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Contribution of GOD and DRASTIC methods to the estimation of vulnerability to pollution of the Boumaiza alluvial groundwater (North-East Algeria)

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Abstract

The plain of Boumaiza is an agricultural region covering 88.8 km² and contains an alluvial aquifer considered as the only and main underground water reserve. This reserve plays a crucial role for the socio-economic and agricultural development of the region. As a result, a study on the vulnerability of the Boumaiza alluvial water table to pollution was carried out in order to protect this resource. The application of GOD and DRASTIC methods for indexing and weighting environmental factors required the implementation of a Geographic Information System, using ArcGIS 10.3 software. The analysis of the results found by the application of the two methods GOD and DRASTIC showed a spatial distribution of two classes of vulnerability. GOD with a low class and the other average covering respectively 20.5% and 79.5% of the total area with as determining factors the depth of the water body and the unsaturated zone. The homogeneity of the third parameter representing the type of slick seems to have a limited influence. DRASTIC also stands out with two classes of vulnerability, one strong with 97.9% and the other very strong with only 2.1% of the entire region. The determining factors for this method are the depth of the water body, recharge, the unsaturated zone of the aquifer and the slope. Generally speaking, the result shows that this slick is characterised by a fairly significant vulnerability to pollution. The catchments located in the plain according to their uses (AEP, agricultural or industrial) require close protection perimeters essential and remote if the threat of contamination is proven.

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Introduction

The preservation of the Boumaiza alluvial plain's underground resources is a vital environmental and economic challenge in a global context of climate change. The growing demand for water as a result of population influx and the economic expansion of the region can lead to degradation of groundwater resources if they are chronically overexploited and exposed to different sources of pollution. The latter is due to the intensity of industrial activity on the one hand (Ben Amor Cannery, Bona Soft Drink Complex, ONAB, Brickworks, Hdjar Soud Cement Works) which can generate pollution from industrial raw wastewater discharges. On the other hand, the agricultural vocation that characterizes the Boumaiza region can generate diffuse pollution through the use of chemical fertilizers, pesticides and herbicides. These human-related activities, mainly, are intensifying and limiting the use of this precious natural resource. As a result, the development of pollution vulnerability maps for the Boumaiza alluvial plain can guide regulators to ensure better management and adequate responses in the event of observed contamination.

In this context, studies on the vulnerability of aquifers allow the delineation of potential areas at risk of groundwater contamination and help define criteria for land use in target areas and prevention of pollution threats (Nouacer *et al,* 2004; Sedrati *et al,* 2016 a, b). According to Foster *et al.* (1993), groundwater contamination occurs when the load of contaminants on soil or leachate generated by urban, industrial, agricultural or mining activities is not adequately controlled and some components exceed the natural attenuation of subsoil capacity and cover layers. The development of vulnerability maps using indexed methods has become increasingly used worldwide over the last three decades. Examples of the application of these methods alone or in combination have been published by Aller *et al.* (1987), Foster (1987) Canter *et al.* (1987), Lobo Ferreira *et al.* (1995), Al-Adamant *et al.* (2003), El-Naqa (2004), Chaffai *et al.* (2006), Draoui *et al.* (2007), Gabriel *et al.* (2009), Carloni *et al.* (2011), Ben-Daoud *et al.* (2012), Khemiri *et al.* (2013), Al-Rawabdeh *et al.* (2013), Drias and Toubal (2015) or Lathamani *et al.* (2015). The aim of this work is to present the results of the GOD and DRASTIC methods, which use three and seven parameters respectively, thus providing an estimate of the vulnerability of the study area and an assessment more or less justified in relation to the quality of the data and the number of parameters available.

Material and methods

Presentation of the study area

The Boumaiza alluvial plain located in the North East of Algeria. It belongs administratively to the daïra of Ben Azzouz (wilaya of Skikda) between latitudes 36°44' and 36°49' North and longitudes 7°16 and 7°27 East. It is bordered to the north by the village of Ben Azzouz and to the south by Aïn Charchar and Bekkouch Lakhdar, to the east by Lake Fetzara and to the west by the Mechta of Ain Nechma (Fig. 1).

The region is drained by the West Kebir wadi in its North-East part. It is characterized by a very low relief, altitudes varying between 15 and 30m and a perimeter of 47.12km. The climate of this region is temperate, characterized by a hot and dry summer (Tmoy = 25.6°C) and a mild and humid winter (Tmoy = 12.6°C) with an average rainfall of about 623mm. These climatic conditions favor the development of typical vegetation where market gardening predominates, as well as eucalyptus plantations near agglomerations linked to stagnant water zones.

Geologically and hydrogeologically, the Boumaiza alluvial plain is characterized by alluvium with a maximum thickness of 110 m distributed over the entire plain. Silts, clays and sandy clays separate the clay soils on the surface and the gravel deposits that characterize the deep water table.

The substratum is represented by the clayey-sandstone sediments of Numidian and Cretaceous flysch.Piezometric measurements of the deep water table of the plain made it possible to draw up piezometric maps for two periods, the high water period (Fig. 2) and the low water period (Fig. 3).

The direction of flow for the high water period (April 2017) highlighted two directions: the first, the waters come from the north-northeast, south-east and south-east for the supply of Lake Fetzara; the second is from the south-east direction at the level of the Kebir wadi towards the extreme north-western part of the study area.

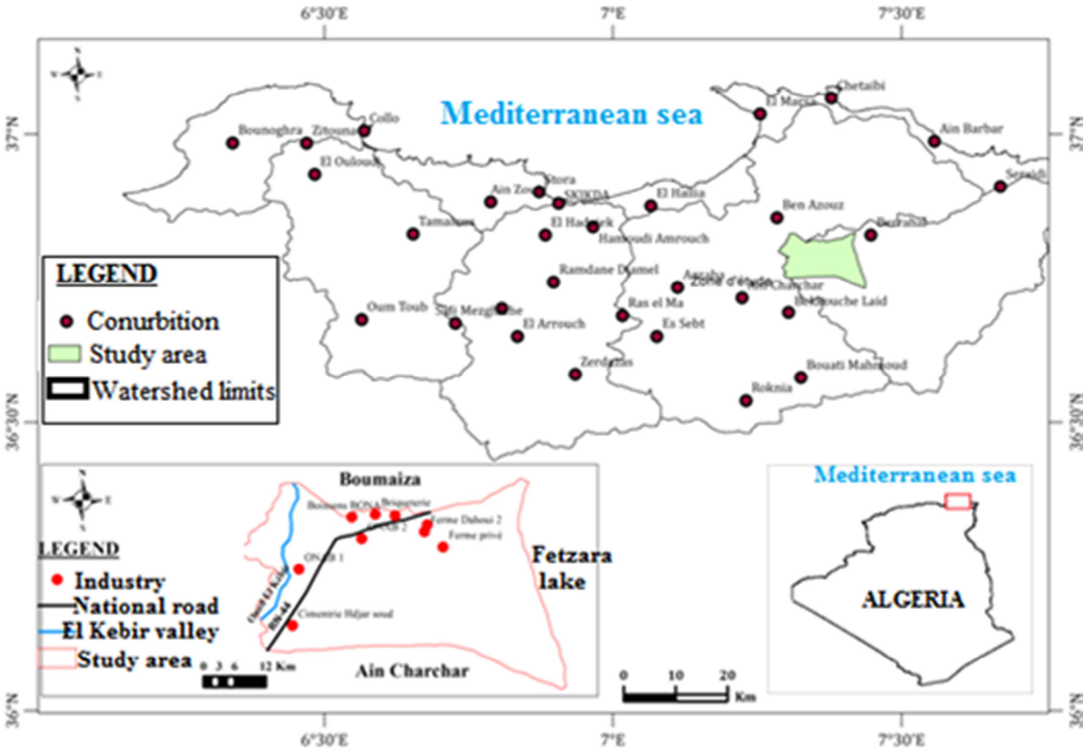

Fig. 1. Geographical location of the Boumaiza alluvial plain.

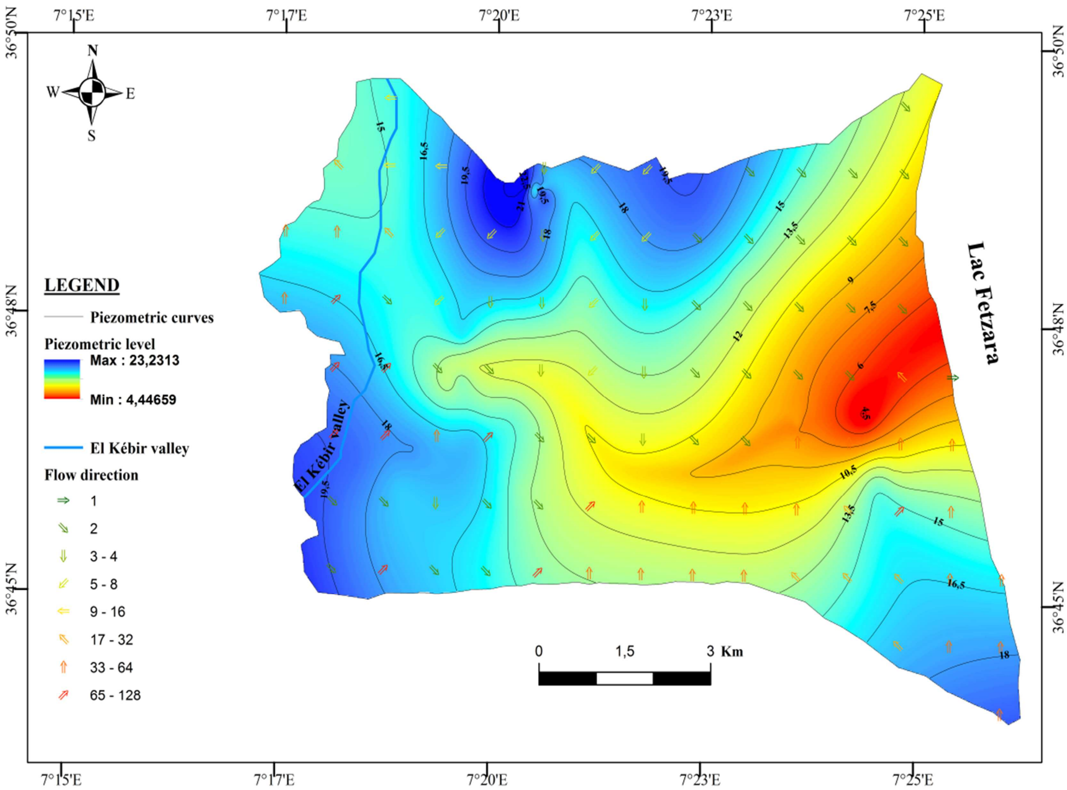

Fig. 2. Piezometric map of the high water of April 2017.

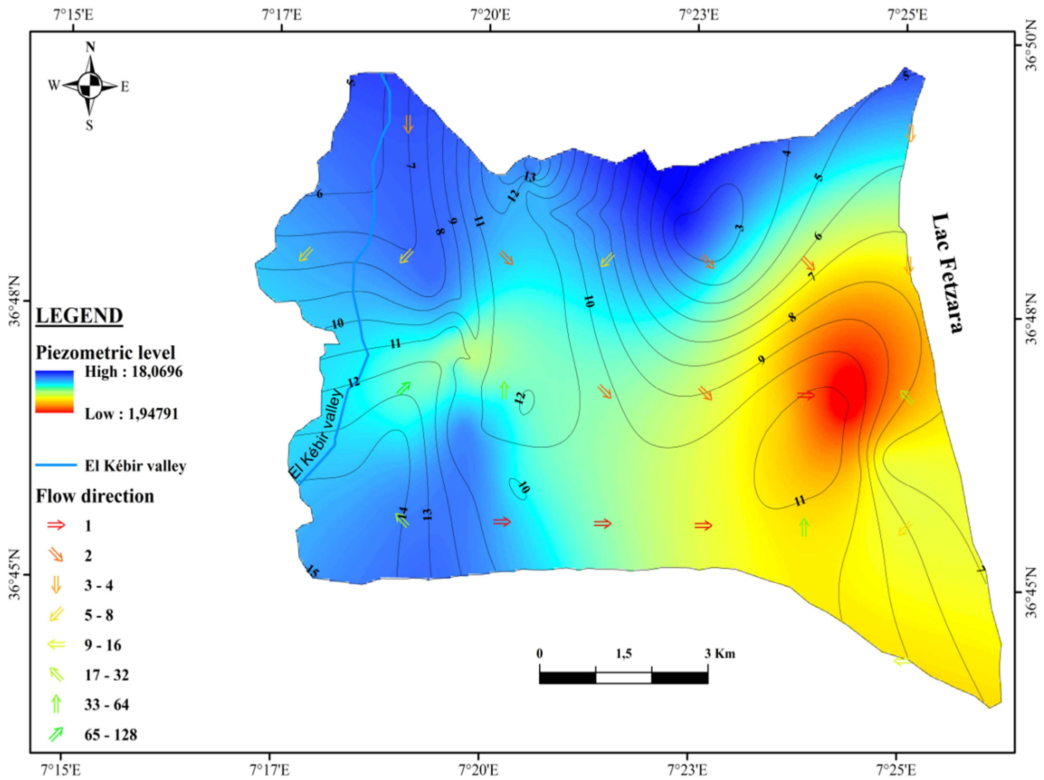

Fig. 3. Piezometric map of the low water of January 2017.

Methodology

Many methods for determining groundwater vulnerability have been developed in the world, in this work the mapping and calculation of vulnerability to pollution have been carried out by index mapping methods with weighting of GOD and DRASTIC criteria through the application of the geographic information system ArcGIS 10.3.

The latter allowed the integration and spatial distribution of the weighted scores assigned to the parameters used in the two methods and the representation of these parameters (Jourda *et al*, 2007) in the shapefile format (vector format). With the "Spatial Analyst" extension the shapefiles were converted to Grid (raster format), each Grid represents the spatial variation of the weighted scores for each parameter (Chandoul *et al*, 2008).

The GOD method is to have a quick idea on the vulnerability, however the DRASTIC method considered more precise given the importance given to several parameters that can influence the general vulnerability of the slick.

Description of the GOD method

The GOD method is a method that uses three parameters which are the type of slick (G), the lithology of the unsaturated zone of the aquifer (O) and the depth of the slick (D) to present the vulnerability of the aquifer to vertical percolation of pollutants through the unsaturated zone (Table 1).

The vulnerability index is calculated by multiplying the coefficients of the three GOD parameters as follows: IGOD= Ci * Cp * Ca. Where:

IGOD : is the potential pollution index (GOD index) or degree of vulnerability;

Ci : is the coefficient of the aquifer type;

Cp : is the coefficient of depth of the slick;

Ca : is the lithology coefficient of the aquifer.

The different ranges of the GOD Index obtained were compared with the vulnerability classes (Table 2). The GOD index has a minimum value of "0" and a maximum value of "1". Generally speaking, GOD indices are divided into five vulnerability classes ranging from "very low" to "extreme" (Foster and Hirata, 1991).

Table 1. GOD Method Parameter quotations.

GOD parameters	Description	Quotations
Tablecloth type (G)	No aquifer	0
	Artesian	0,1
	Confined	0,2
	Semi confined	0,3
	Free with cover	0,4- 0,6
	Free	0,7- 1
Lithology of the Zone Not Saturated of the aquifer (O)	Residual soil	0,4
	Alluvial silt, clay, marl, fine limestone	0,5
	Wind sand; siltite; tuff; igneous or metamorphic fractured rock	0,6
	Sand and gravel; sandstone; tuff	
	Gravel (colluvium)	0,7
	Limestone	0,8
	Fractured limestone or karstic	0,91
Plane depth of water (D) in metres	< 2	1
	2-5	0,9
	5-10	0,8
	10-20	0,7
	20- 50	0,6
	50-100	0,5
	>100	0,4

Table 2. GOD Index value ranges and corresponding classes.

Intervals	GOD Classes
0 – 0,1	Very low vulnerability
0,1 – 0,3	Low Vulnerability
0,3 – 0,5	Moderate Vulnerability
0,5 – 0,7	High Vulnerability
0,7 – 1	Extreme Vulnerability

Description of the DRASTIC method

It is the most widely used method in the world for assessing vulnerability to potential aquifer pollution by parametric systems (Aller *et al,* 1987). It is based on seven parameters (classified into three categories: surface parameters (slope of the terrain T, effective recharge R, and soil type S); parameters of the unsaturated zone (lithology of vadose zone A, depth of water body D) and parameters of the aquifer (lithology of aquifer I, hydraulic conductivity of aquifer C). Each criterion is mapped with an index, also called a rating (C) typically ranging from 1 to 10 and a weighting factor (P) is then applied to the different criteria in order to relativize their respective importance in terms of vulnerability (Table 3).

The method determines the DRASTIC index (Id) which characterizes the degree of vulnerability of a given sector of the slick (Table 4). This index is defined as follows:

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

Where D,R,A,S,T,I,C, are the parameters mentioned above:

c: rating given to each parameter

p: weighting factor assigned to each parameter.

Table 3. Classes, scores and weights of the seven parameters (Lallemand-Barrès, 1994).

D : Depth of the water body (m) P=5		R : Effective recharge (R) (mm/year) P=4	
0 – 1,5	10	0-50	1
1,5 – 4 ,5	9	50-100	3
4,5 – 9	7	100-180	6
9 – 15	5	180-250	8
15 – 23	3	> 250	9
23– 31	2		
>31	1		
A : Nature of the saturated zone P=3		S : Soil type P=2	
Karstic limestone	10	Not very thick or absent	10
Basalt	9	Gravel	10
Sand and gravel	8	Sand	9
Solid limestone	6	Clay, aggregates	7
Solid sandstone	6	Sandy silt	6
Shales in sequence	6	Stringer	5
Altered metamorphic, sandstone	4	Silty Silt	4
Metamorphic	3	Clayey silt	3
Solid Shale	2	Clay not aggregated and not cracked	1

D : Depth of the water body (m)		R : Effective recharge (R) (mm/year)	
P=5		P=4	
T : Topography (slope of the land %)		I : lithology of the vadose layer	
P=1		P=5	
0-2	10	Karstic limestone	10
2-6	9	Basalt	9
6-12	5	Sand and gravel	8
12-18	3	Sand and gravel with silt and clay	6
> 18	1	Limestone, sandstone, shale	6
		Sandstone	6
		Limestone	6
		Shale	3
		Silt/clay	1
C : Permeability (m/s)			
P=3			
>9,4 10-4	10		
4,7.10-4 à 9,4 10-4	8		
32,9.10-5 à 4,7.10-4	6		
14,7.10-5 à 32,9.10-5	4		
4,7.10-5 à 14,7.10-5	2		
4,7.10-7 à 4,7.10-5	1		

Table 4. DRASTIC vulnerability assessment criteria.

Vulnerability Index	Level of vulnerability
< 100	Low
101 – 140	Medium
141 – 200	Strong
>200	Very strong

Results and discussion

Elaboration of the GOD map

The GOD method (Fig. 4) uses an approach where vulnerability is defined according to the inaccessibility of the unsaturated zone in the sense of the penetration of the pollutant and the attenuation capacity of the underlying layer in the saturated zone (Sinan and Razack, 2007). In the Boumaiza alluvial plain, GOD (IGOD) values range from 0.21 to 0.42. The possible values of the GOD index are divided into classes as shown in Table 2. According to these values, there are two classes of vulnerability distributed over the entire Boumaiza plain (Fig. 5). First, class of low vulnerability: whose GOD coefficients vary between 0.21 and 0.3 occupies the north-western part and the southern part, over an area of 18.2km² or 20.5% of the area of the slick studied. This degree of vulnerability is explained by the nature of the unsaturated zone of the aquifer (metamorphic, sandstone and marl), as well as the relatively deep depths compared to other places on the plain. Second, class of moderate vulnerability whose GOD coefficients vary between 0.3 and 0.42 occupies the majority of the central part of the plain and 70.6km² or 79.5% of the groundwater area studied.

This degree of vulnerability is explained by the nature of the unsaturated zone of the aquifer (silts, sands and sandy clay), as well as depths ranging between 5 and 10m.

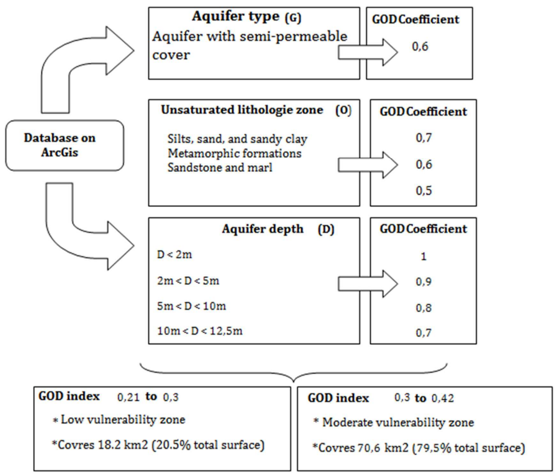

Fig. 4. Representative diagram of the GOD index calculation method.

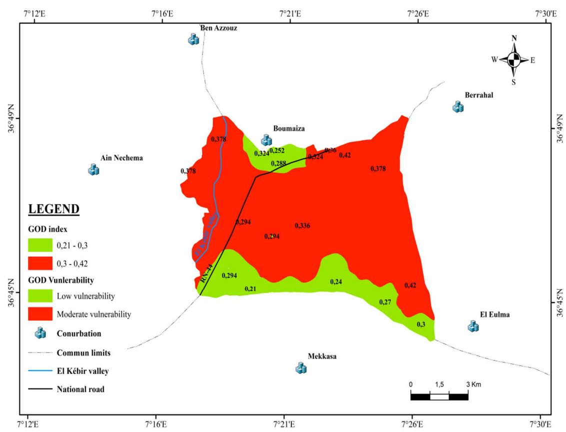

Fig. 5. Vulnerability map of the Boumaiza alluvial aquifer with GOD method.

Elaboration of the thematic layers of the seven DRASTIC parameters

Depth of the water body: The groundwater table depth parameter is a very important parameter in aquifer vulnerability assessment (Jordan *et al.,* 2005). Interpolations were made from 29 holes in the database. Examination of the thematic map of the water depth parameter (Fig. 6) shows that the lowest indices (ID=25) are located in the southwestern part where depths vary between 9 and 15 m over an area of 14.05% of the total area.

The most important showings are located in the North-East and South-East parts with ID=45 to 50 over an area of 30.68km². The ID=35 index covers 58.7% of the plain and represents depths ranging from 4.5 to 9m. Effective recharge (R): Effective recharge plays a critical role in the transfer of the water slide from the ground surface to the underlying aquifer. The results of the water balance show that the value of this parameter is estimated at 100mm over the entire study area. Then, the DRASTIC index is of the order of 9 distributed over the entire plain. Aquifer lithology (A): We determined this parameter from the texture of the terrains that constitute the unsaturated zone. From the geological map of the region, a score was assigned for each type of terrain, from the most permeable to the least permeable. Exploitation of geophysical prospecting reports and interpretive geo-electric sections have shown that the lithological nature of the aquifer studied consists essentially of gravels, cobbles, sandstones and sands. Then, only one lithological class was determined which is sand and gravel, its rating is 8 with a DRASTIC index of about 24. Soil type (S).

The nature of the soil and its thickness are the two factors that determine the purifying character and the ability of the soil to let a pollutant infiltrate (Bézèlgues *et al.,* 2002).

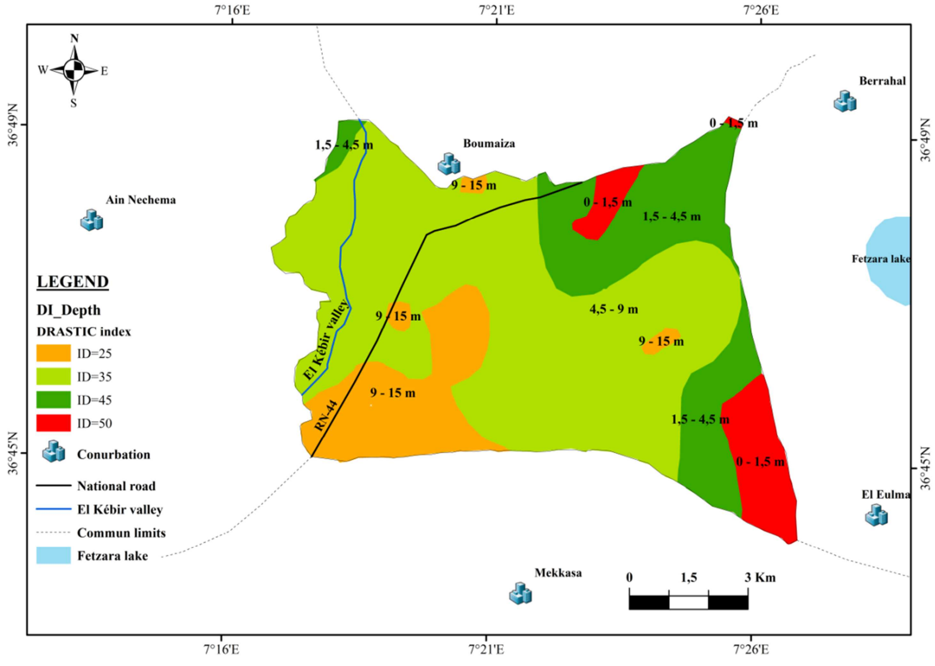

Fig. 6. Spatial distribution map of the DRASTIC index of water depths.

To determine this parameter, we used the map of soil recognition in Algeria, Bône au 1/200.000. The soils encountered in the region are divided into five types. The index values were determined according to the different soil types. Examination of the soil nature index map shows that silts and sandy silts spread over almost the entire study area represent an average vulnerability risk of a DRASTIC ID= 10 to 12 index. The rest of the soils, represented by clay and silt distributed over the alluvial plain periphery, have low DRASTIC indices ranging from 2 to 8 (Fig. 7). Topography (T).

The steeper the slope of the land, the greater the runoff of water and therefore the contamination of groundwater is low. Slope values were estimated by reference to the digital terrain model MNT-STRM-3arc and its projection on a predefined coordinate system on ArcGIS. Examination of the index map shows five slope ranges of which 98% are represented by slopes ranging between 0 and 6% (which characterizes the study area which is a plain) with a high DRASTIC index between 9 and 10. The slopes that vary between 6% and 31.5% are located on the extreme southeast and northwestern part of the study area with low DRASTIC indices between 1 and 5 (Fig. 8).

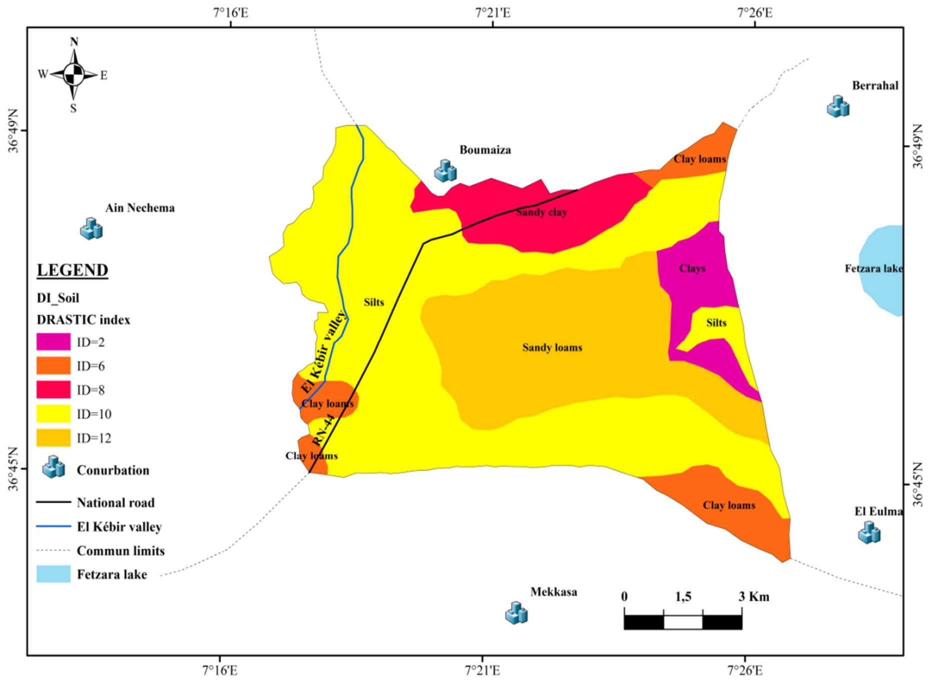

Fig. 7. Spatial distribution map of the DRASTIC index for soil type.

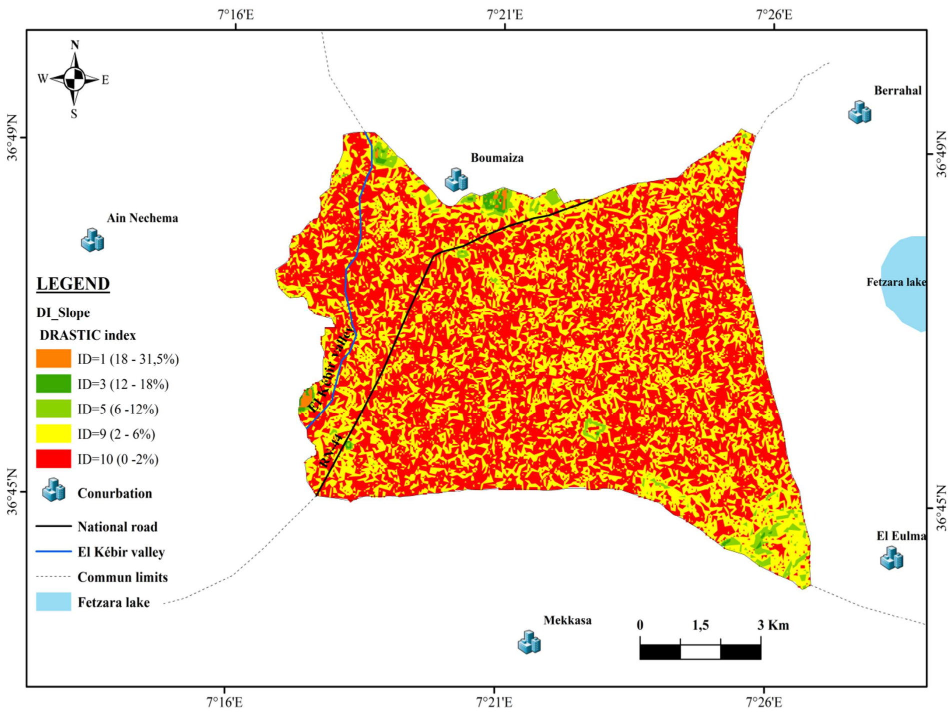

Fig. 8. Spatial distribution map of the DRASTIC index for the slope.

Nature of the unsaturated zone (I): The impact of the unsaturated zone is considered to be a very important parameter in the application of the DRASTIC method with a weight (Ip = 5). The consultation of the various geological and geophysical documents (maps and sections), made it possible to define that the unsaturated medium is constituted by a detritic material of very heterogeneous granulometry covering more than 80% of the surface of the plain (silts, sands and sandy clays) and extends over the central part of the East to the West with a relatively very high DRASTIC index (ID=40) with a rating of 8; the metamorphic formations which are located in the North (ID=20), sandstones and marls (ID=30) which are located in the South of the plain of Boumaiza representing 20% of its surface (Fig. 9).

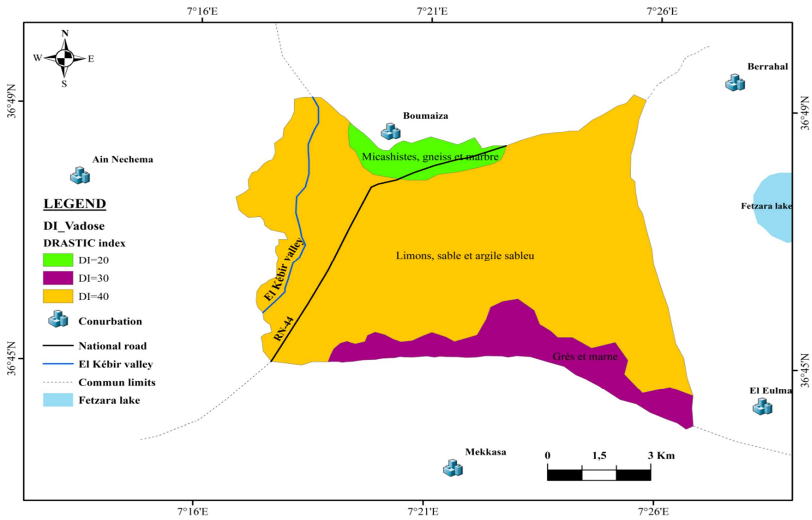

Fig. 9. Spatial distribution map of the DRASTIC index for the unsaturated zone of the aquifer.

Hydraulic conductivity (C): The permeability of the aquifer layer provides information on the rate at which pollutants propagate through the aquifer. The more important this parameter is, the faster the transfer of pollutants is. Data on the permeability of the aquifer are those obtained in the contribution to the hydrogeological study of the West Kebir Wadi Valley of Skikda, Algeria (Khammar, 1981). From these data, the permeability information layer is determined by GIS interpolation. The permeability values used are distributed under one class; $9.1*10^{-4}$ m/s < C < $1.8*10^{-3}$ m/s throughout the region with a rating of 10, giving a very high DRASTIC index (ID=30).

Summary map (vulnerability to pollution by the DRASTIC method)

By superimposing the seven weighted maps, we obtain the DRASTIC index map The DRASTIC index (ID) of the Boumaiza alluvial plain ranges from 144 to 202. The low values of this index (144-160) are recorded in the northern part over a very small area (0.64 km²). The values of this index oscillating between 160 and 180 occupy an area of 37.86 km² and represent the equivalent of 29.6% of the total area of the study area. The largest part represented by 61.5 km² (69.65%) characterized by very high DRASTIC indices varying between 180 and 202 spreading over the majority of the plain of Boumaiza occupying the central part of the North-East towards the West.

For vulnerability mapping, two vulnerability classes are used as shown in Table 5 below. From the vulnerability map of the Boumaiza alluvial groundwater (Fig. 11), we can see that this groundwater is characterized by the spatial extent of the highly vulnerable lands that dominate the total area of the study area by 86.57 km², or a percentage of 97.9%, hence the DRASTIC indices which vary between 144 and 200. These sites are characterized by a permeable unsaturated zone, shallow groundwater and silt soils and sandy silts that may increase the risk of pollution.

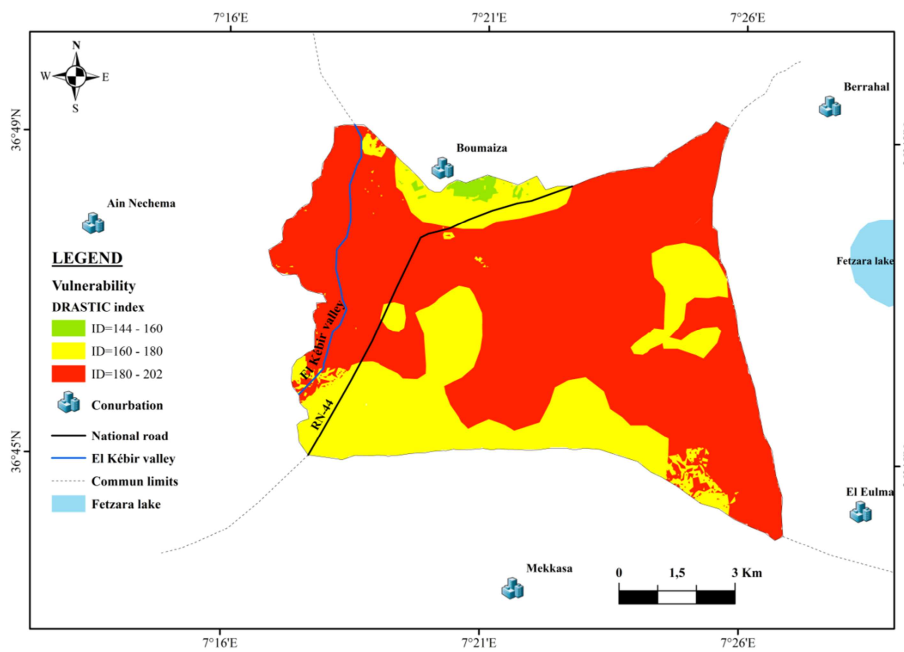

Fig. 10. Spatial distribution map of DRASTIC index.

The rest of the land represents 2.3Km² or a percentage of 2.1% of the total area of the plain of Boumaiza with DRASTIC indices that vary between 200 and 202. These are highly vulnerable areas (very high vulnerability), defined by the same characteristics as areas of high vulnerability (a permeable unsaturated zone and sandy silt soils), with a very slight slope (0 - 2%) and shallow water depths that vary between 1-1.5 m thus increasing their risk of pollution and making the area very vulnerable.

Table 5. DRASTIC vulnerability assessment criteria.

Vulnerability Index	Level of vulnerability
< 100	Low
101 – 140	Medium
141 – 200	Strong
>200	Very strong

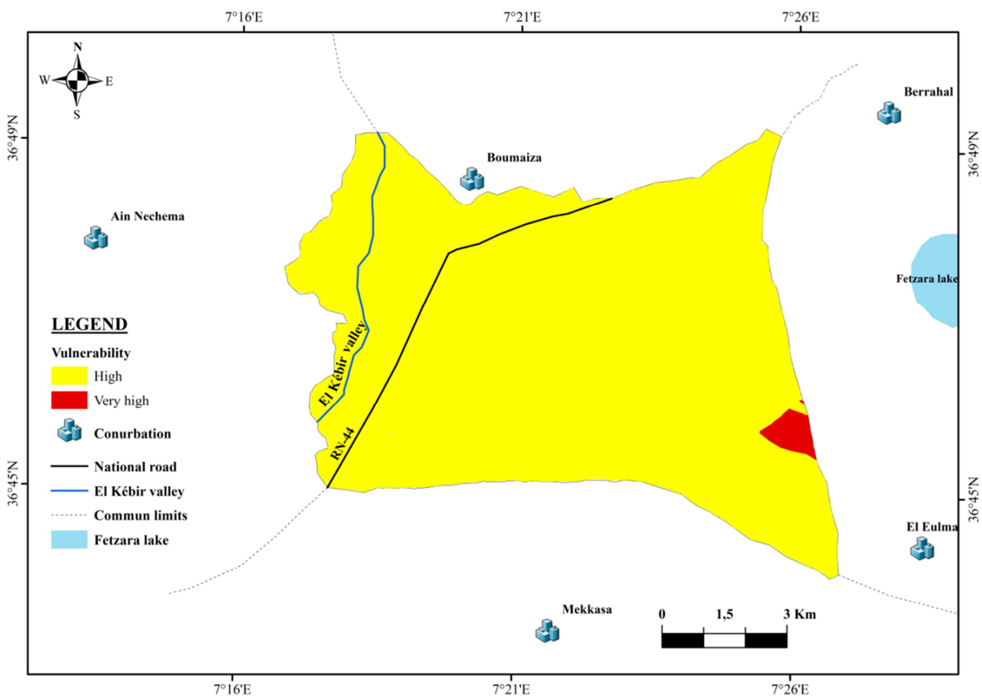

Fig. 11. Vulnerability map of the Boumaiza alluvial aquifer with DRASTIC method.

Conclusion

The study of the vulnerability of the Boumaiza alluvial groundwater based on the establishment of the groundwater sensitivity estimation map to contamination in general according to the GOD and DRASTIC estimation method. According to the GOD index values, two classes of vulnerability are distinguished: one is low occupying the north-western and southern part, the other moderate occupying the majority of the central part of the plain (70.6km²), or 79.5% of the surface area of the slick studied. According to the DRASTIC method considered more precise compared to the method we also distinguish two classes of vulnerability distributed over the entire plain of Boumaiza: High vulnerability class covering the majority of the area of the Boumaiza alluvial plain by 86.57 km2 or a percentage of 97.9%. Very high vulnerability class covers 2.3 km² or a percentage of 2.1% of the total area of the study area.

The high vulnerability that characterizes the majority of Boumaiza's alluvial groundwater exposes it to a significant danger of pollution. Therefore, the importance of the Boumaiza alluvial groundwater to the socio-economic development of the region, recommends preserving its threatened water resources by providing perimeters of protection of the water catchment works located in the region under consideration.

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