Middle-East Journal of Scientific Research 23 (5): 808-816, 2015
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2015.23.05.22143

Assessment and Vulnerability Mapping to Pollution of the Karstic Groundwater of Saïda's River Valley (Algeria) by the DRASTIC Method

[1]*M. Boudjemaa,* [1]*A. Labani,* [1,2]*Y. Bouchikh,* [1]*M. Terras,*
[1]*G. Kerrache and* [1]*N.N. Adda-Hanifi*

[1]Environment and Water Resources Laboratory; University of Saida, Algeria
[2]INRAA, Division agrosystem Ouest and steppe, Sidi Bel Abbes

Abstract: The alteration of the Saïda's mineral waters quality is due to several factors mainly anthropogenic as water treatment plant dysfunction located in upstream watershed of the river, the practice of intensive agriculture using fertilizers and pesticides and the releases of the industrial zone. This situation, source of serious public health requires care through the development of a vulnerability map. It is a valuable document for all concerned land managers since it is based on controlling of karstic groundwater vulnerability in the valley of the river by the application of the method 'DRASTIC'. The main objective sought is the sustainable protection of groundwater resources and prevent their contamination.

Key words: Vulnerability · Pollution · Ground-water · DRASTIC · Saida

INTRODUCTION

The region of Saida shelters a significant groundwater and surface water resources; these waters are solicited for the purpose of water supply, including agricultural and industrial economic activities. The mineral water called "Saida" is known both regionally and nationally with their physicochemical quality and remains dependent on these resources. Geological facies of these waters is due to the karstic subsoil nature. The infiltration rate of water into the karst is quite fast and there lies relatively for a short time, the karst is very vulnerable to pollution [1].

The valley of Saida's river was the subject of several studies that have highlighted its vulnerability [2]. It is in this context and in order to a better understanding, that vulnerability maps are a synthesis of the lithological, structural and hydrogeological knowledge of an area, they identify areas where the risk of groundwater contamination is the most important.

Vulnerability maps are a valuable tool to manage and develop a territory with the goal of protecting groundwater resources and prevent their contamination.

Presentation of the Study Area

Location: The study area is located in the Tellian highlands; it is an agro-forestry-pastoral region [3]. It belongs to the watershed of Saida's River, which is part of the Macta watershed (Fig.1).

The structure of the watershed of Saida's River is a notched valley from south to north (Fig. 1) except the northernmost portion where the direction is NW-SE. The watershed surface is 621.2 Km^2 and the perimeter is estimated at 131,7 km.

Geological and Hydrogeological Aspects: The mountains of Saida are a large structural plateau, where carbonate formations of the Bajo-Bathonian forms the top strength member (Fig. 2). Rocks are mainly dolomites and highly karstified limestones [2]. They are covered by the thick training "clayey sandstone" of the Callovo-Oxfordian at the valley of the Saida's river (Fig. 3) and in some places, by more unconsolidated recent formations (Quaternary, Plio-Quaternary and Neogene).

The Karst of surface is represented mainly by dolomite, which are plentiful and give birth to penetrable and spectacular funnels as Ouled Amira cave and Slouguia cave. At the bottom of the dolomites funnel,

Corresponding Author: A. Labani, Environment and Water Resources Laboratory; University of Saida, Algeria.

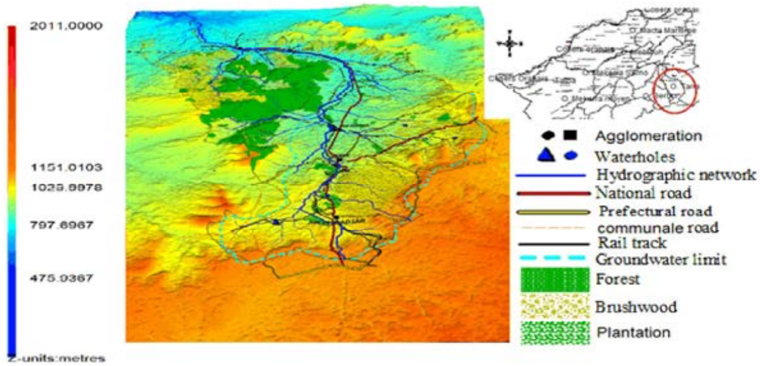


Fig. 1: Location of the watershed of the Saida's River (Saida's DTM).

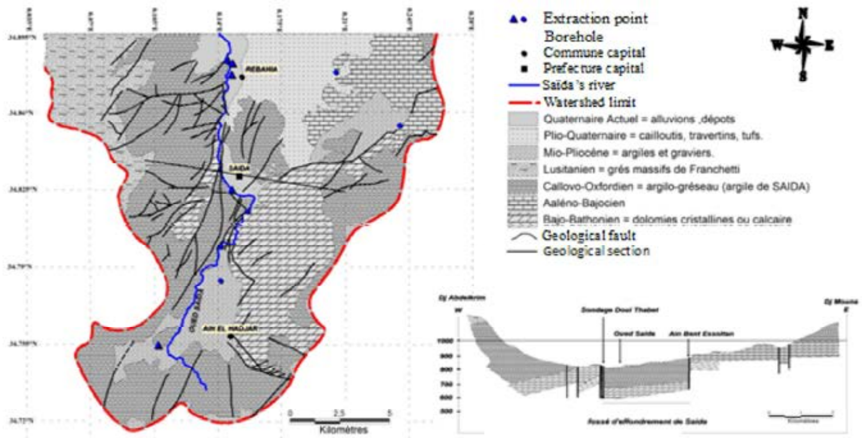


Fig. 2: Map and geological section in the region of Saida [2].

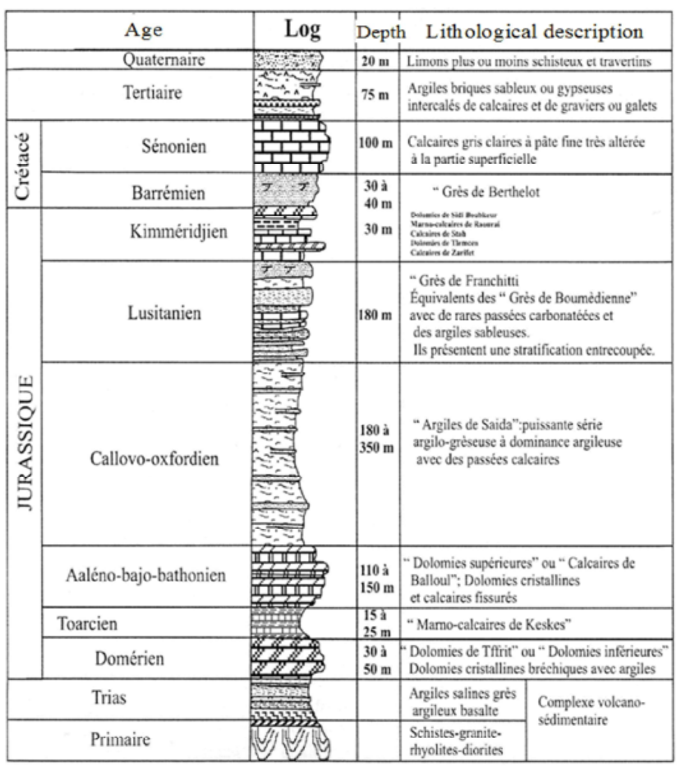


Fig. 3: The stratigraphic log of Saida's mountains [2].

sinkholes were formed by developing collapse of the adjacent empty karst including Bir Hamama wells. From a hydrogeological view, the valley of Saida is characterized by the presence of two major types of aquifers that have practical interest: surface water and karstic aquifer.

The Surface Water: It colonizes the Callovo-Oxfordian and Plio-Quaternary detrital rocks. This sheet is well established in the valley of the Saida's river, which the aquifer is formed by the upper layers of Plio-Quaternary cover with part (clayey sandstone) of the training, as a common reservoir, shallow drained by several outlets as Tebouda, Ain, Ain Sidi Ali and Ain Bourached sources.

Karstic Groundwater: This aquifer is by far the most widely used for feeding agglomerations in waters, industry and for agriculture. It is subservient to the lower and medium Jurassic carbonate formations essentially constitute of dolomite and limestone resting on impermeable Triassic bedrock. This aquifer has a free part of the "plateau" and some captive part in the region of the valley of the Saida's river under the most recent Callovo-Oxfordian and Plio-Quaternary land.

MATERIALS AND METHODS

Data Acquisition: The identification of the study area as well as the evaluation of the seven parameters requires the knowledge of the geology, hydrogeology, soil science, topography and meteorology. These information are usually contained in reports or existing databases, various documents, maps on the region, served next to the seven DRASTIC parameters (Table 3).

Assessment and Vulnerability Mapping

Vulnerability Characterization and Mapping: According to [6], aquifer vulnerability is defined as a relative property, immeasurable and dimensionless, based on the assumption that the environment can provide protection to the groundwater against human impacts, particularly those caused by incoming pollutants in the subsurface environment. The Vulnerability therefore assesses the weakness of this natural protection.

The vulnerability is expressed through drawn up maps at different scales, these maps must respond to two concerns such as preventing by the localization of the sensitive areas where pollution can seriously affect the protection of the groundwater and the protection by the implementation of special accommodations (sealing of the storage and piping, etc.), of the protection perimeter of the groundwater abstraction and the networks quality.

Using the Method DRASTIC: The DRASTIC method developed in the 1980s by the NGWA (National Ground Water Association) in the United States, for assessing the vulnerability of groundwater to pollution.

In practice, each parameter was divided into intervals of significant values and was assigned a numerical increasing rating, according to its importance in vulnerability.

The acronym DRASTIC stands for the initials of seven factors determining the value of the vulnerability index [7]: The water depth (D); effective recharge (R); the aquifer materials (A); soil type (S); topography or slope (T); the impact of the aerated zone or vadose zone (I) and the hydraulic conductivity or permeability of the aquifer (C).

Table 1: Main sources and documents used for the DRASTIC parameter estimation.

DRASTIC Parameters	Information main sources
The water depth	- Geophysical prospecting in the region of Saida. - Piezometry Measuring (1991campaign).
- Effective recharge	- Climate data from the Rebahia station. - Hydrogeological study [2].
- The aquifer materials	- Geological map of Saida [4] - Geological map [5]
-Soil type	-Agro-pedological study of Saida - Pedological map of Saida scale: 1/50000.
- Topography or slope	- Saida's DTM. - Topographic Maps scale: 1/50000.
- The impact of the vadose zone	- Hydrogeological study [2]. - Geophysical prospecting in the region of Saida [4]. - Lithological sections of drill [2]
- Hydraulic conductivity	- Pumping tests. - Hydrogeological study [2].

Table 2: Weight of DRASTIC parameters [8].

Parameters	Importance (weight) of the parameter
- The water depth	5
- Effective recharge	4
- The aquifer materials	3
- Soil type	2
- Topography or slope	1
- Impact of the vadose zone	5
- Hydraulic conductivity	3

To each parameter is assigned a scale comprising intervals where a score is assigned according to the characteristic of environment. Each parameter has been classified into associated classes with scores ranging from 1 to 10. For example, over the depth of the water is great, greater the score is low. Each of the seven parameters was then multiplied by a scaling factor (Dp) sets of 1 to 5, which increases with the importance of the parameter in the estimation of vulnerability.

The DRASTIC vulnerability index denoted I_D was determined. It describes the degree of vulnerability of each hydrogeologic unit. I_D was calculated by summing the product of the rating parameters by the importance (weight) of the corresponding parameters according to the equation:

$$I_D = Dc \times Dp + Rc \times Rp + Ac \times Ap + Sc \times Sp + Tc \times Tp + Ic \times Ip + Cc \times Cp$$

where D, R, A, S, T, I and C are the seven parameters of the DRASTIC method, "p" is the importance (weight) of the parameter and "c" the rating associated.

The importance (weights) of the DRASTIC method parameters used is those defined by [8]. These values are represented in Table 2. Tab. II.

The hydrogeological units delimitation is the first step of the DRASTIC method. This delimitation is made from a set of directly or indirectly characteristics linked to the infiltration and water flow from the surface to the interior of the aquifer.

The vulnerability of each hydrogeological unit is proportional to the characters of its own, in addition, the same unit can be subdivided into several sub-units according to the spatial variation of various parameters dictated by the DRASTIC method.

The design of the hydrogeologic units for the development of the pollution vulnerability map of the karstic groundwater of Saida's river, was conducted on a regular squared grid of 1 km × 1 _km. The resulting grid contains 245 pixels, for a total of 245 km^2 treated area (at the watershed of Saida's river level).

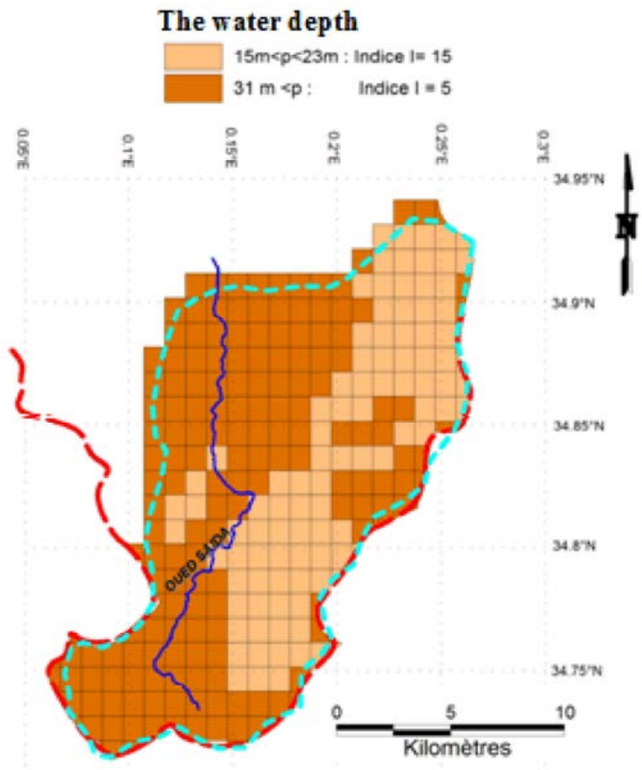
The mesh is in a kilometric order, it is a large area where the available maps are with small scale (1/50000). The seven cards are obtained by digitalizing of the existing maps, this method has developed thematic maps for each parameter of the DRASTIC method (Fig. 4).

The Vulnerability Map Using: For each of the seven parameters considered, a thematic map is made on which are delimited areas according to intervals rating determined by the system DRASTIC. The superposition of the seven thematic resulting maps gave the final map of groundwater pollution vulnerability (Fig. 5), the calculated DRASTIC index ranges between 82 and 181.

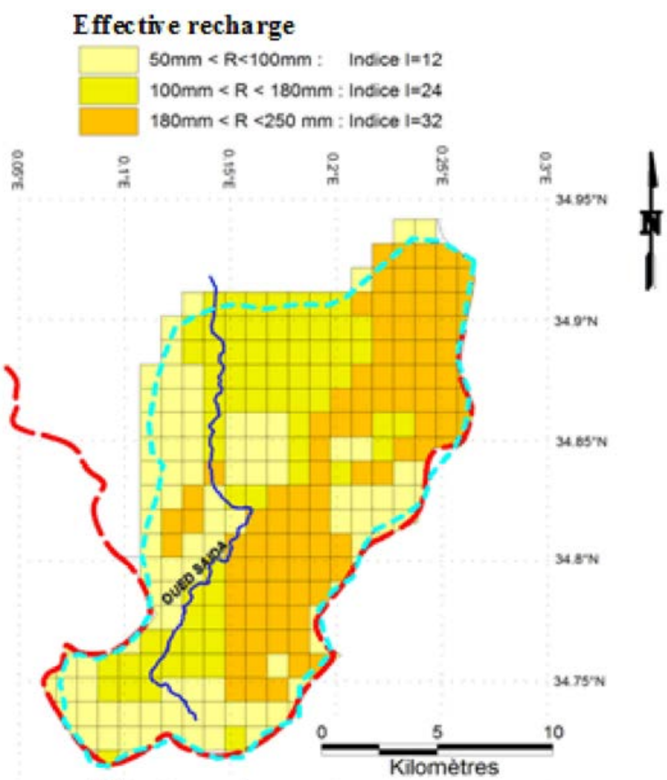
The application of this method to study Saida's karstic groundwater allowed us to discriminate two main areas with high vulnerability. The first is located in the South-eastern part and the northeastern part of the watershed where the vulnerability index reached a value of 181, the first is characterized by karstic outcrops east of Ain el Hajar until Ain Zerga, through the gorges of the old Saida, with the presence of large diagonal fault, adding the presence of high permeability soil associated with low depth of the water and the high recharge which favor conditions to increase the vulnerability to pollution of the aquifer by agricultural activity. As for the second zone, located near the city of Saida until Rebahia, it is characterized by the existence of a fault southbound north at the river of Saida, in addition to outcrops of dolomite formations very karstified facilitating pollution.

The moderate vulnerability zone where the DRASTIC index is $100 < I < 150$, is located to the north of the watershed, to the west and north of the city of Rebahia and south-west of the watershed. This area is marked by outcrops of the Plio-Quaternary.

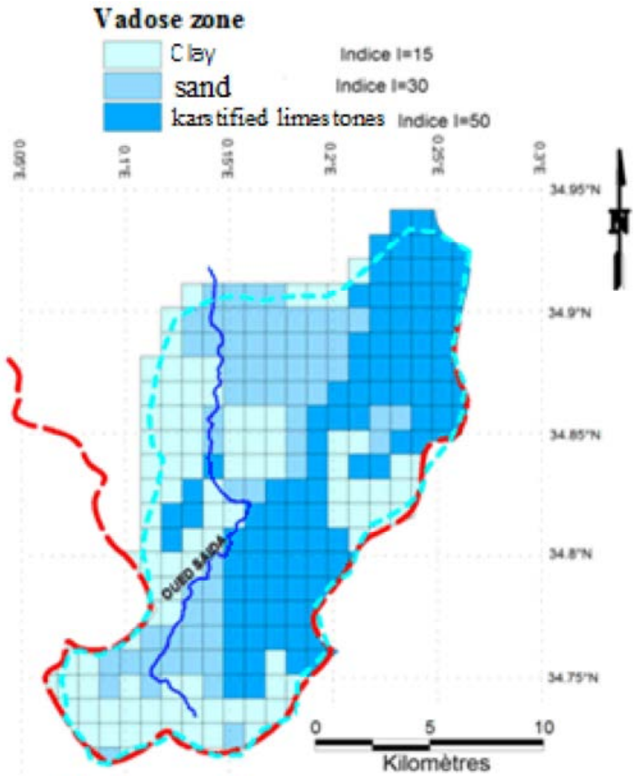
The low vulnerability zone ($1 < 100$) are generally observed in areas where the vadose zone is composed of clays that are an impervious formations.



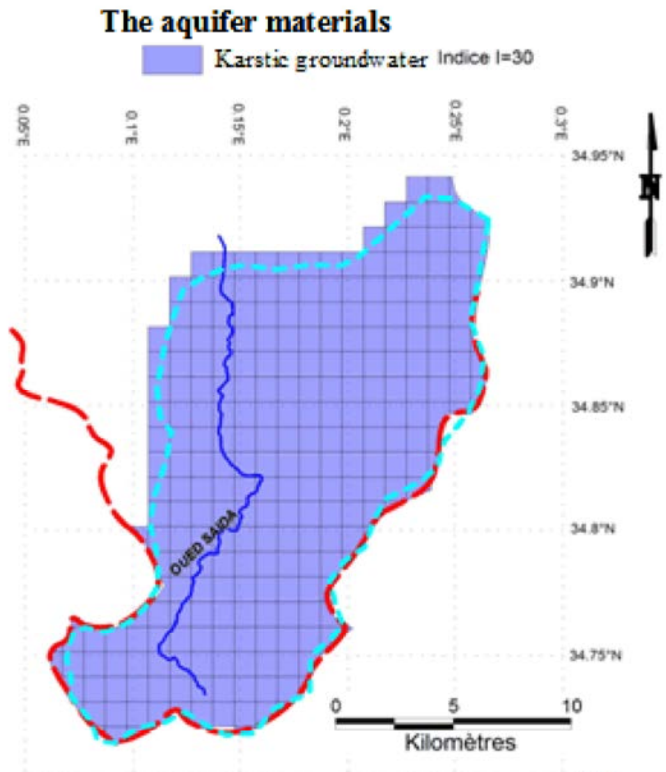
Isobaths of the water depth map



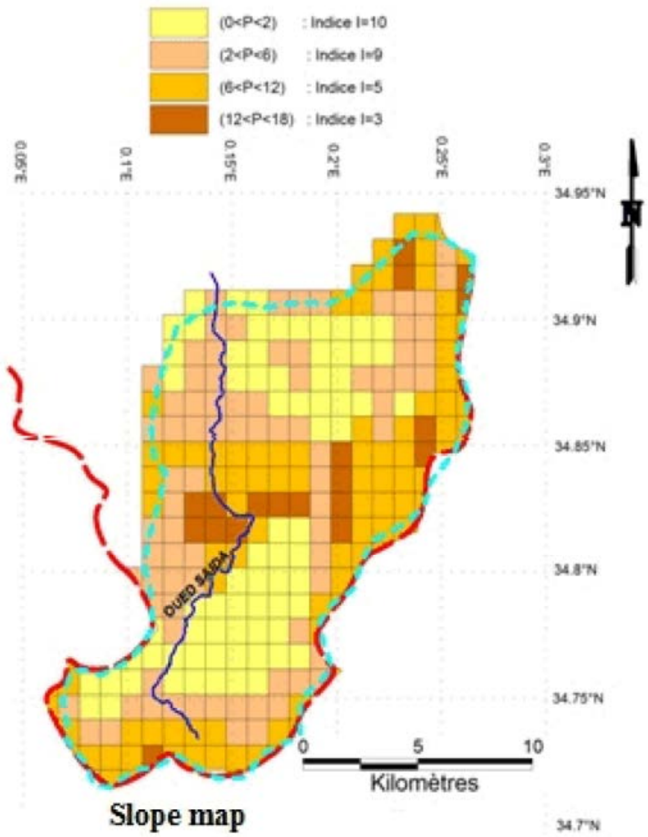
Effective recharge map

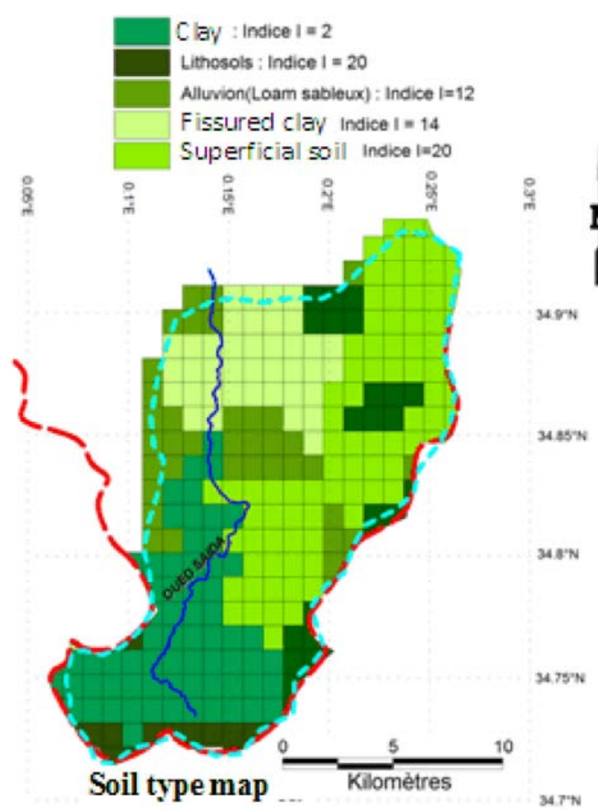


Vadose zone impact map



The aquifer materials map


(0<P<2) : Indice I=10
(2<P<6) : Indice I=9
(6<P<12) : Indice I=5
(12<P<18) : Indice I=3
0.05°E
0.1°E
0.15°E
0.2°E
0.25°E
0.3°E
34.95°N
34.9°N
34.85°N
34.8°N
34.75°N
34.7°N
N
OUED SAIDA
0 5 10
Kilomètres
Slope map


Clay : Indice I = 2
Lithosols : Indice I = 20
Alluvion(Loam sableux) : Indice I=12
Fissured clay Indice I = 14
Superficial soil Indice I=20
0.05°E
0.1°E
0.15°E
0.2°E
0.25°E
0.3°E
34.9°N
34.85°N
34.8°N
34.75°N
34.7°N
N
OUED SAIDA
0 5 10
Kilomètres
Soil type map

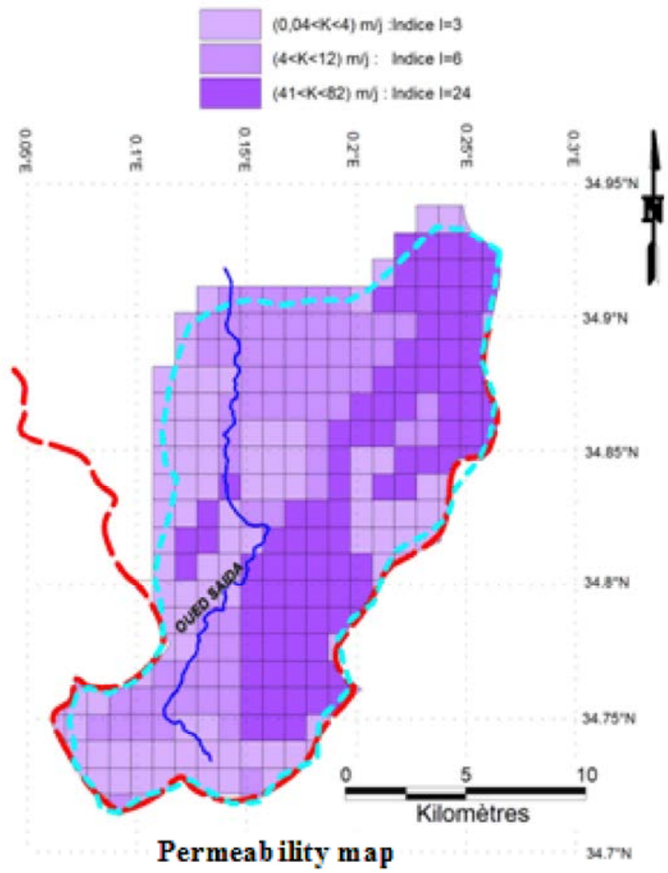


Fig. 4: The DRASTIC seven index maps.

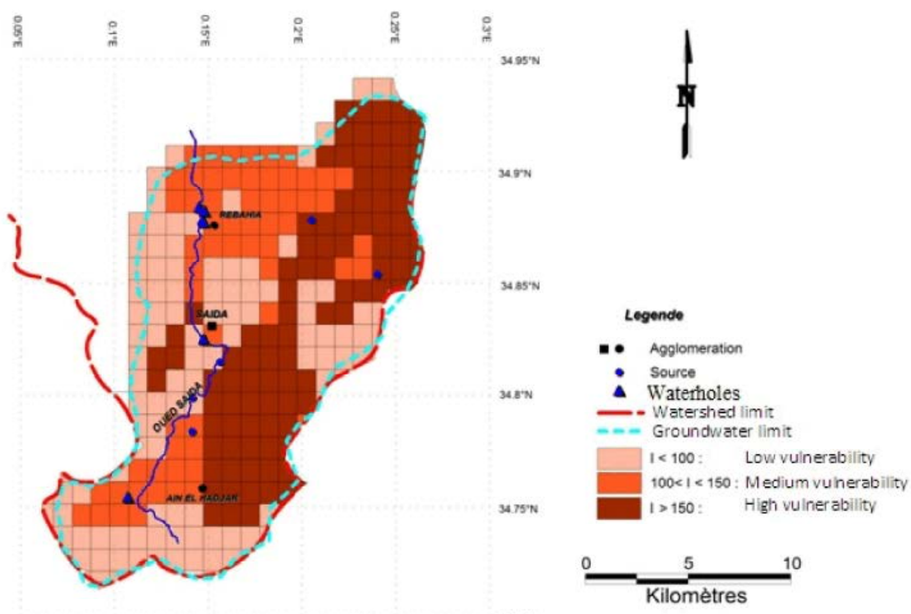


Fig. 5: Vulnerability to pollution map of the karstic groundwater of Saida.

CONCLUSIONS

The karstic waterground pollution causes are many and varied, the most famous are those related to human activity, including:

- A high urbanization with high consummation of water, producing a considerable quantity of waste water piped to the river of Saida that is it main outlet.
- An industrial zone located on the groundwater and near the fault, discharges its effluents into the river of Saida.
- Heavy use of fertilizers and pesticides in agriculture where trickle irrigation dominates.
- An implementation of the public dumps on dolomitic land.

The realization of the vulnerability map and the assessment of water quality of the water in the valley of Saida's river by application of the DRASTIC method confirm the predisposition of this area to pollution particularly from a human activity.

From the superposition of index maps, we have achieved the map of vulnerability to pollution of Saida's karstic groundwater which highlights two vulnerable areas; a south-east, north-east of the watershed and the second in the Saida-Rebahia urban zone.

The presence of these high vulnerability zones could be justified by the existence of large areas of refills which must be associated to sectors with shallow groundwater and permeability that characterizes this region.

Mapping the vulnerability to pollution of the groundwater can then be used to develop guidelines for land development schemes taking into account the preservation of these resources. It should theoretically conditioning the land use plans or at least be able to target areas where drastic measures of protection should be adopted.

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