the Thiessen method and converted themselves into Raster mode.

Mathematical queries under Spatial Analyst and Raster Calculator were executed (multiplication and division of Rasters) to obtain the final map of the spatial distribution of the recharge in mm/year (See Figure 13).

### III.4.3 Aquifer Media (A) :

This map is made on the basis of the litho-stratigraphic logs of 29 boreholes, the lithological variations of the boreholes were extracted in Excel, the lithological passages in the region were extracted in polygonal form using the geological map.

### III.4.4 Soil Media(S) :

The soil is depending on the shelter of the sediment that covers it plays a role very effectively on the ability to reduce and / or retain the speed of pollutants through the hydrogeological system, very important for the estimation of vulnerability. Soil is often represented as a favorable environment for the accumulation and transformation of matter.

The soil map of the alluvial plain of Affreville (J.Boulaine, 1955) was vectorized under the ArcGis platform in .SHP format. A reclassification was assigned to each type of soil in such a way that this manipulation allowed us to reduce the number of typological polygons of the soil to less than 10 classes.

### III.4.5 Topography (T):

The slope of the land is a very important factor for the estimation of the vulnerability since it determines the final surface as part of the precipitation, and therefore delimits the regions in which there is a greater possibility that the pollutants can infiltrate from the surface to the aquifer. The highest values of this parameter are allocated to the gentlest slopes where the possibility of pollutants to spread is reduced. In addition, the slope can be a good indicator of the soil type and indirectly determines the capacity of the hydrogeological system to retain pollutants.

For the determination of the degrees of slope of the plain, we went through the processing of the Digital Terrain Model "DTM" extracted and clipped from the DEM North-Algeria one whose resolution is 30 m, then we proceeded to a percentage reclassification of each grid of this DTM in the Spatial Analyst Tools platform.

### III.4.6 Impact of the vadose zone (I) :

Once the water depth is known, an initial division into unsaturated or saturated subzone can be made. After determining the thickness of the unsaturated zone and the relative lithological variations of the hydrogeological stratigraphy of the region.

To determine the spatial distribution of this parameter, we had to go through consultations of the litho-stratigraphic logs 29 log of boreholes, by studying their lithological variations in Excel, interconnections were applied between the latter, MapInfo and RockWorksR, to follow the lateral variations of the lithologic facies, it was necessary for us to switch to three-dimensional modeling under RockWorksR, the lithologic passages in the region were extracted in polygonal form.

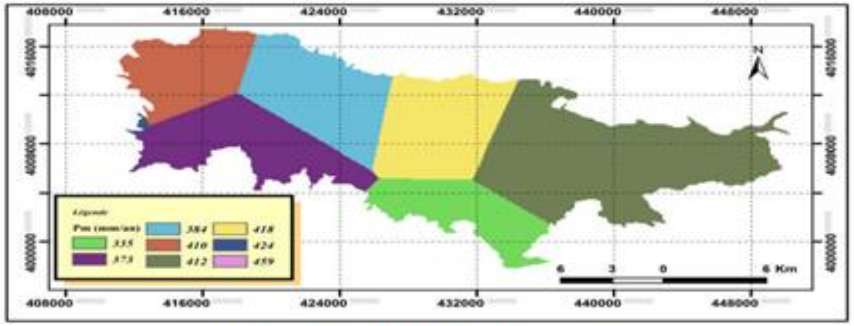
### III.4.7 Hydraulic conductivity (C):

The determination of the parameter C is mainly based on the elaboration of a cartography of the distribution of the hydraulic conductivities obtained from the pumping tests made in the plain. The data seemed insufficient from the start with 11 pumping tests, stratigraphic logs of boreholes and wells, the hydrogeological maps of Algiers and Energo for the entire study area were also integrated.

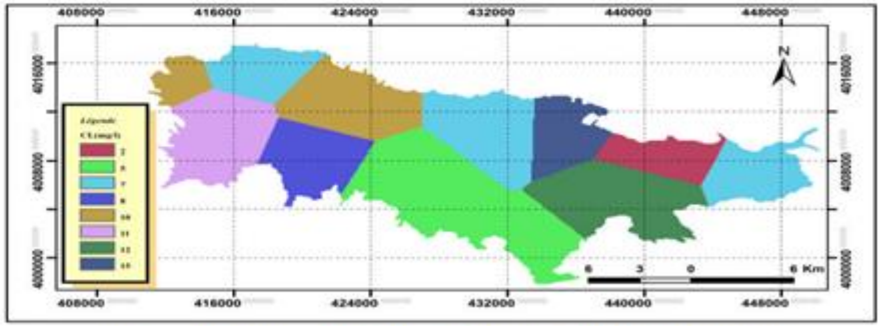
The values of hydraulic conductivity were determined in 26 points more or less well distributed in our study area, the mapping of the spatial distribution of conductivity was made based on the interpolation of these values by Kriging

### III.4.8 Land use (LU) :

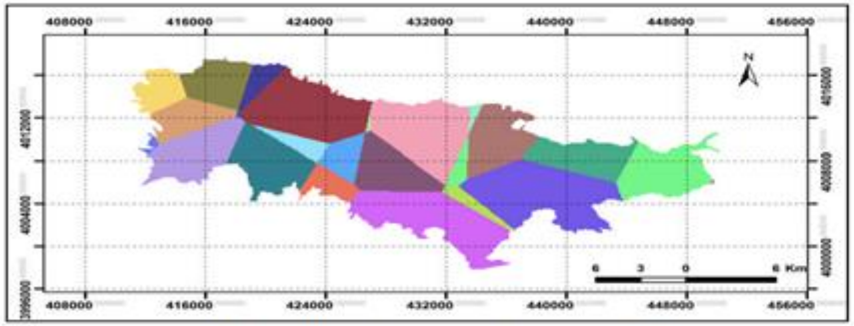
The land use pattern (LU) has strong bearing on groundwater quality. Therefore, land use pattern is included in vulnerability mapping. For the present study, analysis of groundwater, surface water, trace elements, and subsequent interpretation indicated that urban land use (industrial and sewage pollution) demonstrated maximum impact followed by rural (pesticides and fertilizers) land use.(Alam, Umar et al. 2014)



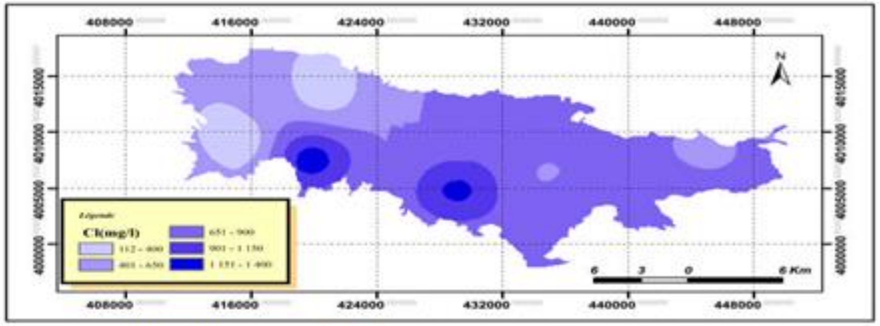
a.Spatial distribution of precipitation



b.Spatial distribution of chloride concentrations from precipitation



c.Multiplication of the map a times the map b



d.Spatial distribution of groundwater chloride concentrations

**Figure.14**: Maps established for the application of the so-called C.M.B Chloride Mass Balance method

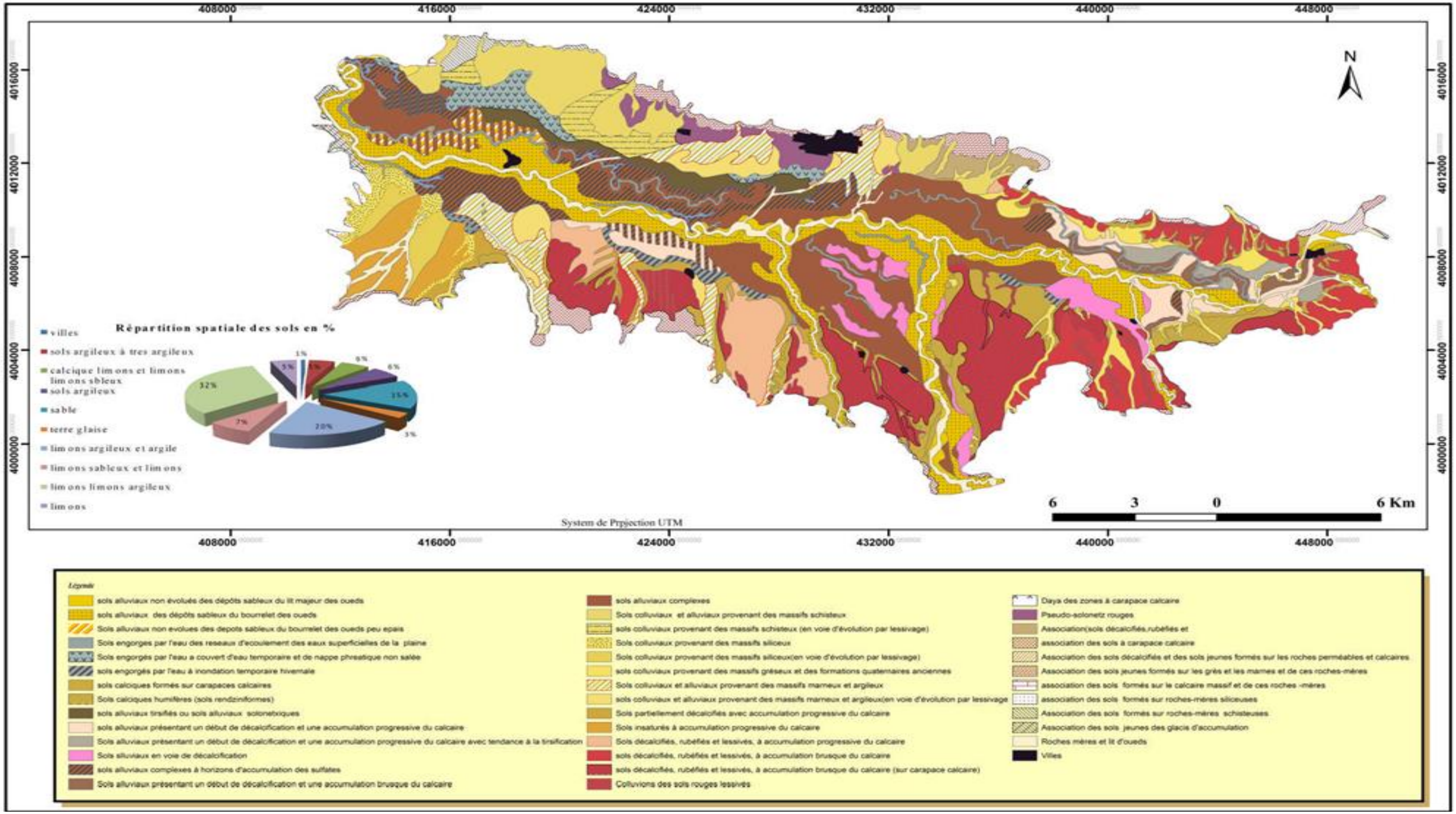



**Figure.15** Vectorized soil map of the alluvial plain of Khemis Miliana (J.BOULANE,1955)

## III.5 the Application of Geographic Information System (GIS) :

GIS has emerged as a powerful tool for storing, analyzing, and displaying spatial data and using that data for decision-making in several fields, including engineering and environmental fields (Lo and Yeung, 2003).

The study is carried out with the help of ARCGIS10.2.2 entered in a GIS environment. Spatial Analyst, an extension of ArcGIS 10.2.2, was used to determine the spatio-temporal behavior of groundwater quality.

The different thematic layers on hardness, pH and ionic concentrations are prepared using a spatial interpolation technique by inverse distance weight (IDW).

This contour method was used in the present study to delineate the locational distribution of water pollutants or their constituents.

The (IDW) method is one of the most common algorithms. Here, the predicted value at each point is equal to the weighted average of the data points. The weighting factor of each data point is equal to the inverse of its distance from the point to the power K; where k is defined as user. The larger the value of k, the more localized the interpolation.

This algorithm gives continuous and smooth prediction, but the probability of having "bull's eye" is higher (RockWorks 2006, Burrough and McDonnell, 1998; van Dijk et al. 1999).

The realization of the groundwater quality classification map for pH, TH, EC, TDS, Cl, SO4, HCO3, NO, Ca, Mg, Na and K from thematic layers, based on the standards of Algerian water quality for drinking water, were created by GIS techniques to determine their spatial variations in the study area.

**Table 13.** The weight (wi) and the relative weight (Wi) of each chemical parameter.

| **Parameter** | **Standards Algeria** | **Weight (wi)** | **Relative weights (Wi)** |
|---|---|---|---|
| pH | 8.5 | 3 | 0.08 |
| TDS | 1500 | 5 | 0.13 |
| CL | 500 | 5 | 0.13 |
| SO4 | 400 | 5 | 0.13 |
| Na | 200 | 4 | 0.11 |
| K | 12 | 2 | 0.05 |
| HCO3 | 500 | 1 | 0.02 |
| Ca | 200 | 3 | 0.08 |
| Mg | 60 | 3 | 0.08 |
| NO3 | 50 | 5 | 0.13 |

## III.6 Overlay analysis:

The mapping of vulnerability to groundwater pollution was done by overlaying the layers representing the different parameters in the DRASTIC-LU models. Theoretically an overlay is necessary for each parameter; however some of these parameters are often associated. In some areas of our region, the unsaturated zone and the aquifer medium are identical. In other areas, the soil and the topography are intimately related.

The data used to generate the vulnerability index map can be produced at various scales; in our case we choose a medium scale of 1 /300000. The hydraulic conductivity values are often extrapolated and interpolated from reference points or simply estimated from the aquifer environment. When creating the map, it is therefore important to try to "justify" the scale either by making generalizations or interpolating models or to find the most detailed information available in the region.

Finally, thanks to a specific function in GIS software called Overlaying Analysis, the different maps for each parametric model are generated by the Raster Calculator function of the Spatial Analyst extension.

After mapping all the parameters in thematic form, the vulnerability map was obtained by overlaying the different parametric maps and the calculation of vulnerability indices according to the DRASTIC-LU model was generated for a pixel grid size (30 m × 30 m). For each grid cell (pixel), the vulnerability index was calculated as the weighted sum of the parameters according to the equation quoted above (Eq.1).

The vulnerability index according to the DRASTIC-LU model was calculated and the final vulnerability map was subdivided into classes related to degrees according to the classification of Civita and al, (1994).

## III.7 Sensitivity analysis:

Sensitivity analyses allow for the recognition of uncertainty in parameter estimation by observing changes in the results while using the input parameter set. Sensitivity analysis can indicate the most important and influential parameters for estimating intrinsic groundwater vulnerability. This is important both for experts implementing a vulnerability model and for users using vulnerability maps. Experts could use sensitivity analysis for consistency assessment of analytical results. In addition, the results of the sensitivity analysis can indicate which parameters are much more influenceable. Sensitivity analysis can guide users to a more effective interpretation of the vulnerability index(Napolitano and Fabbri 1996)

The type of sensitivity analysis used in this study focused on the "map removal" technique(Babiker, Mohamed et al. 2005)This Map removal technique was implemented by removing a parameter and at the same time testing the effect of this removal on the final result of the DRASTIC-LU model in the study area. The goal of the test is to identify which parameter can be removed without significantly affecting the DRASTIC-LU model output. The removal maps for each parameter were compared individually with the final map based on the visual variation index.

## III.8 Conclusion :

The application of the DRASTIC-LU model for the estimation of the intrinsic vulnerability of the alluvial aquifer in the study area is presented here, using the example of the plain of Khemis Miliana. The DRASTIC-LU method is based on the evaluation of eight parameters that are described according to the geological, hydrogeological conditions that directly affect the sensitivity of the aquifer and the influence of human activity that leads to groundwater contamination. Also, this model can be applied and developed for each type of aquifer, this model must be adapted to different hydrogeological conditions. Therefore it is extremely important to have a very good hydrogeological, hydrological and geological knowledge of the region to better determine the different parameters of the DRASTIC-LU model.

# Chapter IV

# Result and Discussion

**Djilali Bounaama University of Khemis Miliana**

**Faculty of Nature and Life Sciences and Earth Sciences**

**Earth Sciences Department**

# IV.1 Establishment of the Groundwater Vulnerability Map according to the DRASTIC Model:

The degree of intrinsic vulnerability indices map to groundwater pollution of the alluvial plain of Khemis Miliana has been developed based on the mapping of each parameter presented, we will in this chapter map and interpret the results of each parameter:

## IV.1.1 Model parameters-DRASTIC:

### IV.1.1.1 Depth of groundwater (D):

The evaluation of this parameter was made on the basis of the most recent piezometric measurements, made in 2017. The depths of groundwater in the alluvial plain of Khemis Miliana were evaluated by geostatistical interpolation, they vary between 1.5 meters and 40 meters in the plain, the central part is marked by a variable threshold that oscillates between 9m and can reach values up to 30 m locally Oued Massine and Deurdeur, in the eastern part of the study area going to the South-East in the vicinity of the city of Djendel, the depths can reach maximum values of 37.55 m. On the other hand, the western part towards the south-west of the city of Aribs, downstream part, is delimited by low depths, not exceeding 9 meters in depth.

The appropriate scores for the depth intervals that vary in the study area with the corresponding classes table 14 that were attached on the map representing the spatial distribution has index according to the model-DRASTIC chosen in our study.

**Table 14.** Rates and weight assigned to the depths of the alluvial plain of Khemis Miliana

| Class | Rate | Weight |
|---|---|---|
| 0 - 1.5 | 10 | 5 |
| 1.5 - 4.5 | 9 | |
| 4.5 - 9 | 7 | |
| 9 - 15 | 5 | |
| 15 - 22 | 3 | |
| 22 - 30 | 2 | |
| 30 - 37 | 1 | |

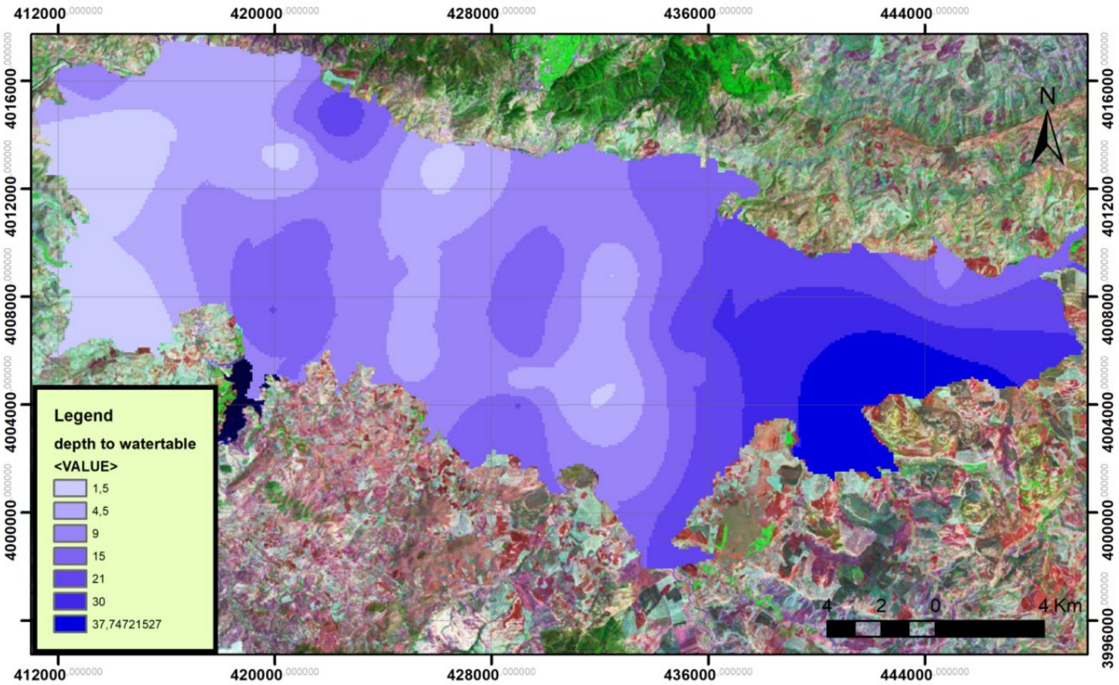



**Figure.16:** Spatial distribution of groundwater depths in meters in the study area

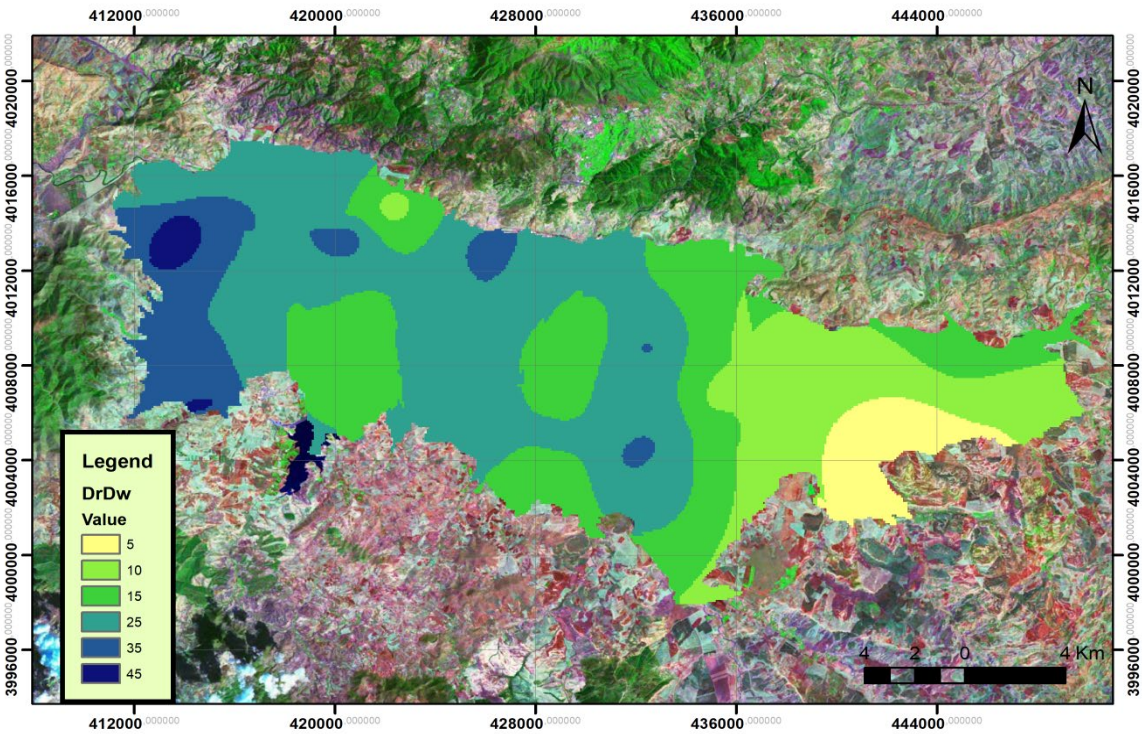



**Figure.17:** Spatial distribution of groundwater depths in meters in the study area assigned to their rating and weight

### IV.1.1.2 Net Recharge (R) :

Effective recharge plays a key role in the transfer of water from the ground surface to the underlying aquifer. This parameter is particularly difficult to evaluate in hydrogeological studies.

The recharge in our region is distributed more or less as follows: the highest recharge values with an interval between (20-37 mm/year) are found in the north-western part of the plain near the town of Arib and in the south-western part near Jebel Doui, while the lowest values cover almost the entire plain.

Since the recharge variations in the whole study area are estimated to be less than 50 mm/year, we have given them a single score equal to 1 with a multiplier weight equal to 4 according to the DRASTIC model.

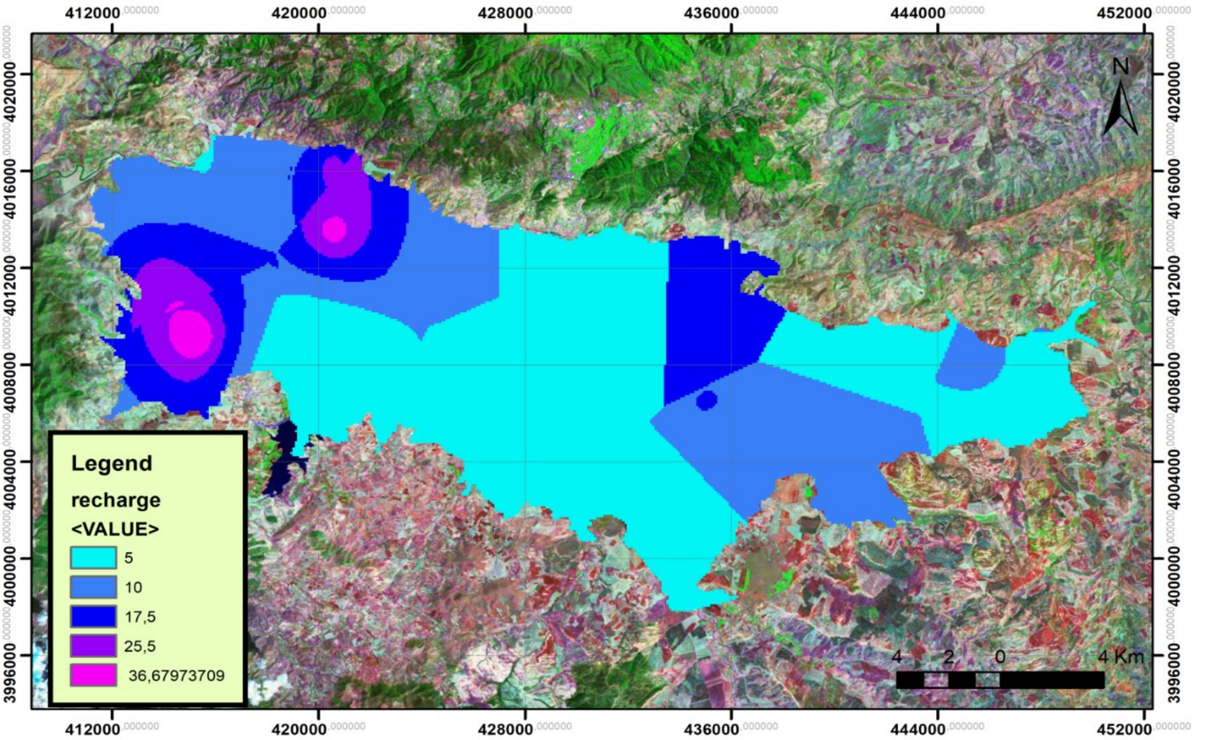



**Figure.18 :** Spatial distribution of groundwater recharge in the study area

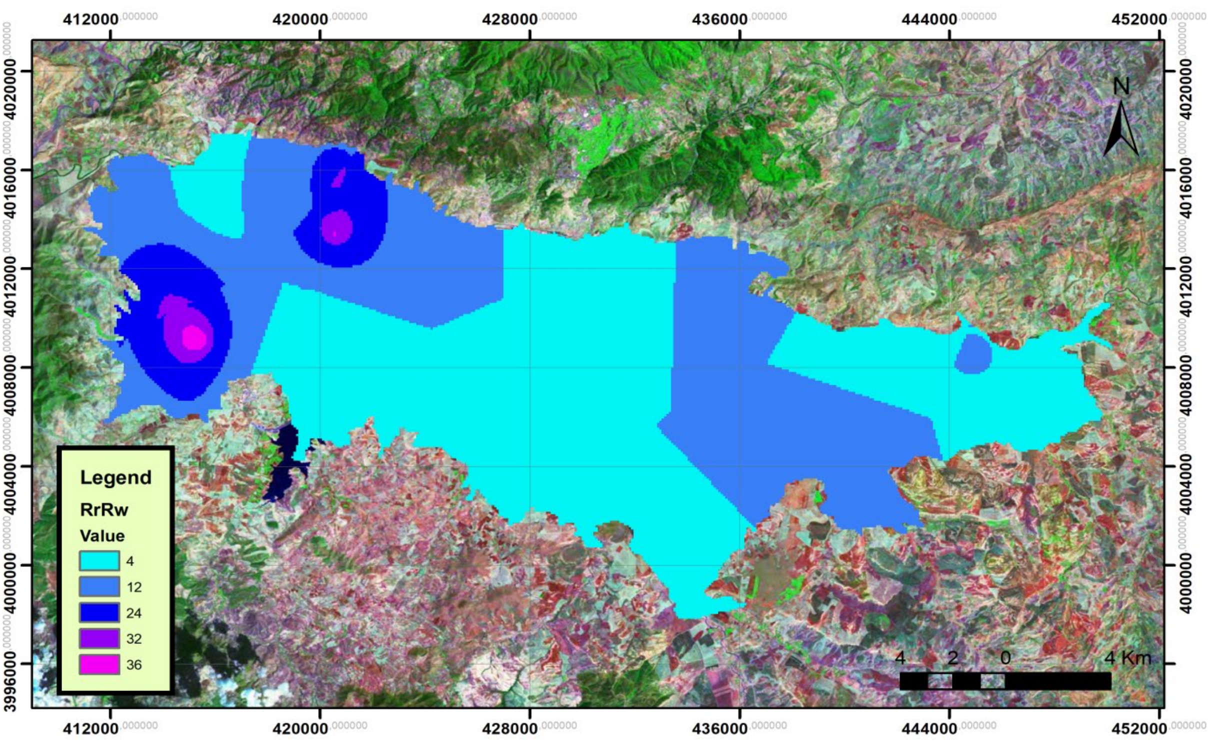



**Figure.19:** Spatial distribution of groundwater recharge in the study area assigned to their rating and weight

### IV.1.1.3 Aquifer media (A):

The description of the material constituting the saturated and unsaturated zone, was carried out thanks to the explanatory note of the geological sketch of the area and the geological and lithological sections of the drillings collecting the aquifer.

The parameter aquifer medium designates the lithology of the aquifer, it intervenes in the trapping of the pollutants escaped to the power of absorption of the ground. Its identification was based on the logs and lithological sections of the drillings carried out in the study area.

The analysis of the map of the aquifer environment, showed us that the lithological materials constituting the alluvial aquifer of the plain of Khemis Miliana are essentially constituted by recent alluvium which represents 48% of the total surface, old alluvium (21%), alluvial cones (29%) and calcareous shells (2%)

The corresponding scores for each lithological type were reported in 4 classes according to table 15.

A score of 8 for the recent alluvium which represents 48% of the total surface of the aquifer; 3 for the alluvial fans with a coverage of 29%; a score of 7 was attributed to the ancient alluvium which is very developed especially in the southern part of the region, while the materials constituted of calcareous shells between the city of Djelida and Bir.o.khalifa, a score of 9 was attributed to it and which covers only (2%).

**Table 15**.Rates and weight assigned to the aquifer media of the alluvial plain of Khemis Miliana

| Aquifer media | Rate | Weight |
|---|---|---|
| Recent alluvium | 8 | 3 |
| Dejectacone | 4 | |
| Ancient alluvium | 6 | |
| Limestone shells | 2 | |

It should be noted that the central part of our region is characterized mainly by recent alluvium. The lithological materials of the alluvial cones are generally developed at the south-western edge near the city of Djelida and to the north, going towards the west of the city of Khemis Miliana.

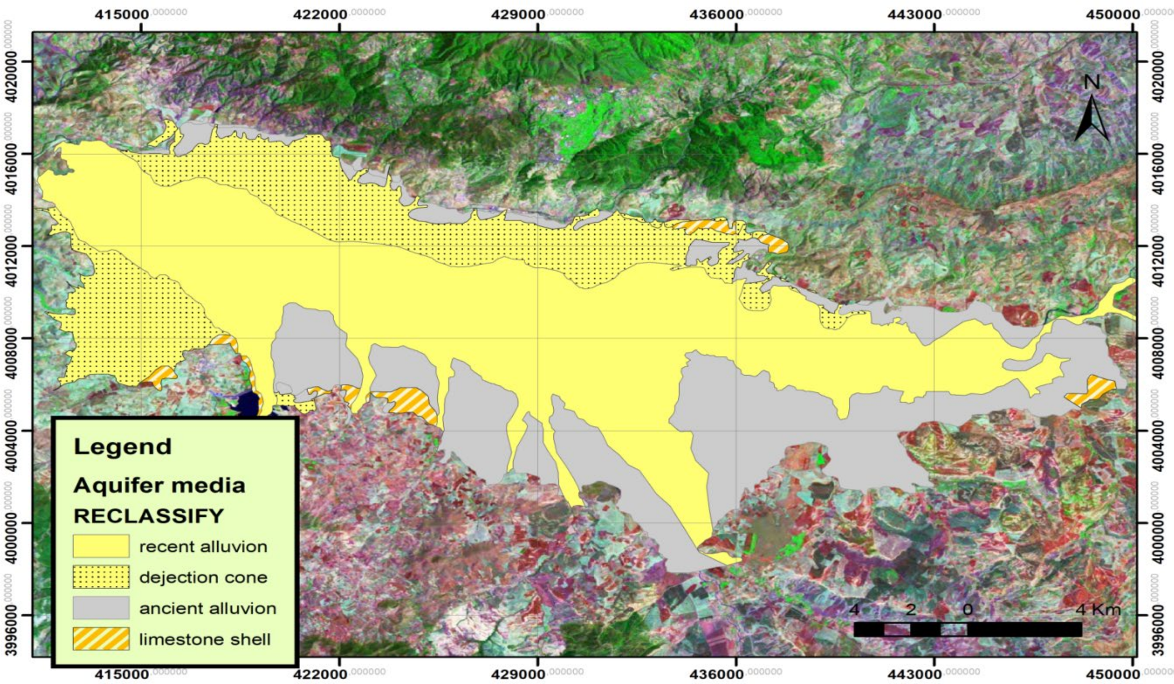



**Figure.20:** Spatial distribution of the saturated zone in the study area

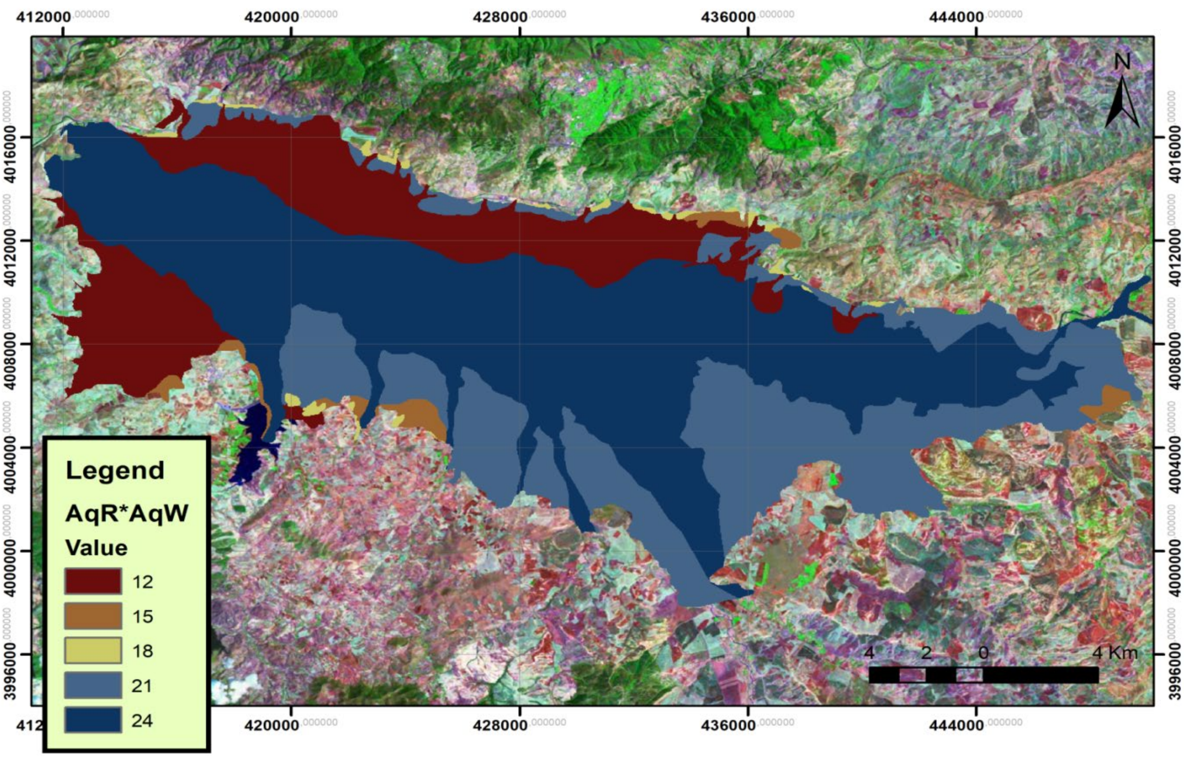



**Figure.21:** Spatial distribution of the saturated area of the study region assigned to their rating and weight

### IV.1.1.4 Soil media (S):

The nature of the soil has an influential impact on the contamination of the aquifer by pollutants from the surface. It can decrease, delay or accelerate the process of pollutant propagation towards the aquifer. The richer the soil is in clay or silt, the greater the absorption of pollutants, and the greater the protection of the groundwater.

The soil map of the study area has been vectorized under a GIS platform, a database has been established, and that has allowed us to make spatial queries for the calculation of scores and weights are summarized in the table below:

**Table 16**.Rates and weight assigned to the soil media of the alluvial plain of Khemis Miliana

| Soil type | Rate | Weight |
|---|---|---|
| cities | 1 | 2 |
| clayey to very clayey soils | 2 | |
| calcareous silts and sandy silts | 6 | |
| Clayey soils | 2 | |
| loam | 4 | |
| clayey silts and clays | 4 | |
| Clayey loams | 3 | |
| sand | 9 | |
| Sandy loam and silt | 6 | |
| silt | 3 | |

The lithological nature in terms of pedology and the facio-lithological analysis, showed us that: 43% of the total surface of the plain is occupied by silts and clayey silts, the clay and the alluvial soils of sandy deposits occupy 13 and 12%, respectively. The clayey to very clayey soils which are located between Khemis Miliana and the Aribs and which keep a certain protection, represent 9 % of the total surface, while, the sandy silts and silt with 7 and 5 %, are limited in the south-western zone near the city Djelida.

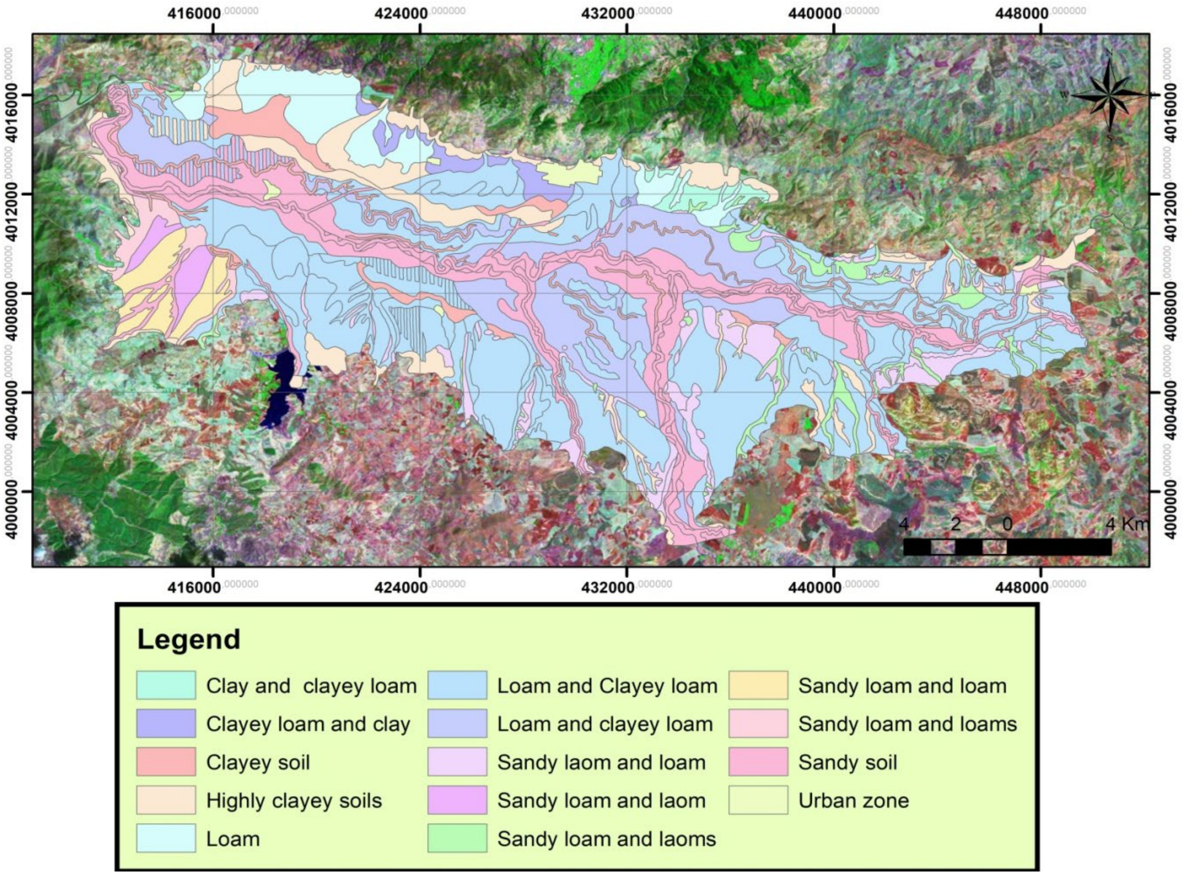



**Figure.22:** Spatial distribution of soil facies in the study area

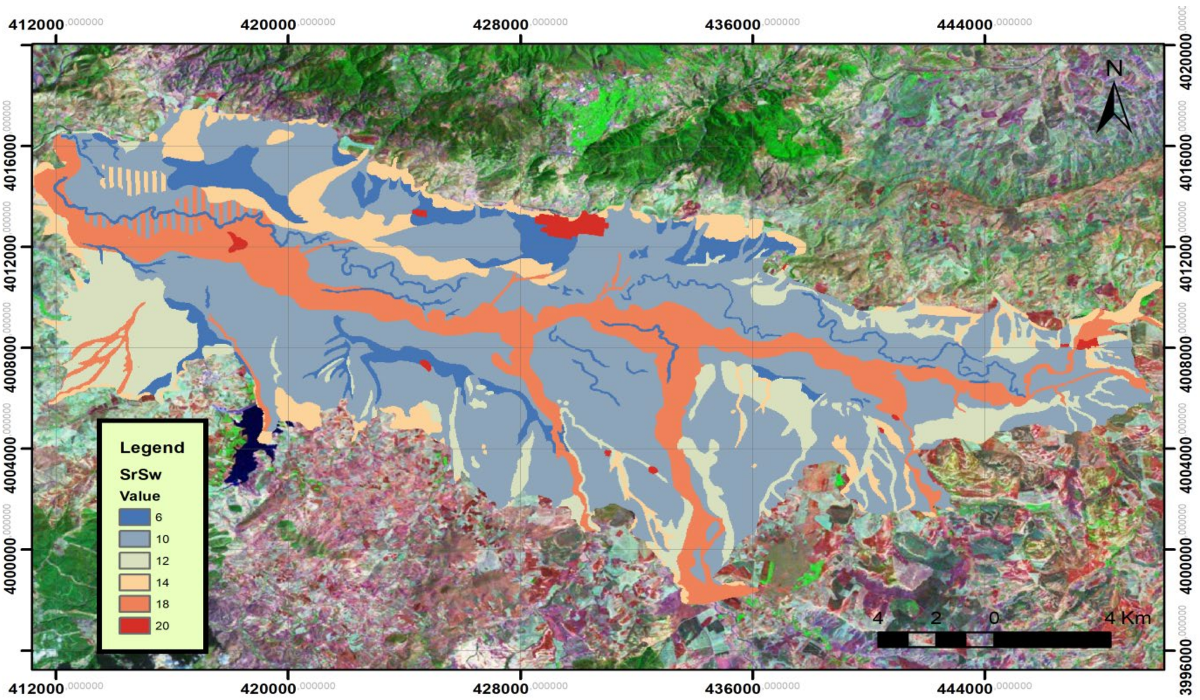



**Figure.23:** Spatial distribution of soil facies types in the study area assigned to their rating and weight

### IV.1.1.5 Topography (slope) (T):

The slope parameter is represented by the degrees of slope in percentage, this parameter translates the aptitude to the runoff and to the infiltration of the surface waters towards the groundwater and thus reflects the capacity of these waters to introduce polluting agents towards the groundwater. Indeed, the greater the slope of the land, the greater the runoff of water and consequently the contamination of groundwater is low. On the other hand, an area with a low slope has a tendency to retain water for a long period of time, which allows a greater potential for migration of contaminants from the surface to the groundwater by infiltration.

Five classes of slope degrees were appropriate to the alluvial plain of Khemis Miliana with intervals: 0-2, 2-6, 6-12, 12-18 and more than 18%, score values of 10, 9, 5, 3 and 1 were given to these intervals respectively with a multiplier weight is equal to 1 according to the model-DRASTIC.

**Table 17.** Rates and weight assigned to the slopes of the alluvial plain of Khemis Miliana

| Class | Rate | Wieght |
|---|---|---|
| 0 - 2 | 10 | 1 |
| 2 - 6 | 9 | |
| 6 - 12 | 5 | |
| 12 - 18 | 3 | |
| >18 | 1 | |

It should be noted that, according to the histogram map analysis, almost the entire study area is determined by a very low slope, ranging from (0-2%) and covering 80% of the total area of the plain.

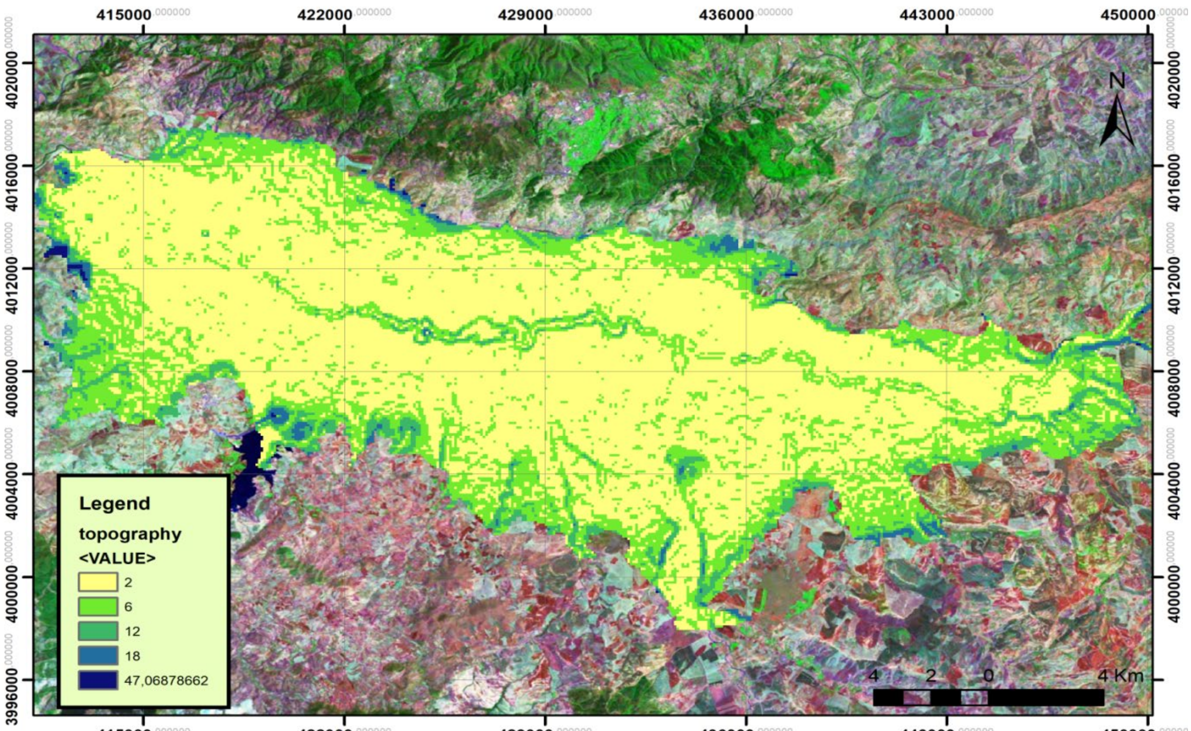



**Figure.24:** Spatial distribution of the slope degree of the study area

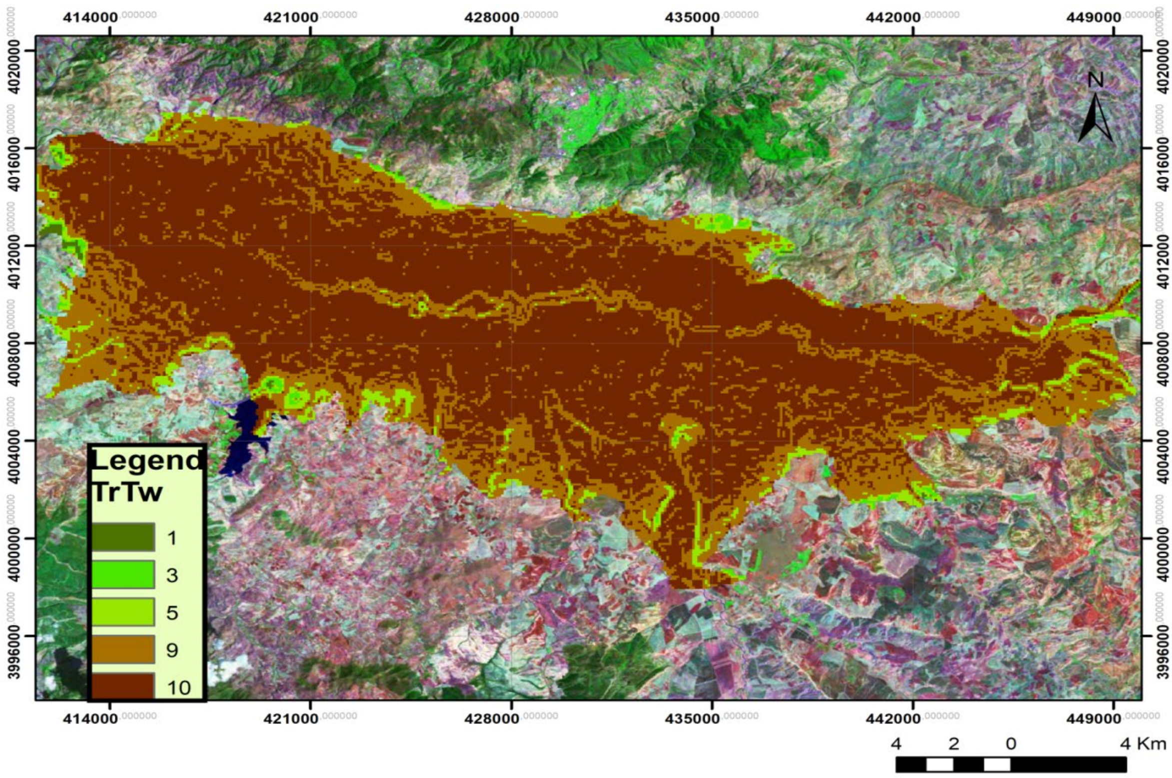



**Figure.25:** Spatial distribution of the slope degree of the study areaassigned to their rating and weight

### IV.1.1.6 Impact of the vadose zone (I):

The role of the unsaturated zone is very important in the Drastic method, since the nature and thickness of the zone above the piezometric level, control in a notable way, the vulnerability to pollution of the reservoirs.

In our study area, eight lithology classes have been distinguished: Clayey gravels which are developed at the southern edge of the plain and occupy 35% of the total area of the region, clays and silts are spatially delimited in the north-western part around the town of Aribs and in the east of the plain with a coverage of 61% of the total area, On the other hand, the formations that are considered permeable are located in the east of the plain near the city of Ain Sultane and in the west between the city of Aribs and Sidi Lakhdar and cover only 4% of the total area of the plain.

In the southern part of the plain, where the silty clay materials should assert a better protection of the aquifer are not well developed, under which are the permeable and thick alluvial fans with a thickness that sometimes reaches the 50 m at the immediate edges of the plain. According to the DRASTIC model, the scores that are related to the materials of the vadose zone distinguished in our study area and the multiplier weight given to this parameter are represented in the following table:

**Table 18**. Rates and weight assigned to the Impact of the vadose zone of the alluvial plain of Khemis Miliana

| **Class** | **Rate** | **Wieght** |
|---|---|---|
| clay | 1 | 5 |
| Clay gravel/sand/gravel/silt | 6 | |
| Sand and gravel | 8 | |

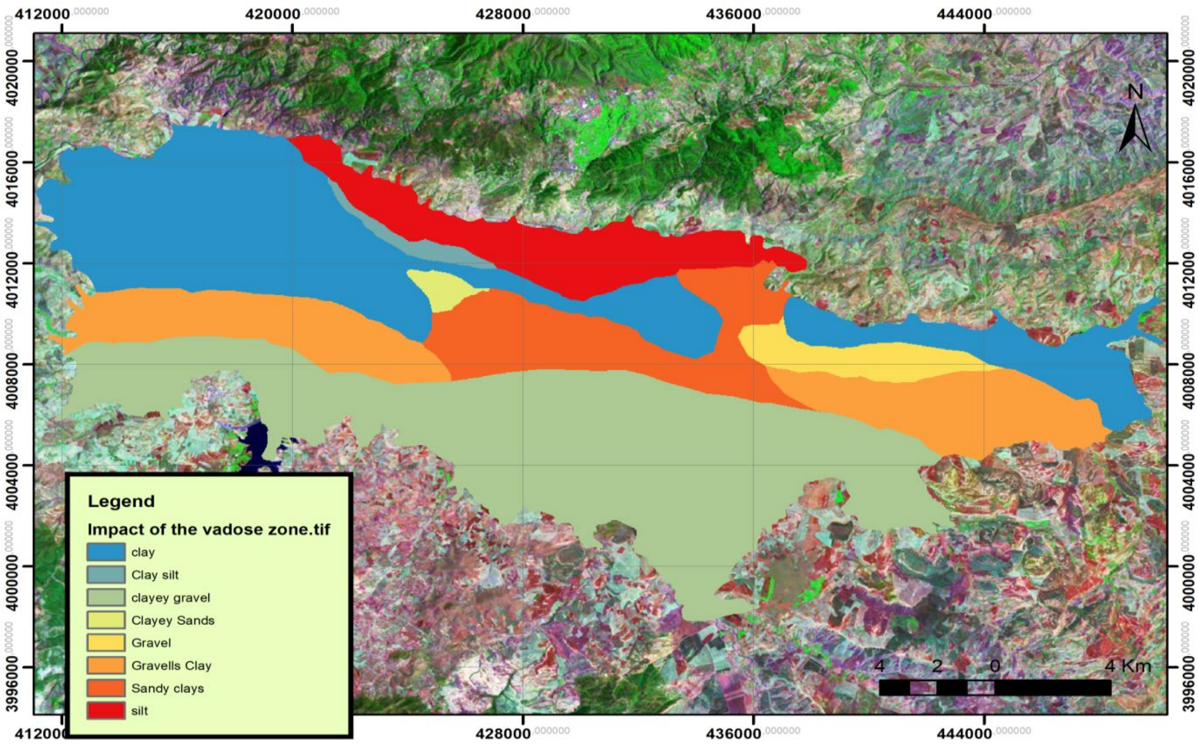



**Figure.26:** Spatial distribution of the unsaturated zone in the study area

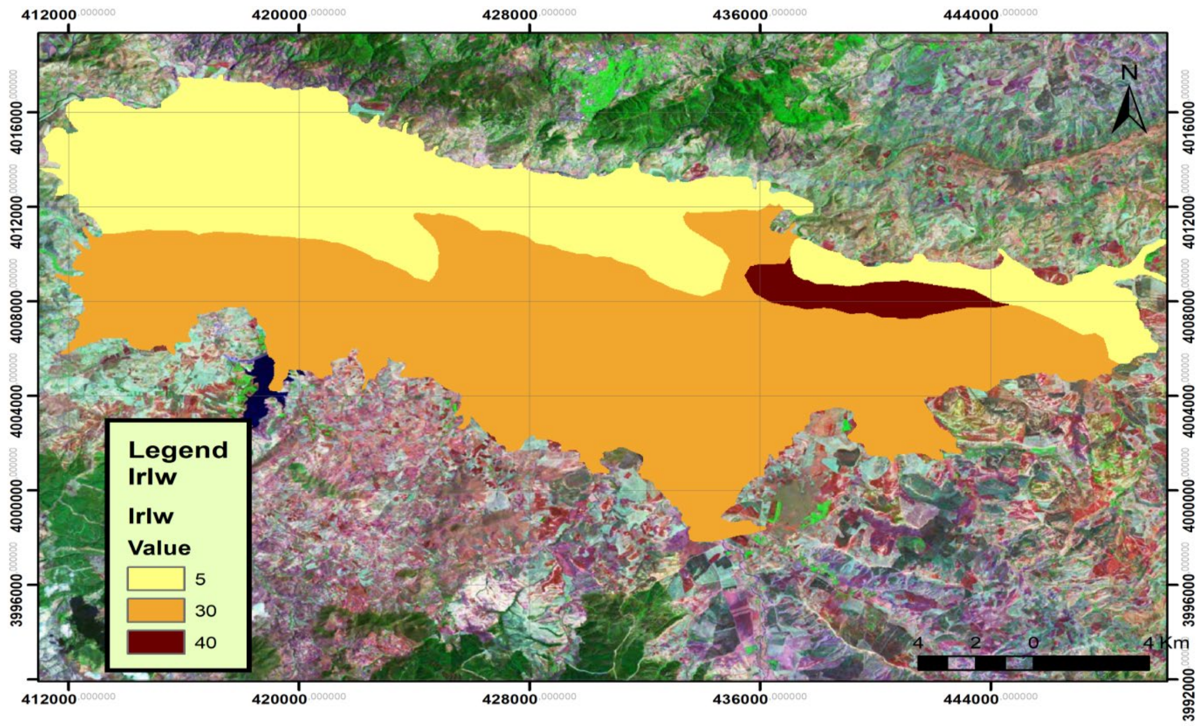



**Figure.27:** Spatial distribution of the unsaturated zone of the Study Region assigned to their rating and weight

### IV.1.1.7 Hydraulic Conductivity (C):

The hydraulic conductivity of the aquifer gives us information on the speed of migration of pollutants and their dispersion in the water table from the point of injection, at the surface, to the saturated zone and, consequently, their concentrations in the water table. The higher this parameter is, the faster the transfer of pollutants.

The values of hydraulic conductivities used for the establishment of the map of spatial distribution of this parameter have been evaluated and obtained from pumping tests poorly distributed, so for this reason we had used a combination of collection from the transmissivity map already done with that of the depths of groundwater . The hydraulic conductivities are calculated by dividing the transmissivities by the power of the water table. The values thus obtained are low to medium overall and the interpolation of these point data allowed us to establish the map of parameter C.

Three classes of hydraulic conductivity were distinguished and indexed according to the DRASTIC model. A class of high values (40-81 m/d) located in the central part of the plain between Khemis Miliana and Sid Lakhdar and in the East near the town of Djendel in the upstream part and which represents 14% of the total surface, A second class of medium values (28-40 m / day) located at the central level between Khemis Miliana and Ain Sultane and extends from Sidi Lakhdar to the Aribs in the north and the threshold of Doui in the south west which covers 50% of the surface of our study area. The third class of low values between (19 and 28 m / day) and which covers part of the downstream area and is developed between Massine and Deurdeur which also covers 36% of the area studied. The scores and weights that have been assigned to the classes in Table 19.

**Table 19**. Scores and weights assigned to the Hydraulic conductivity of the alluvial plain of Khemis Miliana

| Class | Rate | Wieght |
|---|---|---|
| 21.7 -28.42 | 4 | 3 |
| 28.42 - 40.6 | 6 | |
| 40.6 - 68 | 8 | |

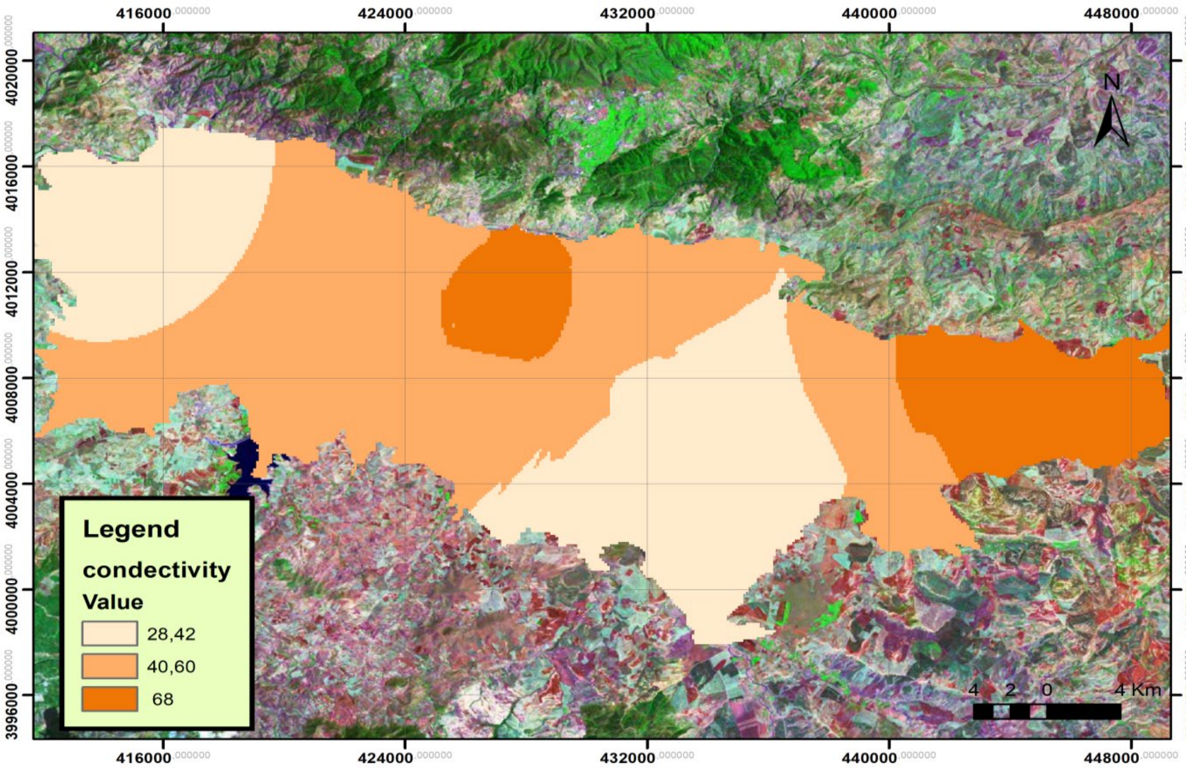



**Figure.28:** Spatial distribution of the hydraulic conductivity in the study area

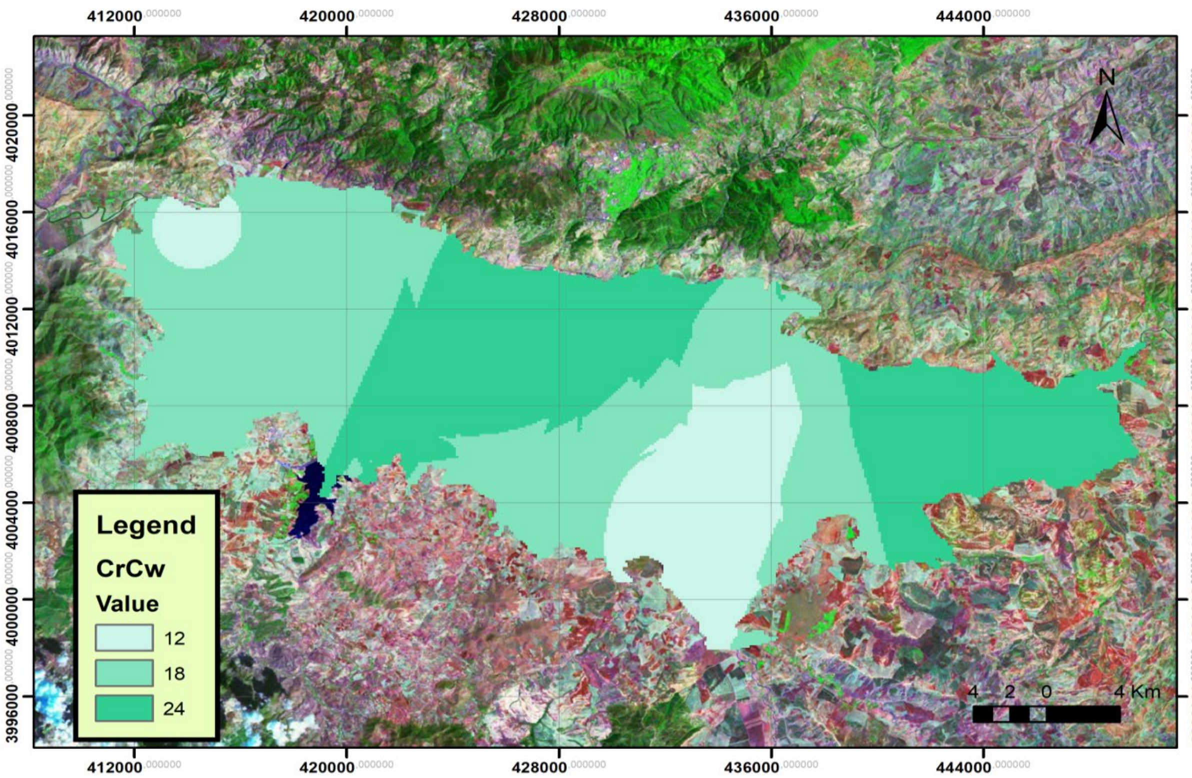



**Figure.29:** Spatial distribution of the hydraulic conductivity of the Study area assigned to their rating and weight

### IV.1.1.8 Land use (LU) :

Land use is an important human intervention that influences vulnerability assessment(Anane, Abidi et al. 2013)It could negatively impact groundwater through application of fertilizers and pesticides in agricultural land use, and through the disposal of chemical compounds in water bodies and landfills associated with industrial areas. (Anane, Abidi et al. 2013)

A land use map of the study area was obtained; the main land uses present are water body, urban and rural agricole zone; the ratings was adopted as follows, 1 for water body 7 for urban area and 9 for rural agricole zone, and the land use parameter was given a weigh of 4.

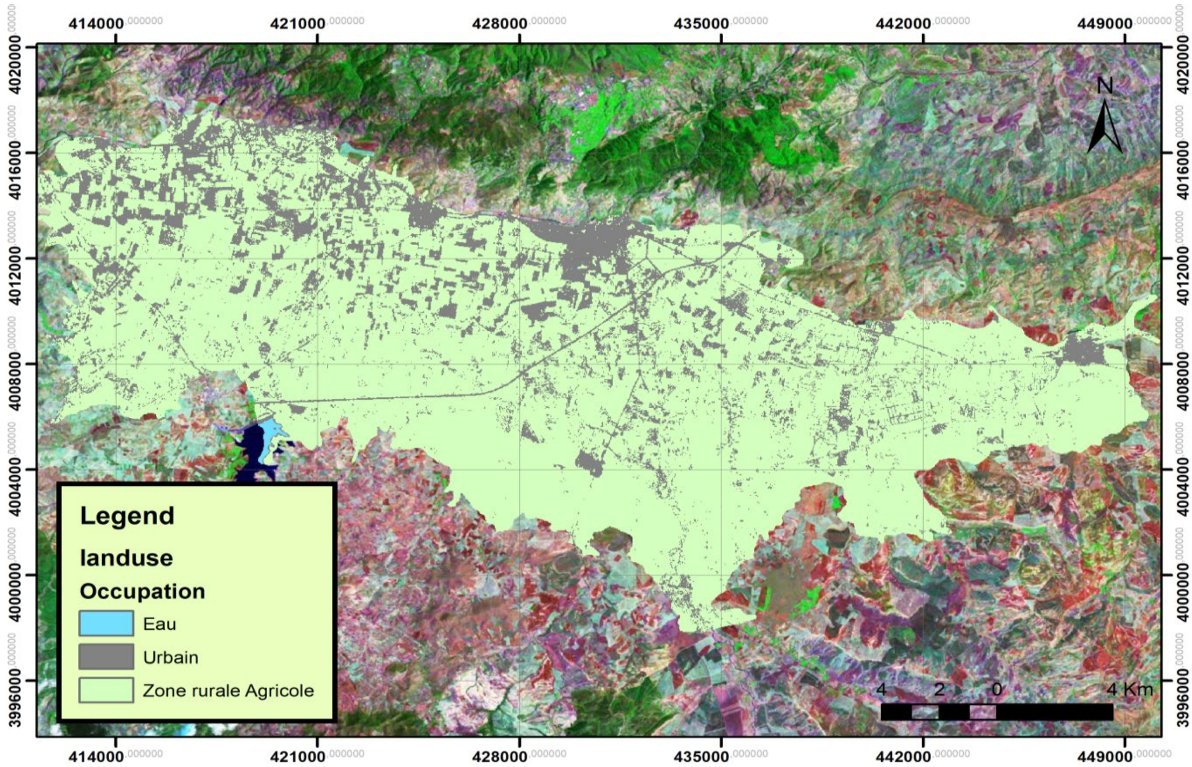



**Figure.30:** Spatial distribution of the land use in the study area

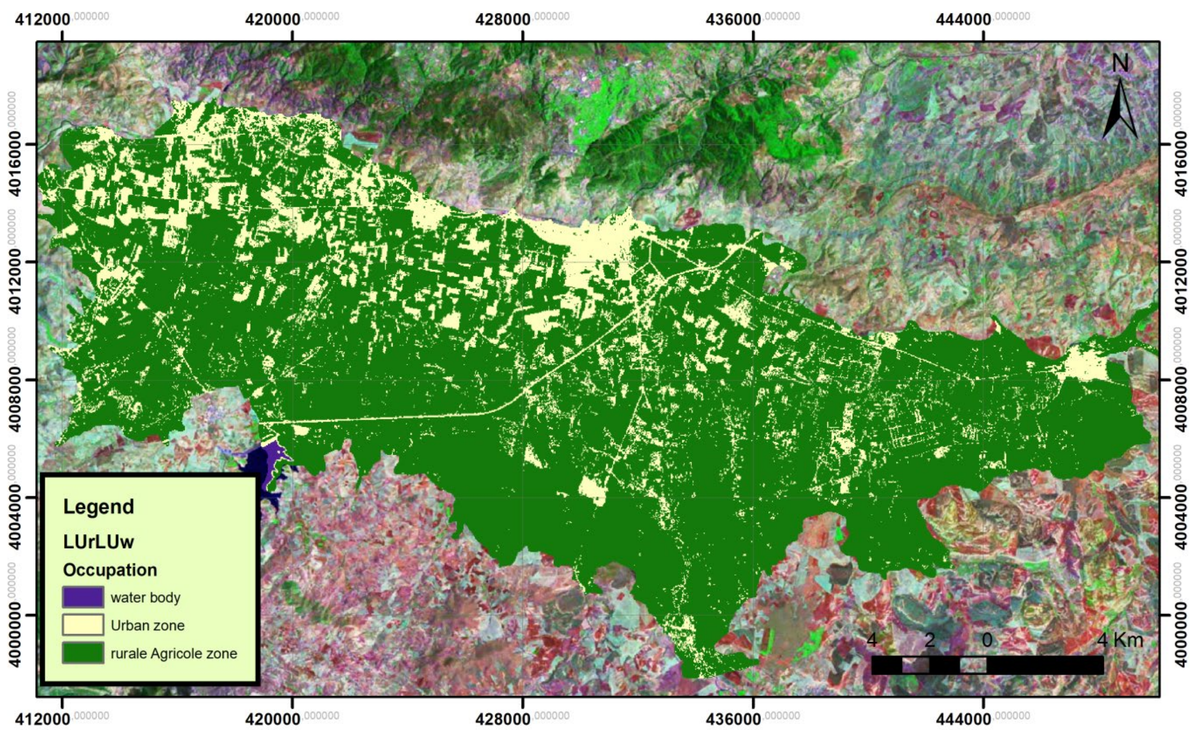



**Figure.31:** Spatial distribution of the land use of the Study area assigned to their rating and weight

## IV.1.2 Summary map (vulnerability to pollution):

First of all, it should be noted that this "DRASTIC" method was only applied to the alluvial groundwater, for which we were able to gather the data necessary for the study.

The pollution vulnerability map is a synthesis of the eight previous thematic maps. It allows us to visualize the main areas at risk, which are translated by high, or very high, vulnerability indices of the "DRASTIC" parameters.

The method used for the elaboration of the map of the intrinsic vulnerability of groundwater to pollution is carried out by eight parameters, known as Model-DRASTIC-LU mapping. Several partial index maps were developed and then overlaid, the depth of the water level, impact of the vadose zone, hydraulic conductivity, land use are the most effective parameters in relation to the net recharge, aquifer medium and soil type. The vulnerability of groundwater, map of contamination potential has been generated, (see Figure 32), the analysis of this map shows that 8% of the area is characterized by a degree of a very low vulnerability, 12% of the total area is characterized by a degree of low vulnerability, 21% of the total area is characterized by a degree of medium low vulnerability, while 33% of the area is characterized by medium high vulnerability, 6% of the area is characterized by a degree of very high vulnerability. The south-western and northern parts of the study area are characterized by a high vulnerability zone of 19%.

The major part of the plain of Khemis Miliana is characterized by a low degree of vulnerability, which represents the total surface of the plain; which dominates the Upstream part and almost all the southern part between Oued Massine and Deurdeur. We can see indices that range between 100 and 150, for the area between the city of Ain Sultan and Khemis Miliana is also affected by this degree of vulnerability.

According to the result of the final map of vulnerability, obtained by applying the DRASTIC-LU method, we note that the south of the plain and growing to the southern edges, as well as the south-western part, are the most vulnerable areas, therefore the most exposed to the risk of groundwater contamination. The groundwater vulnerability map is used as an effective preliminary tool for planning, policy and operational levels of decision-making regarding the management and protection of groundwater

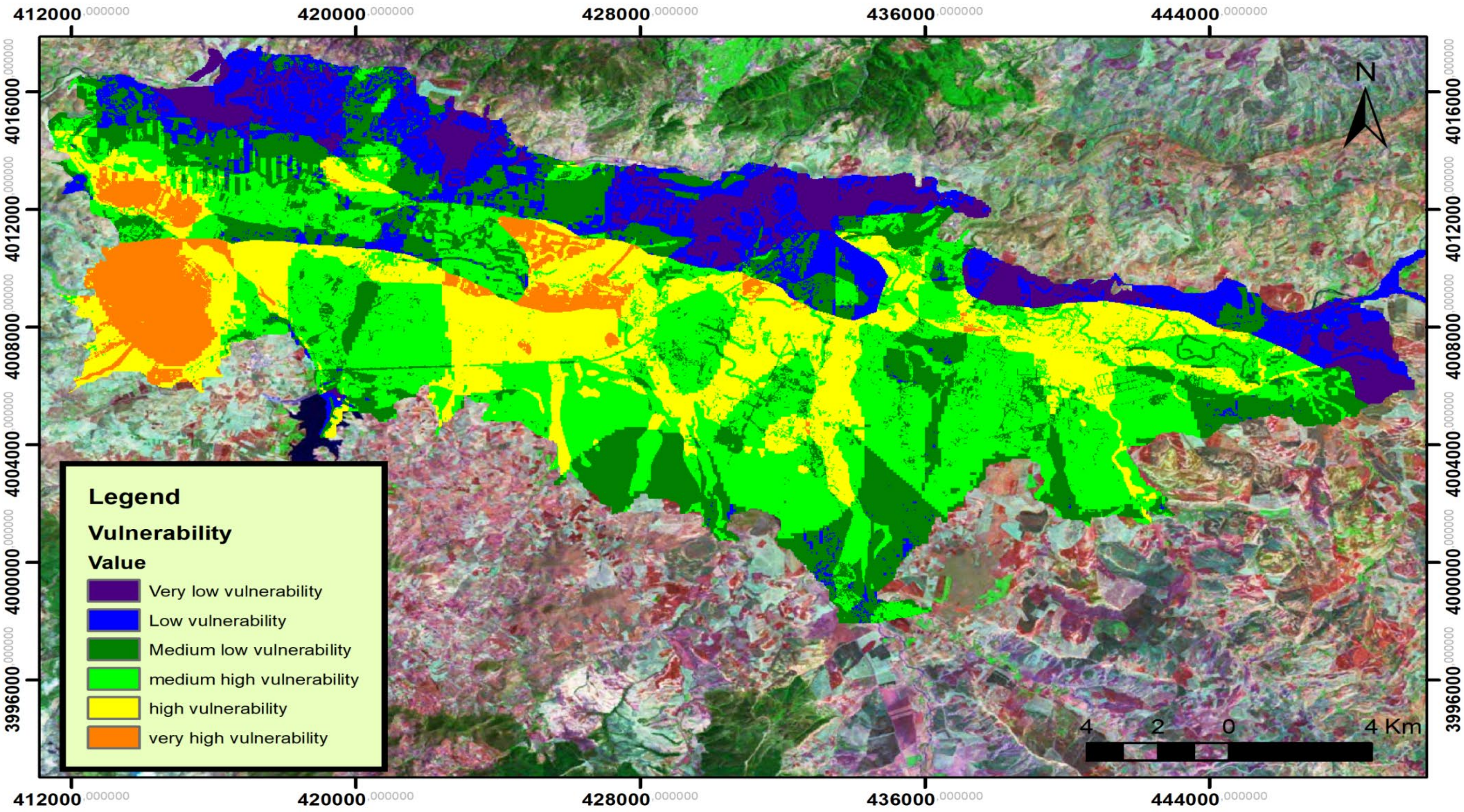



**Figure.32:** Vulnerability Map of the Alluvial Plain of khemis Miliana

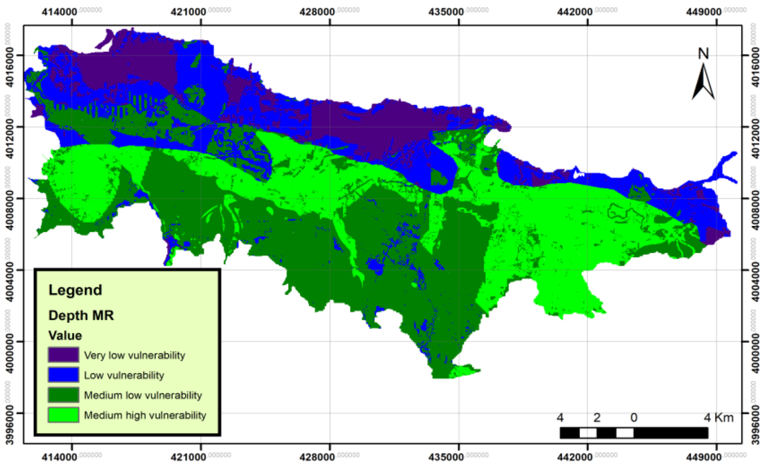



**Figure.33:** The Depth map removal

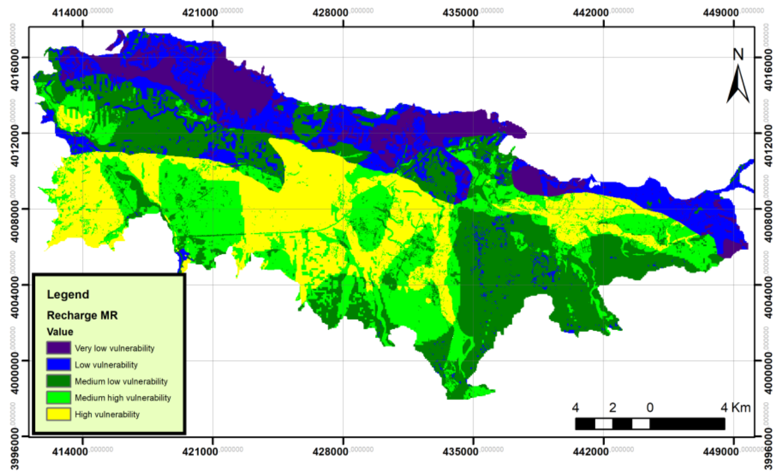



**Figure.34:** The Recharge map removal

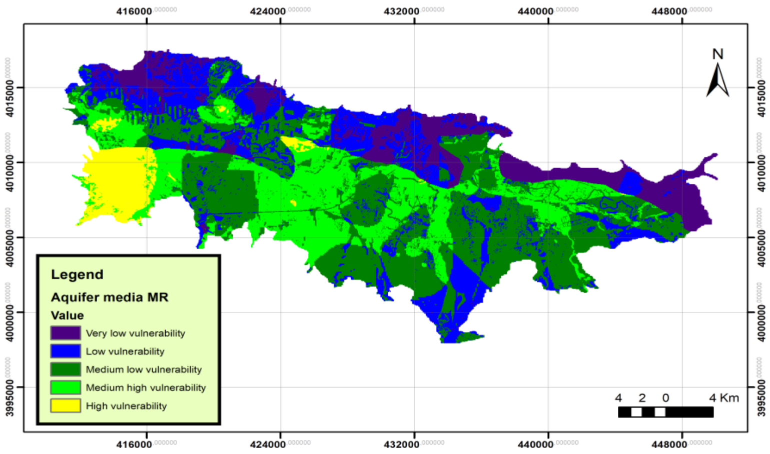



**Figure.35:** The Aquifer Media map removal

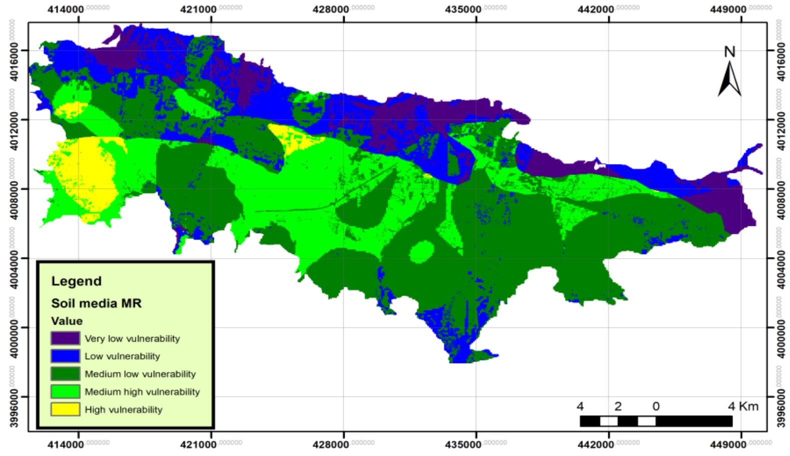



**Figure.36:** The Soil Media map removal

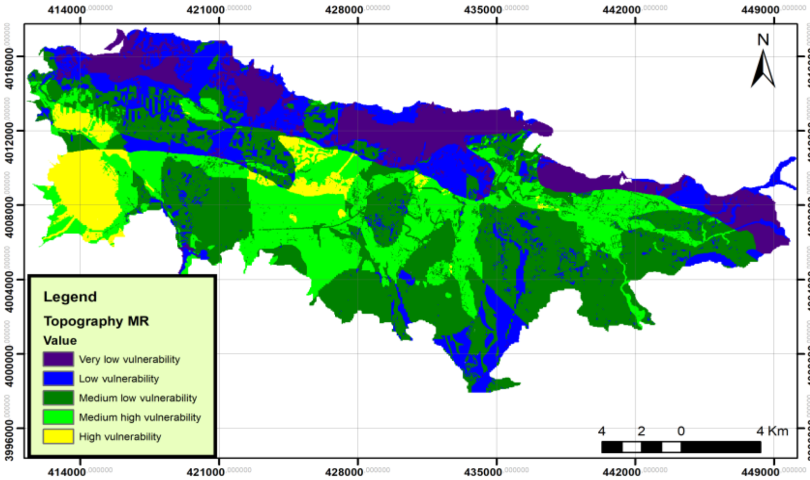



**Figure.37:** The Topography map removal

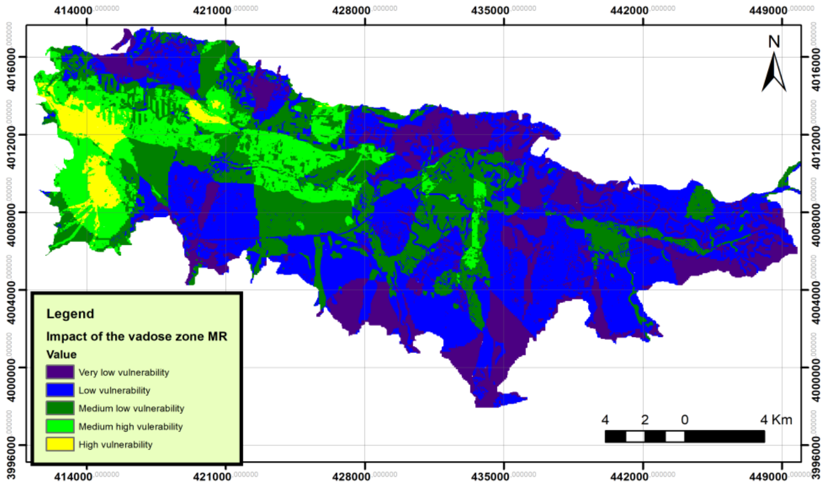



**Figure.38:** The Impact of the vadose zone map removal

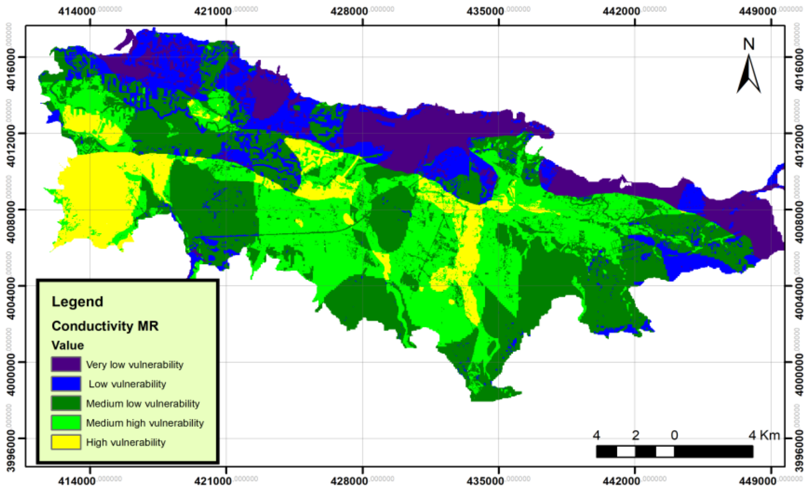



**Figure.39:** The Hydraulic Conductivity map removal

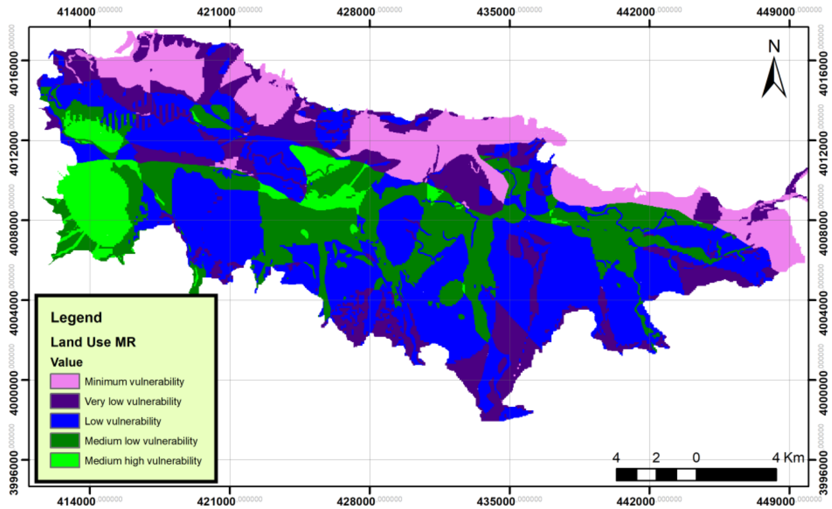



**Figure.40:** The Lans Use map removal

## IV.2 Sensitivity analysis:

Sensitivity analysis allows us to recognize uncertainty in the estimation of parameters, by observing changes in the results, while using different sets of input parameters. The sensitivity analysis indicated the most important and influential parameters to be chosen when establishing the vulnerability and risk maps for groundwater contamination .

Sensitivity analyses using the Map-removal technique based on a visual variation index, showed that, depth to groundwater, land use and impact of the vadose zone are the most sensitive variables and show a great influence,the influence is much more concentrated in the southern area; while conductivity, soil type, slope and aquifer media shows a moderate influence that is almost equal; however, the recharge parameter shows a small influence that it can be removed from the vulnerability analysis due to its tiny impact on the result model.

The results indicates that in the study area; land use and depth to groundwater should be considered more seriously when planning specific remedial measures for groundwater protection.

# General Conclusion

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Earth Sciences Department

## General Conclusion:

This study was performed using a GIS model and the DRASTIC-LU method to determine the vulnerability of groundwater in the Alluvial Khemis Miliana Plain which is located in the Upper Cheliff basin area. Seven parameter maps were prepared in a GIS environment and vulnerability classification of the plain was performed using GIS techniques.

The DRASTIC-LU Vulnerability Index was computed as between 96 and 196. Based on hydrogeological field investigations and using a quintile classification method, these values were reclassified into six classes namely very high (167–195), high (154–167), medium high (144–154), medium low (133–144), low (121–133) and very low (96–121), vulnerable aquifer areas which cover 6,19,21,34,12 and 8% of the plain , respectively.

The sensitivity analysis revealed that the intrinsic vulnerability of the study area is primarily due to the groundwater deep -depth to water table, and impact of land use because of the higher effective weight these parameters carried. The map removal sensitivity analysis indicated that the vulnerability index is highly sensitive to the removal of this parameters , and is least sensitive to the removal of the topography.

It was concluded that the final recommendation derived from the combination of DRASTIC –LU with sensitivity analysis could be used as an efficient tool for local authorities and policy makers to manage groundwater resources of Khemis Miliana alluvial plain.

# Bibliographic References

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Earth Sciences Department

## Bibliographic References :


- ❖ Alam, F., R. Umar, S. Ahmed and F. A. Dar (2014). "A new model (DRASTIC-LU) for evaluating groundwater vulnerability in parts of central Ganga Plain, India." Arabian Journal of Geosciences**7**(3): 927-937.
- ❖ Albinet, M. and J. Margat (1970). "Cartographie de la vulnérabilité à la pollution des nappes d'eau souterraine." Bull. BRGM**2**(3): 4.
- ❖ Anane, M., B. Abidi, F. Lachaal, A. Limam and S. Jellali (2013). "GIS-based DRASTIC, Pesticide DRASTIC and the Susceptibility Index (SI): comparative study for evaluation of pollution potential in the Nabeul-Hammamet shallow aquifer, Tunisia." Hydrogeology Journal**21**(3): 715-731.
- ❖ Asadi P, Ataie-Ashtiani B, Beheshti A (2017) Vulnerability assessment of urban groundwater resources to nitrate: the case study of Mashhad, Iran. Environ EarthSci 76, 41.
- ❖ Babiker, I. S., M. A. Mohamed, T. Hiyama and K. Kato (2005). "A GIS-based DRASTIC model for assessing aquifer vulnerability in Kakamigahara Heights, Gifu Prefecture, central Japan." Science of the Total Environment**345**(1-3): 127-140.
- ❖ Baghapour, M. A., A. Fadaei Nobandegani, N. Talebbeydokhti, S. Bagherzadeh, A. A. Nadiri, M. Gharekhani and N. Chitsazan (2016). "Optimization of DRASTIC method by artificial neural network, nitrate vulnerability index, and composite DRASTIC models to assess groundwater vulnerability for unconfined aquifer of Shiraz Plain, Iran." Journal of Environmental Health Science and Engineering**14**(1): 13.
- ❖ Chandoul, I. R., S. Bouaziz and H. B. Dhia (2015). "Groundwater vulnerability assessment using GIS-based DRASTIC models in shallow aquifer of Gabes North (South East Tunisia)." Arabian Journal of Geosciences**8**(9): 7619-7629.
- ❖ Elfarrak, H., M. Hakdaoui and A. Fikri (2014). "Development of vulnerability through the DRASTIC method and geographic information system (GIS)(case groundwater of Berrchid), Morocco." Journal of Geographic Information System**2014**.
- ❖ Gaaloul N, Cheng AH-D (2003**)** Hydrogeological and hydrochemical investigation of coastal aquifers in Tunisia-Crisis in overexploitation and salinization. Second International Conference on Saltwater Intrusion and Coastal Aquifers-Monitoring, Modeling, and Management. Merida, Mexico, March 30-April 2, 2003
- ❖ Hamzaoui-Azaza F, Ameur M, Chaouch R, Ben Cheikha L, Gueddari M, Carrillo-Rivera JJ (2020) Assessment of groundwater quality based on GIS and

geochemicalmethods: coastalaquifer of Bouficha (North-EasternTunisia). J CoastConserv 24, 45.

- Machiwal, D., M. K. Jha and B. C. Mal (2011). "GIS-based assessment and characterization of groundwater quality in a hard-rock hilly terrain of Western India." Environmental Monitoring and Assessment**174**(1): 645-663.
- McLay, C., R. Dragten, G. Sparling and N. Selvarajah (2001). "Predicting groundwater nitrate concentrations in a region of mixed agricultural land use: a comparison of three approaches." Environmental pollution**115**(2): 191-204.
- Mohammadi, K., Niknam, R. and Majd, V.J., 2009. Aquifervulnerabilityassessmentusing GIS and fuzzy system: a case study in Tehran-Karaj aquifer, Iran. *EnvironmentalGeology Journal*, 58 (2), 437–446.
- Napolitano, P. and A. Fabbri (1996). "Single-parameter sensitivity analysis for aquifer vulnerability assessment using DRASTIC and SINTACS." IAHS Publications-Series of Proceedings and Reports-Intern Assoc Hydrological Sciences**235**(235): 559-566.
- Plymale, C. L. and M. Angle (2002). "Groundwater pollution potential of Fulton County, Ohio." Ohio Department of Natural resources division of water, water resources section, Groundwater pollution potential report no**45**.
- Sartaj, D. M. (2017). Groundwater Vulnerability Assessment Using a GIS-Based Modified DRASTIC Model in Agricultural Areas by Narges Gheisari Supervisors