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Evaluating groundwater pollution and assessing the vulnerability. Case of massive dune of Bouteldja, Algeria

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Key words: Groundwater pollution, Vulnerability drastic, Susceptibility index, Quality index, Massive dune of Bouteldja.

Abstract

The applicability of DRASTI vulnerability assessment method in evaluating the impact of agricultural activities on groundwater quality is tested in many areas in the north of Algeria with modest results. Intensive agriculture requires large amounts of fertilizer and water supplied by irrigation, which induces groundwater contamination by nitrates and organic parameters. Vulnerability mapping is performed with the DRASTIC method and the Susceptibility index (SI), which is an adaptation of DRASTIC. The contamination susceptibility index at a given location was calculated by taking the product of the vulnerability drastic index and the quality index. The massive dune aquifer of Bouteldja study case proposed for the application of this methodology. The study revealed that the area with high vulnerability would increase 73% and is related to hydrogeological factors as well as intensity of agricultural practices. The index map indicates that the most susceptible groundwater occupied the majority of the study area. The validity of these methods in the massive dune of Bouteldja aquifer was tested by a comparison between nitrate concentration and distribution of the vulnerability classes in the study area. This comparison has proved that the SI method is the most valid method. This is due to the introduction of the hydro chemicals parameters.

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Introduction

The intensification of agricultural activities, combined with urbanization is very fast from the massive dune of Bouteldja, resulted in a net increase of water demand, accompanied by a significant pollution into groundwater supplies (Sedrati, 2006). Some diffuse sources of pollution from human activities (agricultural activities, uncontrolled discharging, savage sanitation systems) threatening these resources (Babiker *et al*, 2005).

To recognize the need to an efficient method to protect groundwater resources from contamination, scientists and managers develop aquifer vulnerability techniques for predicting which areas are the most vulnerable (Khemiri *et al*, 2013). The assessment of groundwater vulnerability to pollution has been the subject to intensive research during the past years and a many approaches have been developed to evaluate aquifer vulnerability (Kherici, 1985, Bousnoubra, 2009, Attoui *et al*, 2014).

To preserve the groundwater resources of massive dune of Bouteldja a susceptibility indexing method (Pusalti *et al*, 2009), based on vulnerability and quality index, was proposed.

This new assessment vulnerability methodology shows the area where agricultural activities increase the potential level of groundwater vulnerability to pollution. The validity of these methods in the massive dune of Bouteldja was tested by a comparison between some pollutants concentration (Sedrati, 2006) and distribution of the vulnerability class.

Materials and methods

Study area

The region is the massive dune of Bouteldja which is situated in the extreme Algerian Northeast, between Annaba city and the Algerian-Tunisian border (Fig. 1). It extends along the Mediterranean coast, with a width of approximately 10 km and a surface of 170 Km². The massive dune of Bouteldja has an altitude of 90 m.

It has a triangular form and limited from the North by the Mediterranean Sea, from the South by the Bouteldja plain, from the West by the Mafragh river mouth and from the East by the Rosa cap.

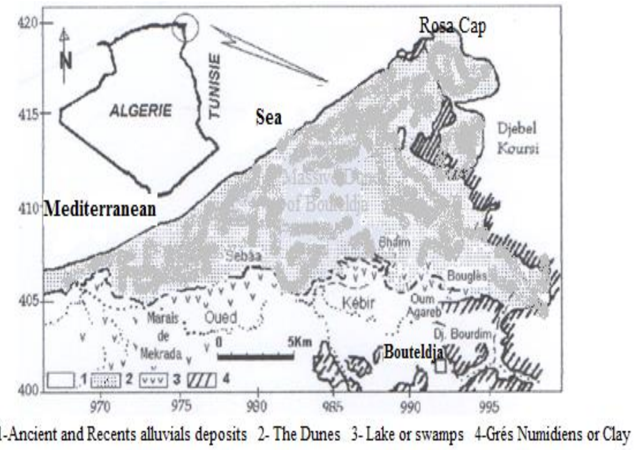


Fig. 1. Location geography and geological map of the study area (from Gaud, 1976, amended 2009).

The aquifer and the vadose zone of the massif dune region are located in Quaternary layer system which is constituted mainly by the sands formations settled on an impermeable clayey sandy substratum, with average permeability 6.10^{-5} to 10^{-4} m.s^{-1} KHERICI [1993]. The effective thickness of the sandy aquifer varies from 40 m in the East to 180 m in the West. Hence, it results in an easily infiltration of nutrients in the groundwater.

The sandy formations, locally clayey sandy constituted a free water table on the whole of the massive dune, except in the South, where the aquifer becomes semi confined. The effective thickness of the sandy aquifer varies from 40 m in the East to 180 m in the West. Taking into account the thickness of these sands and their interstitial porosity, the water reserves are appreciable and exceeded 34 Mm^3/year, but annual abstraction by pumping from more 200 wells stands at 30775m^3/day (Haied, 2015).

The groundwater supply is under threat due to an intense urban occupation as Nitrate measures are generally <10mg/l in the majority of this Aquifer, and exceed 50mg/ltoward agglomeration: Sebaa, Righia and Berrihane (Assassi, 2004; Sedrati, 2006) where one registers values largely higher than the potability standards revealing an important anthropogenic pollution. For these reasons, a new water management planning is highly required.

Materials

Numerous vulnerability modeling approaches is proposed. A comprehensive ground water vulnerability model must include parameters to describe how much a site is risky to be contaminated and how the contaminant moves from the contamination site to the aquifer. In this study, the vulnerability rating used is the Susceptibility index SI (Pusalti, 2009).

The application of these methods required the collection and processing a data, digital and mapping, for the study area. These data were processed and analyzed with different software programs: Surfer 10, Diagramme 2. This enabled us to synthesize our distributed data already translated into digital format. The final results will be translated in the form of maps representing the aquifer vulnerability to pollution.

Vulnerability assessment methodology

DRASTIC Method

This is one of the most used methods in the world. It assigns a note between 1 and 10 and a weight between 1 and 5 for each used parameter (Table 1).

Table 1. Attribution of notes for DRASTIC model parameters.

Class D (m)	Note	Class A	Note	Class S	Note	Class C (m/s)	Note
0 - 1.5		Masive shale		Thin orabsent	1	$1.5.\ 10^{-7}\ 5.10^{-5}$	
1.5 - 4	9	Métamorphic	6	Gravels	10	$1.\ 5.\ 10^{-5} - 15.10^{-5}$	2
4.5 – 9	7	Altered -Sandstone	8	Sands	9	$15.\ 10^{-5} - 33.10^{-5}$	4
9.0 - 15	5	massive limestone	6	Sandy Silts	6	$33.10{-}5 - 5.10^{-4}$	6
15 - 23	3	massif Sandsone Sand	8	Silty loam	3	$5.10^{-4} - 9,\ 5.\ 10^{-4}$	8
23 - 30	2	and gravel	10	Shales	1	$>9{,}5.10^{-4}$	10
>30	1	Karstic Limestone					
Class R (mm)	Note	Class T (%)	Note	Class I			Note
0 – 50	1	0 à 2	10	Silt and Shales			3
50 – 100	3	2 à 6	9	Shale			3
100 – 175	6	6 à 12	5	Limestones			3
175 - 225	8	12 à 18	3	Sandstones			6
>225	9	>18	1	Sand and gravels with passage silt and Shale			6
				Sand and gravels			8

In the present study the DRASTIC method, proposed by the US Environmental Protection Agency (Aller *et al*, 1987; Vrba Zaporozec, 1994) isone method to evaluate the vertical vulnerability based on the following seven parameters: Depth to water (D), net Recharge (R), Aquifer media (A), Soil media (S), Topography (T), Impact of the vadose zone (I), and hydraulic Conductivity (C). Each mapped factor is classified either into ranges (for continuous variables) or into significant media types (for thematic data) which have an impact on pollution potential. Weight multipliers are then used for each factor to balance and enhance their importance. The final vulnerability index is a weighted sum of the seven factors. The DRASTIC index (Di) can be computed using expression (1):

$$Di = Dr.Dw + Rr.Rw + Ar.Aw + Sr.Sw + Tr.Tw + Ir.Iw \ + Cr.Cw (1)$$

Where D, R, A, S, T, I, and C are the seven parameters, r is the rating value of the analyzed subarea, and w is the weight associated to each parameter.

Susceptibility Index (SI) method

The Susceptibility index (SI) with the contamination of water were calculated by taking the product of the vulnerability index *(VI)* and the quality index *(QI);*

$SI = (VI) * (QI)$Pusalti, 2009) .

The index VI is deduced by using the DRASTIC method to evaluate the hydrogeological characteristics of the aquifer. The quality index *(QI)* is calculated by basing our study on the hydrochemical classification of water. The quality index calculation procedure based on a water quality classification scheme was introduced to evaluate hydrochemical data.

The IQ is calculated on the basis of the classification proposed by Pusalti, for irrigation waters, and on that proposed by Neubert *et al*, 2008, for those intended for drinkable water supply (Table 2). The suggested susceptibility indexing method was applied to the Menderes river basin located in western Turkey (Pusalti, 2009), to Chebba Melloulich aquifer of Tunisia (Saidi *et al,* 2012) and to High Cheliff Alluvial aquifer of Algeria (Djoudarand Toubal, 2011). The susceptibility index map shows both hydrogeological and hydrochemical data related to the contamination problem including areas that should be taken into consideration during water management planning. Different DRASTIC parameters described in the section method allowed us to develop thematic maps presented in “Fig. 2”

Table 2. Water classification (Neubert *et al*, 2008, WHO ,2006).

Parameters	Drinking Water Limits				
	Class I (very good)	Class II (good)	Class III (usable)	Class IV (usable with caution)	Class V (harmful)
EC (µS/cm)	0 – 180	180 - 400	400 - 2000	2000 – 3000	> 3000
Cl–(mg/l)	0 - 25	25 - 200			
NO_3^- (mg/l)	0 – 10	10 - 25	25 - 50		> 50
SO_4^{2-} (mg/l)	0 - 25	25 - 250			> 250
Na^+ (mg/l)	0 – 20	20 - 200			> 200

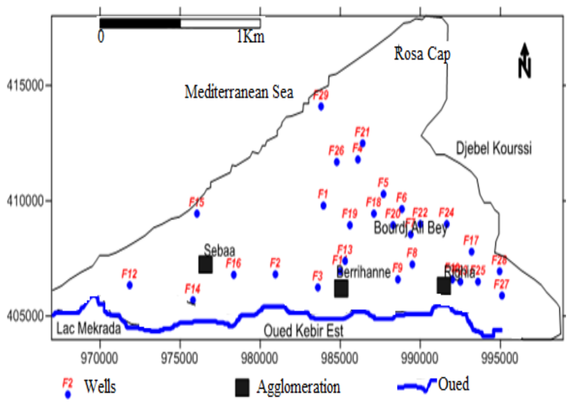


Fig. 2. Groundwater sampling location of the study area.

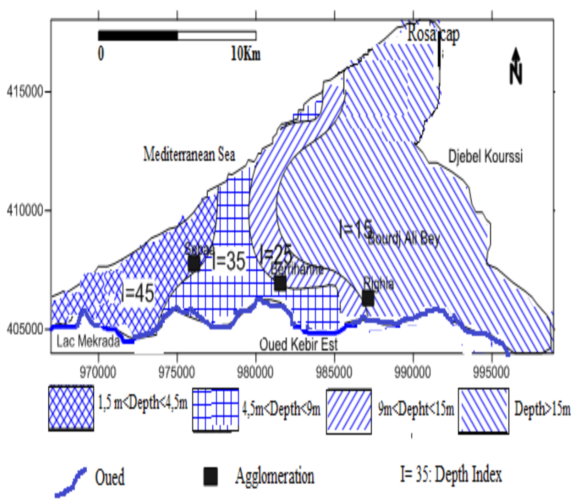
Results and discusions

Analysis of all these thematic maps and the vulnerability map showing the areas that are exposed to the greatest risk of threats occupy the majority of the study area. The combination of all these parameters was used to determine the DRASTIC index ranging from 108-176 (Fig. 3). On the basis of classification (Neubert and Benabdallah, 2003), two classes have developed to DRASTIC method (Fig. 3). They cover respectively for moderate and high class vulnerability, 27% and 73% of the study area.

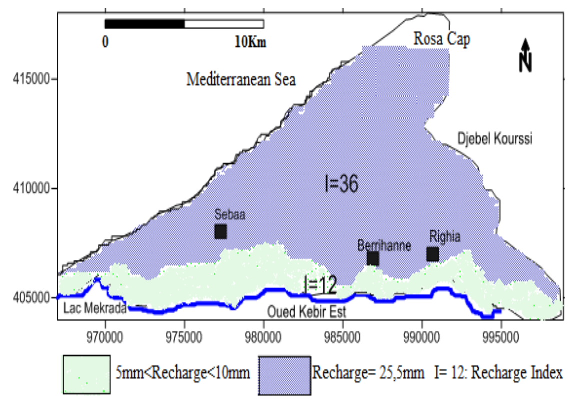
The presence of high vulnerability could be justified by the existence of areas with higher permeability (6.10^{-5} to 10^{-4}m/s) that must associate shallow groundwater table (D <15m).

The massive dune of Bouteldja is relatively a flat topography (2 to 6%), inclined to the north and opening on the Mediterranean Sea.

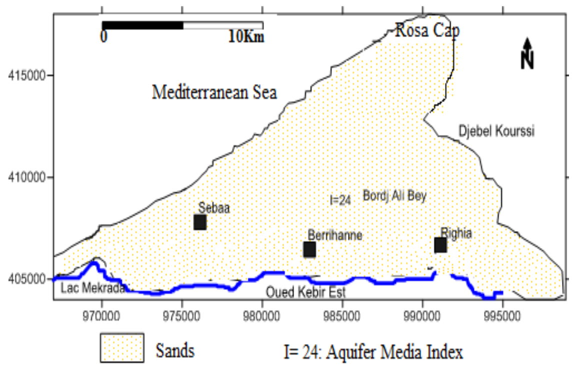
The importance of the depth of groundwater in the assessment of the vulnerability to pollution has already been underlined (Brou, 2013). However, the parameter which strongly influences the vulnerability is the lithology of the unsaturated zone and aquifer materials (Fig. 3 a, g), the both are characterized by the dominance of a single major facies: Sand in almost every of the region. The permeable material is predominant.



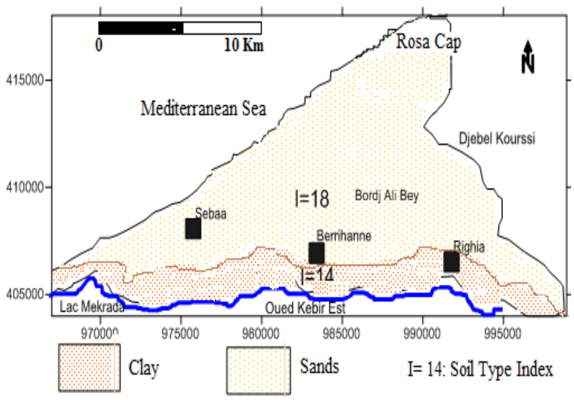
3a. Groundwater Depth D.



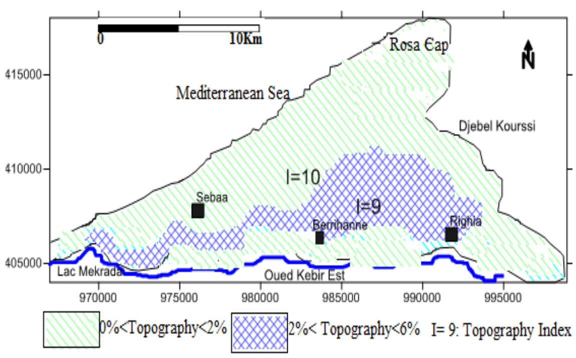
3b. Net Recharge R.



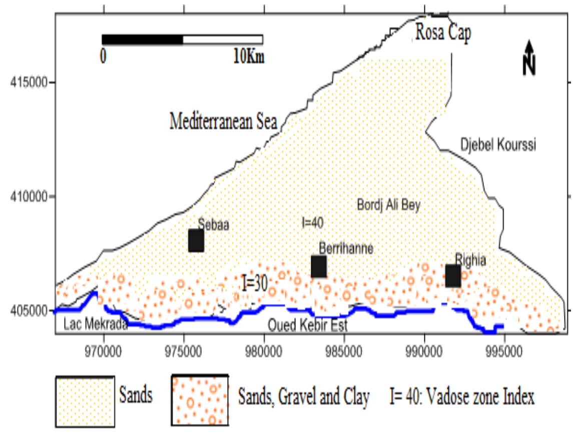
3c. Aquifer Media A.



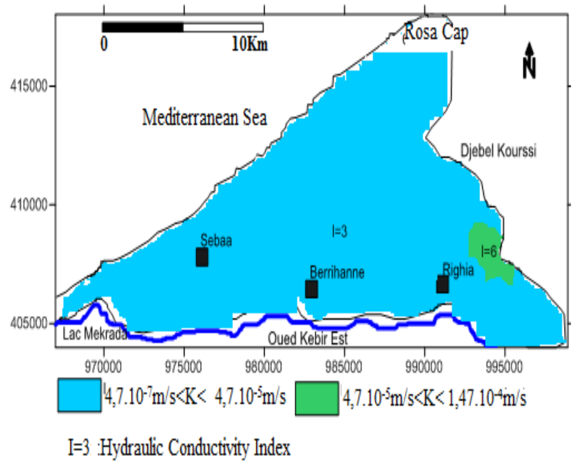
3d. Soil Type S.



3e. Topography T.



3f. Vadose zone I.



3g. Hydraulic Conductivity.

Fig. 3. Seven DRASTIC Maps to compute the vulnerability index (a TO g). Fig. (a-g.) Maps of ground water depth, net recharge, aquifer media, soil type, topography, vadosezone and hydraulic conductivity.

Indeed, the vulnerability analysis map shows that, more than 25% of areas with higher vulnerability is found in a low groundwater depth and high recharge (25,5mm/year) would be a favorable condition for increasing the vulnerability to pollution of aquifers. It results in a low capacity to attenuate the contaminants. It corresponds to the location of the urban areas. The extension of pollution is due to heavy pumping for irrigation and supply water to two city Annaba And El Taref, resulting in increased salinity (coastal region).

In fact, zones with the average vulnerability class generally found at the sand soils with a appearances gravel and clays (confined aquifer) covering approximately 73% of the study area, In terms of susceptibility index, only one class dominated has been identified from the combination of the drastic index and the quality index for drinking water (Fig. 4-5).

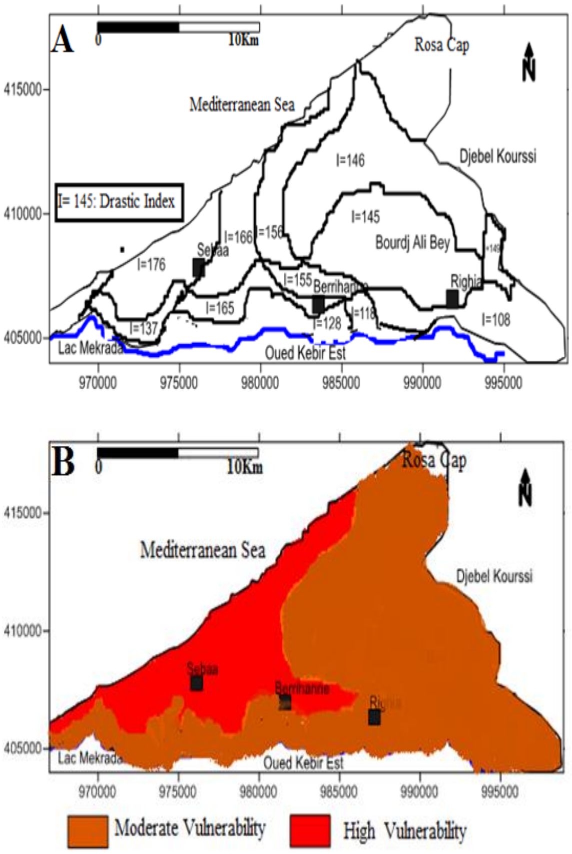


Fig. 4. Map of DRASTIC index (A) and groundwater Vulnerability (B).

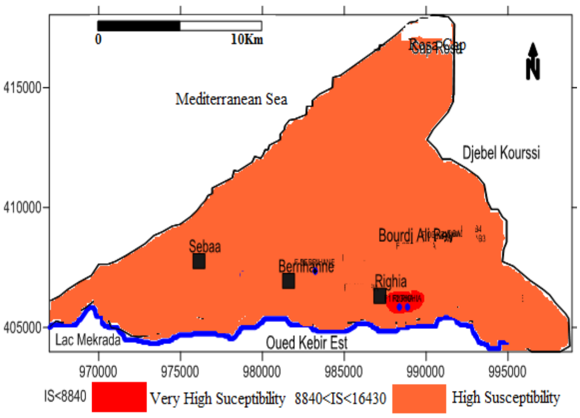


Fig. 5. Drinking water susceptibility index of the Massive dune of Bouteldja.

This is of high water susceptibility index (IS> 8840), As a consequence, this area reveals a high vulnerability. these results thus reinforcing the hypothesis of pollution by Sulphates, Sodium, Nitrates and Chlorides in excess groundwater of massive dune of Bouteldja, because it coincides with a sands, and activities which are hazardous to groundwater such as agricultural (which applies fertilizers and pesticides abundantly) have no proper sewage treatment facilities and the insufficiency or the inexistence of canal evacuation in the majority of towns (Stigter *et al*, 2006), or by the low rate of connection to the cleaning up network. Analyses of BDO_5 (Sedrati, 2006) revealed contents exceeding 5mg/l; thus supporting the preceding observation, and rather confirms the urban origin.

The vulnerability of the dune aquifer towards to possible surface contaminants remains to define and ameliorate by studies in the transfer parameters and organic pollution parameters in the unsaturated zone, the study enabled to definite two zones of pollution risk. At present, the high vulnerable region reveals highly Nitrates contents directly due to the agglomerations activities effect.

The establishment of perimeter protection (Sadoune, 2012) is not sufficient to ensure effective security; it must be complemented by the establishment of an overall plan drainage of sewerage systems and by the construction of stations effluent treatment in urban areas (Bousnoubra, 2009).

Conclusion

The use of both vulnerability data and quality index one in a GIS environment proved to be a powerful tool for the groundwater management. The combining Drastic and susceptibility index show that groundwater in massive dune of Bouteldja is characterized by two classes as follow: moderate vulnerability ranked groundwater areas dominated the study area (≈73%), which occupy more half of the study area, while (>25%) of the massive dune of Bouteldja is higt groundwater vulnerability.

The water susceptibility indexes show a high water drinking quality, covering the majority of the study area. Indeed, there is a very high similarity between the more hazardous pollution zones and the areas with harmful water quality; the susceptibility map prepared by this method therefore reflects the reality.

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