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Original Research Article

CONTRIBUTION OF A GEOGRAPHIC INFORMATION SYSTEM TO ASSESS THE VULNERABILITY TO GROUNDWATER POLLUTION OF THE FREE WATER TABLE FROM THE OUED SOUF REGION (SOUTH-EAST ALGERIA)

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A b s t r a c t

The Oued Souf free aquifer located in the South East of Algeria represents the main water resource used mostly for urban and agricultural activities. The intensive use of chemical fertilizers has led to serious environmental problems such as contamination of the free aquifer in the region. Thus, aquifer vulnerability has been assessed using several different methods (DRASTIC, GOD, and the Susceptibility Index 'SI') based on a geographic information system (GIS). For each method, two vulnerability maps have been developed in the years 2002 and 2012. These maps show that the study area is more exposed to urban, and especially agricultural, pollution. Two classes of vulnerability (moderate and high) have been identified by both DRASTIC and GOD methods. A combined analysis reveals that the moderate class showing 48% (for the GOD method), and the high class showing

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57% (for the DRASTIC method) are the most dominant. However, the Susceptibility Index method (SI) revealed that the vulnerability varies from moderate to very high-level classes. In 2012, about of 53% of the study area was dominated by moderate vulnerability classes. The high vulnerability class also includes a considerable part of the land (41%) around urban or strongly agricultural areas, while only 6% is under very high vulnerability groundwater contamination. In addition, a marked decrease in the vulnerability level was noticed in 2012 compared to 2002. This decrease is mainly due to the lowering of the water table after the installation of a vertical drainage network to evacuate the surplus water to the depression and Chotts areas in the North of the region. These results provide a guide for decision-makers involved in the protection of groundwater pollution in such a vulnerable area.

Keywords: free aquifer, Oued Souf, chemical fertilizers, vulnerability, DRASTIC, GOD, susceptibility index, pollution, SIG

1. INTRODUCTION

The region of Oued Souf has experienced a great agrarian revolution during the last two decades, and consequently the agricultural area which covered 200 ha in 1993, currently exceeds 50 000 ha. This economic revolution requires highly important hydric potentialities and, thereby, generates negative effects on the environment and groundwater [8]. The safeguarding of this precious resource from contamination has become indispensable to preserve the economic, environmental, and social welfare in the region [9]. Moreover, the identification of areas of greater vulnerability contributes to preventing contamination, guiding subsequent water managers to remedy problems of water quality and supply. Several assessment methods have been developed to evaluate the groundwater vulnerability to contamination such as DRASTIC [4], GOD [11], and SI [9]. Thus, the present study aimed to assess the vulnerability and pollution risk of the free aquifer in the Oued Souf region using these parametric methods (DRASTIC, GOD, and SI) combined with the hydrogeological data from a geographic information system (GIS). The DRASTIC and GOD methods were applied and compared with the Susceptibility Index (SI) method map to evaluate the potential risk of groundwater contamination.

2. STUDY AREA DESCRIPTION

The Oued Souf region is located in South-Eastern Algeria within a large syncline covering a total area of 44,587 km^2 and includes a population of 820 thousand inhabitants (2016, according to the DPSB, El Oued). Further, the study zone includes the city of Oued Souf and eleven chief towns (Guemar, Taghzout, Ourmes, Kouinine, Debila, Hassani abdelkrim, Trifaoui, Bayadha, Robbah, Nakhla, El Ogla), occupying an area of 491.29 km^2. The region is subjected to a hyper-arid Saharan climate, which is very hot and dry in the summer and quite cold in the winter [7]. The average annual temperature is around 21.6°C with a maximum of 32.8°C (in July). The average annual rainfall is estimated at about 76 mm/year and, in addition, all the precipitated water evaporates, resulting in practically no runoff or water table recharge [8].

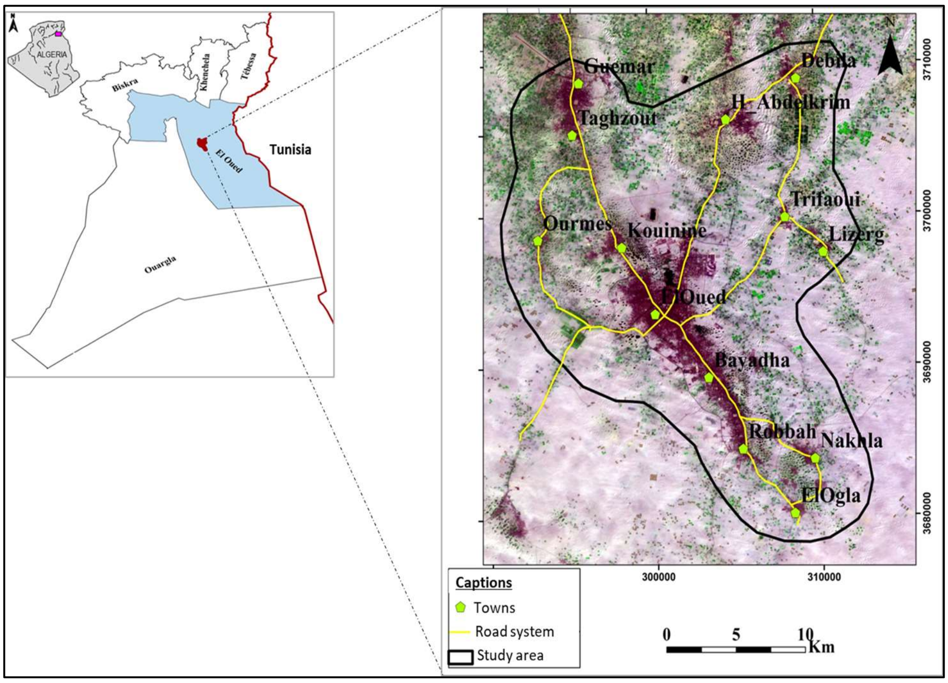

Fig. 1. Geographical localization of the study area

Hydrogeologically, the study zone is part of the Northern Sahara Aquifer System (NSAS), which consists of three aquifers, including two confined aquifers (Continental Intercalary (CI), Terminal Complex (CT) and Free aquifer). It should be noted that the water table is present throughout the Oued Souf region and includes detrital formations of quaternary age with a substratum of 60 m deep and made up of slightly sandy clay [7, 8].

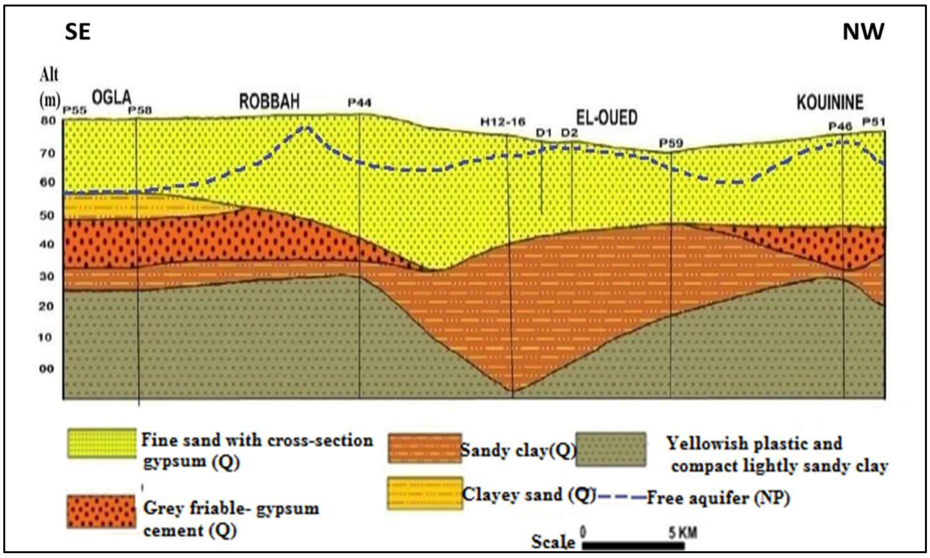

Fig. 2. Hydrogeological section (SE-NW) in the study zone

3. ADOPTED METHODOLOGY

In recent years, various methods of vulnerability assessment of groundwater have been developed, with different approaches taking into account physical, chemical, and biological processes in the saturated zone, to weighting methods between different criteria affecting vulnerability [12]. Index and overlay methods are based on combining maps of various physiographic attributes (geology, soil, aquifer media, depth to water) controlling groundwater vulnerability of the region by assigning a numerical score or rating to each attribute [16]. In this study, the vulnerability mapping and calculation of pollution in the free water table of the Oued Souf region were carried out by DRASTIC, GOD, and SI methods, using the Geographic Information System Software (ArcGIS). The latter enables us to integrate and to spatially distribute the weighted scores attributed to the different methods and their representation [1, 3], each one adopting a specific set of parameters:

- DRASTIC considers 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) [16];
- GOD is a classical system for quick assessment of the aquifer vulnerability to pollution. Three main parameters are considered: the

groundwater occurrence, the lithology of the overlying layers, and the depth to groundwater [16].

• SI involves five layers, which are: Depth to water, Net Recharge, Aquifer media, Topography, and Land Use (LU) [16].

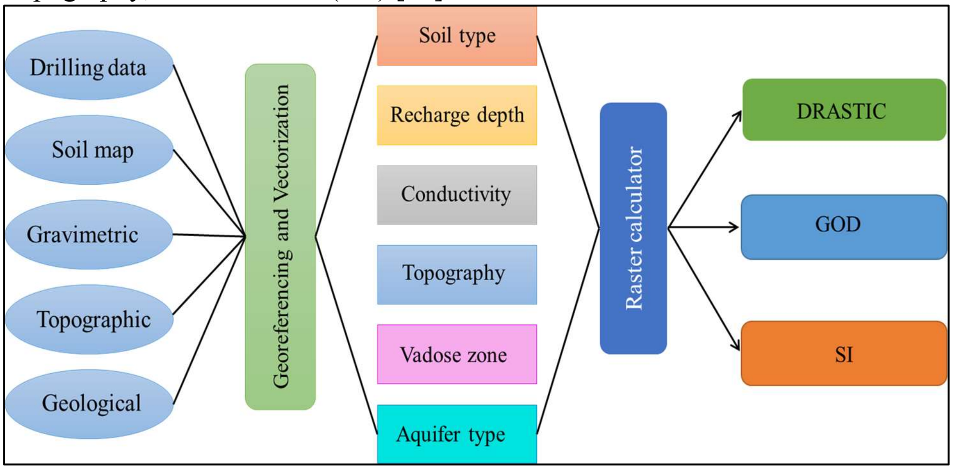

Fig.3. Flowchart of methodology for assessing groundwater vulnerability in the study area

3.1. DRASTIC Method

The DRASTIC method, developed by the services of the USEPA, is a method used to assess the vertical intrinsic vulnerability to aquifer pollution by parametric systems [4]. Also, the method evaluates pollution potential based on a weighted combination of seven hydrogeologic settings: depth to water, net recharge, aquifer media, soil media, topography, impact of the vadose zone, and hydraulic conductivity of the aquifer [11]. The DRASTIC index for the given area is calculated by multiplying each parameter’s ratings by the assigned weights that reflect the relative contribution of each factor to the contamination process in general. The final vulnerability index (Di) is a weighted sum that can be computed using the formula 3.1:

$$I_{DRASTIC} = D_wD_r + R_wR_r + A_wA_r + S_wS_r + T_wT_r + I_wI_r + C_wC_r \quad (3.1)$$

Where, w -Weight factor for parameter, r- Rating for parameter.

The DRASTIC vulnerability map was obtained by running the model in the ArcGIS software in the GIS environment by using the seven hydro-geological data layers [17].

Table 1. Vulnerability DRASTIC classes [11]

Vulnerability degree	**Vulnerability index**
Low	23 - 101
Average	101 - 140
High	141 - 200
Very high	200 - 226

Herein, it is possible to take a maximum value as 226 (100%) and a minimum value as 23 (0%). A classification established by enables us to determine the interval limits of the calculated indices and to match the vulnerability classes to these indices [10].

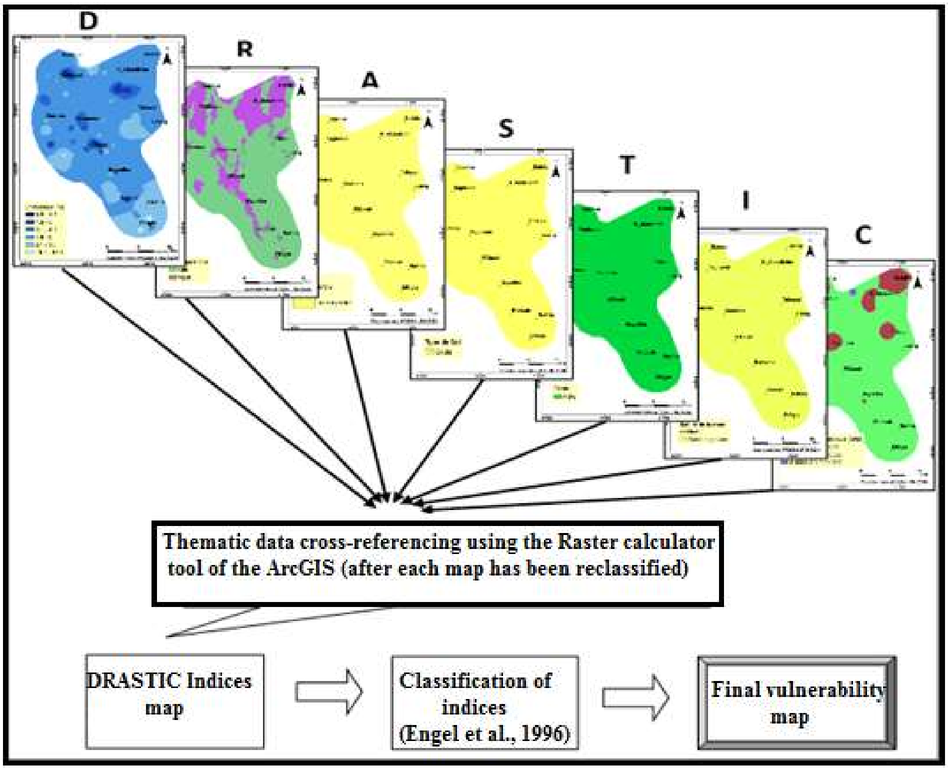

Fig. 4. Flowchart of vulnerability mapping using DRASTIC method

3.2. GOD Method

The GOD method designed in England in 1987 by Foster, requires fewer parameters than the DRASTIC method, and achieves a relatively quick estimation of the vulnerability of an aquifer [5], based on the three vulnerability parameters as indicated below:
G: Type of aquifer according to its containment degree.
O: Lithology of the unsaturated zone.
D: Depth of the water table.
The scores assigned to the classes of the different parameters are less than or equal to 1, since the GOD Vulnerability Index (I_{GOD}) is obtained by multiplying the scores for each of the three parameters according to the following formula 3.2:

$$I_{GOD} = G_c \times O_c \times D_c \quad (3.2)$$

where “c” is the parameter rate.
The GOD Index has a minimum value of "0" and a maximum value of "1". In our case study, the GOD indices are divided into three classes of vulnerability; low, medium, and high, as previously reported [11]. Also [14], the degree of vulnerability increases with the GOD index (GI) [6].

Table 2. GOD Index value ranges [11]

GOD classes	Range
Negligible	0 - 0.1
Low	0.1 - 0.3
Moderate	0.3 - 0.5
High	0.5 - 0.7
Very high	0.7 - 1

The approach for classifying the index map as a function of vulnerability classes is similar to that described above for the DRASTIC method [18].

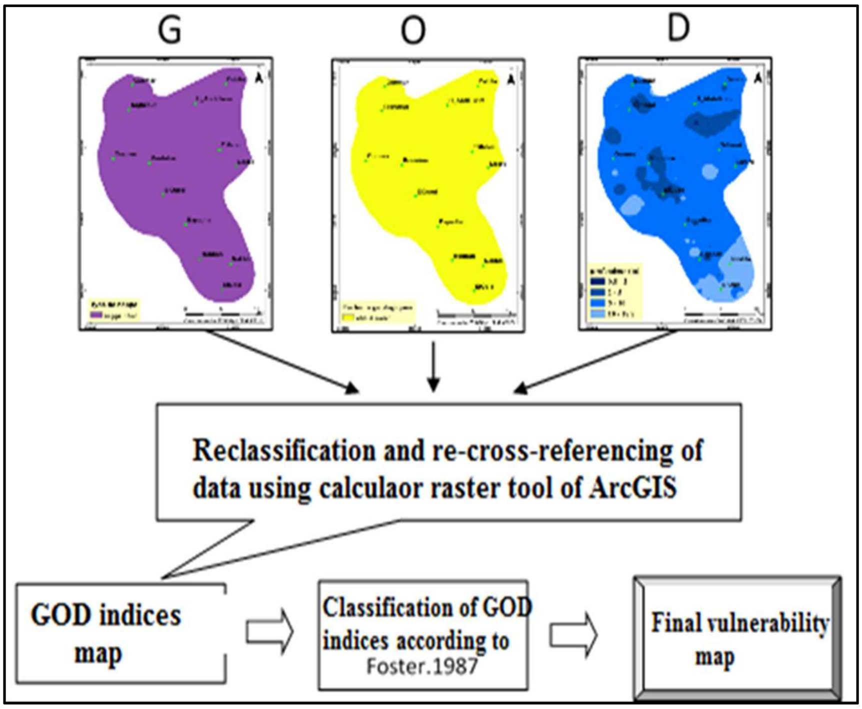

Fig. 5. Flowchart of vulnerability mapping using the GOD method

3.3. Susceptibility index (SI) method

The susceptibility index (SI) method is a specific vertical vulnerability method, developed in Portugal by [15] who took into consideration the agricultural pollutants, particularly nitrates and pesticides. His method is based on using five parameters as follows:

D: Depth of the water table.

R: Net recharge

A: Lithological nature of the aquifer.

T: Topography of the land.

LU: Land use.

The development of the vulnerability map is conducted by calculating the Vulnerability Index (VI) given by the following formula 3.3:

$$I_{SI} = D_cD_p + R_cR_p + A_cA_p + T_cT_p + P_cP_p \tag{3.3}$$

Where the indices "c" and "p" designate, respectively, the dimension and the weight of the studied parameter. Further, the first four parameters of the SI method are the same as those of the DRASTIC method by multiplying the dimensions by

10. The rating values of the new land-use parameter (LU) vary from 0 to 100, ranging from the least vulnerable to the most vulnerable. The weights assigned to the LU parameters range from 0 to 1 depending on the importance of the parameter in vulnerability. This method considers five parameters for the assigned weights.

Table 3. Notation of the criteria used for the SI method

Parameters	D	R	A	T	LU
Weights	0,186	0,212	0,259	0,121	0,222

Moreover, the calculated susceptibility indices represent the aquifer vulnerability risk level, taking a value less than 45, and a maximum value of 100. After the susceptibility index is calculated, the degree of vulnerability may be defined as indicated in Table 4.

Table 4. Classification of the IS vulnerability index [15]

Degree of vulnerability	Vulnerability index
Low	< 45
Average	45-64
High	65-84
Very high	85-100

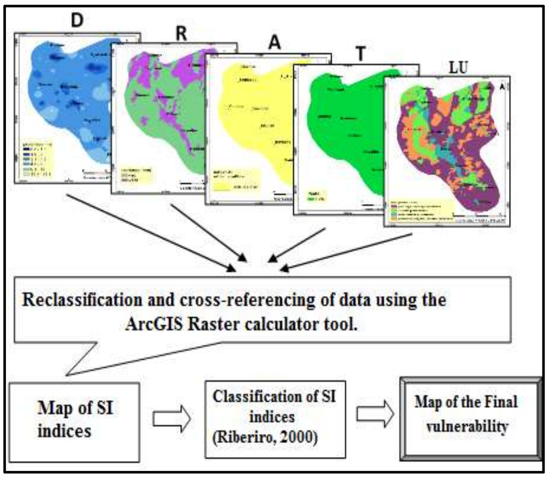

Fig. 6. Flowchart of vulnerability mapping using the SI method

4. RESULTS AND DISCUSSION

The evaluation of various parameters of the DRASTIC method was developed by interpolating several data on the water level measured during the piezometric investigation carried out as part of this study in February 2009.

4.1. The DRASTIC vulnerability map

Two vulnerability maps from 2002 and 2012 were drawn up. The vulnerability index values were found to vary between 117 and 190, and revealed two classes of vulnerability to pollution:

- **Moderate class**: Covering 43% of the surfaces in 2012 and occupying a more important area than that in the year 2002 (20%). This is explained by the greater depths of the water table, exceeding 9m, including South Bayadha and the palm plantations of Mehri and Trifaoui (South of Oued Souf region);
- **Strong class**: Covering 57% of the land in 2012, along with a shrinkage compared to that of 2002 (80%).

For both maps, this class occupies the edges of the study area, where the recharge is nil and the water table depth is less than 9 m.

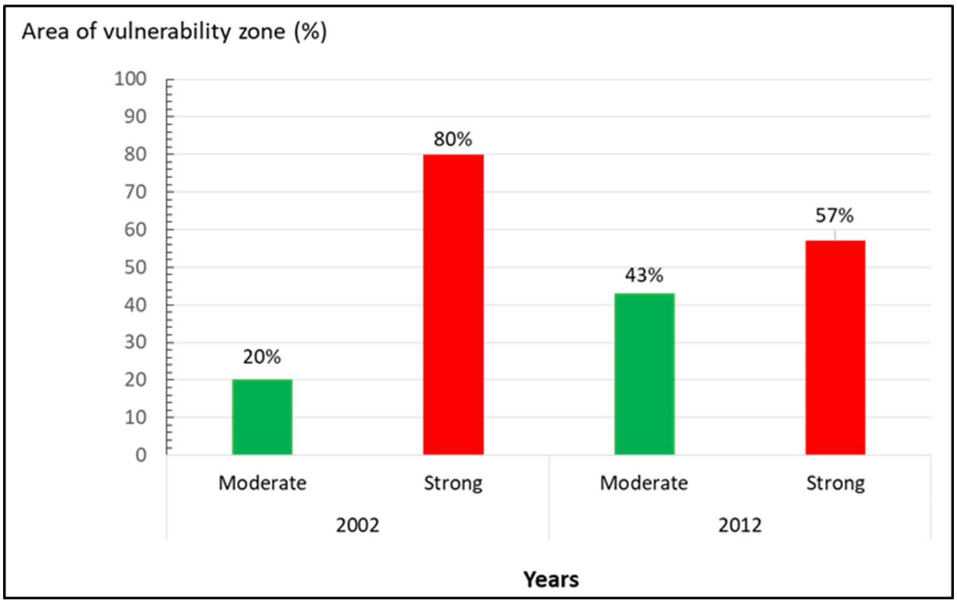

Fig. 7. Distribution of vulnerability degrees according to the DRASTIC method

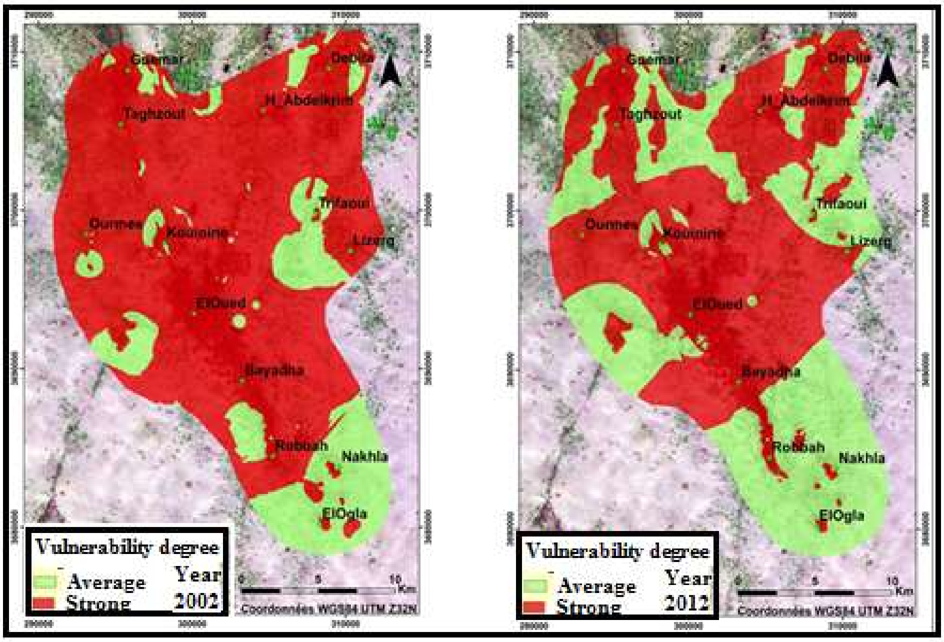

Fig. 8. DRASTIC vulnerability maps of free aquifer for Oued Souf region

4.2. The GOD vulnerability map

The maps obtained in 2002 and 2012 are the consequence of the superposition of the three parameters previously described. In addition, the Global Vulnerability Index (GDI) was found to vary between 420 and 700. The vulnerability maps show two unequally distributed classes [13].

The class of high vulnerability found in 2002 dominates the study area with a rate of 89%, and this would be due to the shallow depths of the water table (varying between 0.8 and 10m), while the moderate vulnerability class represents only 11% of the zone and is due to depths exceeding 10m. Similar to that seen in 2012, the proportions for the moderate (48%) and high (52%) vulnerability classes are almost similar ,with a clear narrowing of the high vulnerability zone.

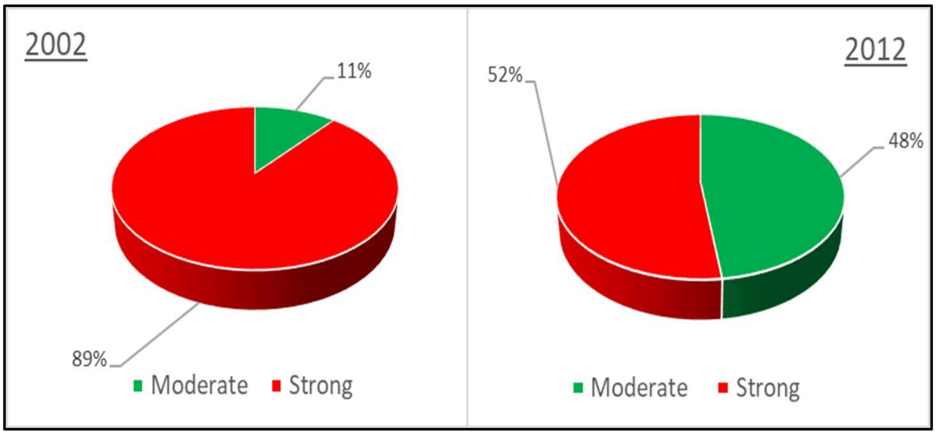

Fig. 9. Distribution of vulnerability according to the GOD method

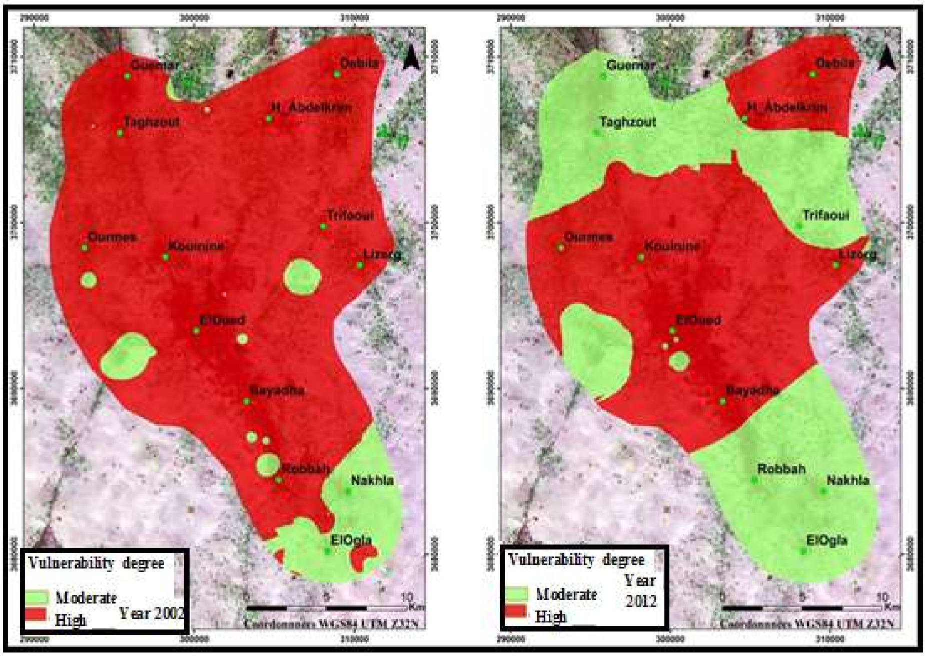

Fig. 10. GOD vulnerability maps of the Oued Souf free aquifer (2002, 2012)

4.3. The SI vulnerability map

The values of the vulnerability indices (I_{SI}) obtained from 2002 vary between 51.62 and 88.62% and the obtained vulnerability map also shows the existence of three degrees of vulnerability: average, high, and very high, exactly as reported by Ribeiro (2000). Furthermore, the study area is dominated by the average-vulnerability class (53%) and includes the agroforestry areas (nearly uninhabited dune areas), where the depth of the water table exceeds 4.5m. Additionally, the high vulnerability class also includes a considerable part of the land (41%) around urban or strongly agricultural areas, so there is subsequent possible use of agricultural pollutants. The very high vulnerability class includes only 6% of the study area and is directly related to the low water table depths (less than 4.5m), mainly in the vicinity of irrigated perimeters and urban areas of some of El Oued's towns (El Oued, Ormes, Debila, south of Hassani abdelkrim and in Trifaoui). Further, the vulnerability map taken from 2012 results in a vulnerability index (I_{SI}) ranging from 49.8 to 88.6%, corresponding to three degrees of vulnerability unevenly spread within the study area. The average degree of vulnerability is 55.5%, and this refers to the least vulnerable dominant class in the study area since a high degree was found to cover 41.5 % of the study area. It is worth noting that the very high vulnerability areas are concentrated near large urbanisations, covering 3% of the study area, and this is reflected in the presence of several sources of pollution, generated by agricultural perimeters and urban areas, and aggravated by the shallow depths of the water table.

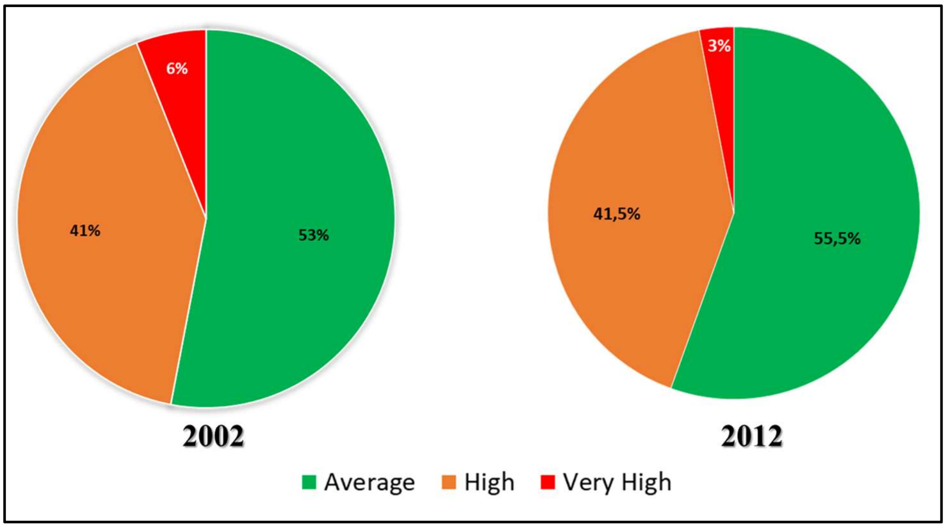

Fig. 11. Distribution of vulnerability according to the SI method

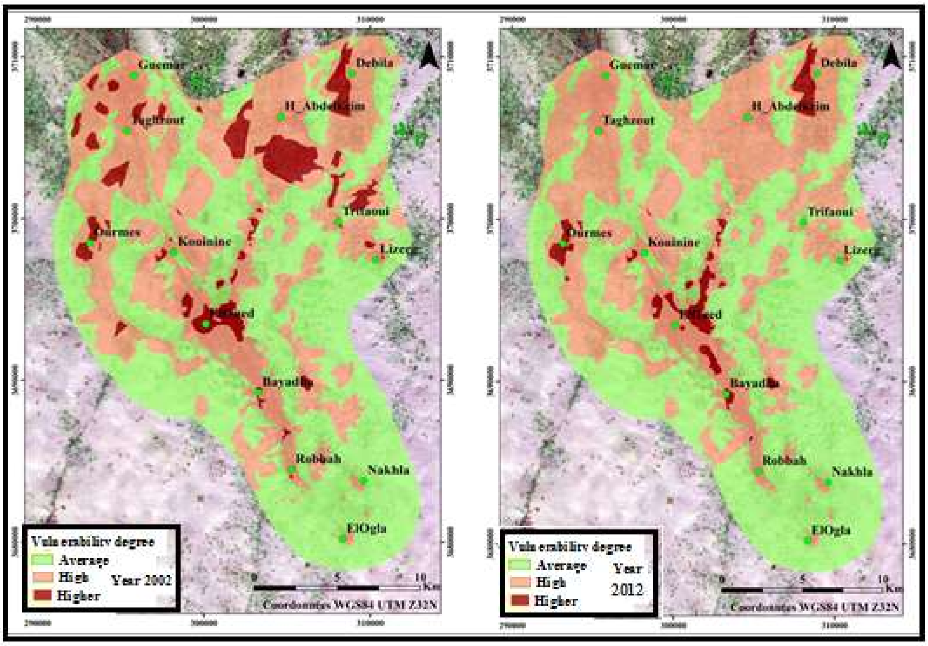

Fig. 12. SI vulnerability maps of the Oued Souf free aquifer (2002, 2012)

5. CONCLUSION

In this study, DRASTIC, GOD, and SI methods using geographic information systems (GIS) were used to assess the groundwater vulnerability of the Oued Souf free aquifer. Differences in the obtained vulnerability maps showed that moderate to high vulnerability levels characterized the Oued Souf groundwater (according to DRASTIC and GOD methods). The DRASTIC vulnerability map indicates that the northern and central sectors of the aquifer are endangered (high-level vulnerability with 57 to 80% in 2012 and 2002, respectively). Whereas the southern and western aquifer regions refer more to the moderate vulnerability class.

Regarding the GOD vulnerability map, the high vulnerability class found in 2002 dominates the study area with a rate of 89%, and this would be due to the shallow depths of the water table (varying between 0.8 and 10m), while the moderate vulnerability class represents only 11% of the zone, owing to the water table depths exceeding 10m. As seen in 2012, the proportions for the moderate (48%) and high (52%) vulnerability classes are almost similar with a clear narrowing of the high vulnerability zone.

However, the SI vulnerability map showed significantly different results from those obtained by the other two methods. The values were reclassified into three highlighted classes (average, high, and very high) occupying 55,5%, 41,5%, and 3%, respectively. This is explained by the shallow depth of the aquifer (7m in 2002 and 10m in 2012). Of particular note is the lithological nature of the aquifer (mainly sand of good permeability), and also the agricultural vocation of the region as well as the high urban concentration, leading to an increase in the vulnerability.

The discussed groundwater vulnerability maps can be a useful tool for land-use planners, hydrogeologists, and water managers. The results from the different vulnerability methods used in the Oued Souf free aquifer show the advantages of using the SI method, which takes into consideration the land use and the risk of fertilizer pollution. In this specific vulnerability method, the land use parameter allows the integration of specific factors for each type of land use, such as the recycling effect in irrigation zones as well as providing a better sensibility to the real local conditions, helping to identify the areas showing a significant risk of groundwater contamination.

REFERENCES

1. Abdeslam, I et *al.* 2017. Application of drastic method for determining the vulnerability of an alluvial aquifer: Morsott - El Aouinet north east of Algeria: using Arc GIS environment. *Energy Procedia* **119**, 308–317.
2. Aït Sliman, A et *al*. 2009. Use of Geographic Information Systems and DRASTIC model to assess the vulnerability of groundwater in the Berrechid plain, Morocco. [Utilisation des Systèmes d'Information Géographique et du modèle DRASTIC pour l'évaluation de la vulnérabilité des eaux souterraines dans la plaine de Berrechid, Maroc]. *Geographia Technica* **2**, 81- 93.
3. Aké, GE et *al.* 2010. Application of DRASTIC and SI methods for defining of vulnerability to pollution by nitrates of the Bonoua water table (South-East of Ivory Coast)**,** [Application des méthodes DRASTIC et SI pour l'étude de la vulnérabilité à la pollution par les Nitrates de la nappe de Bonoua (Sud-Est de la Côte d'Ivoire)]. *International Journal of Biological and Chemical Sciences* **4**, 1676-1692.
4. Aller, L et *al*. 1987. DRASTIC: a standardized system for evaluating groundwater pollution potential using hydro geologic settings. *US Environmental Protection Agency Report EPA* 600/2-87-035. Ada, Oklahoma.
5. Bézèlgues, S et *al*. 2002. Vulnerability mapping of Grand-Terre and Marie-Galatie (Guadeloupe). Phase 1: methodology for determining vulnerability. *Report BRGM*. 51783-Fr, 41.
6. Boulabeiz, M et *al*. 2019. A GIS-Based GOD Model and Hazard Index Analysis: The Quaternary Coastal Collo Aquifer (NE-Algeria). *Groundwater* **57**, 166–176.
7. Bouselsal, B et al. 2018. Management of upwelling phenomenon in the region of El Oued (South-East Algeria) and the possibility of using purified wastewater in irrigation**. [**Gestion du phénomène de la remontée des eaux dans la région d'El Oued (S-E Algérie) et la possibilité d'utilisée les eaux usées épurées en irrigation]. *International journal of Environment & Water* **7**, 82-91.
8. Bouselsal, B et al. 2014. Effects of rising groundwater on humans and the environment: the case of the El-Oued region (SE Algeria). [Effets de la remontée des eaux de la nappe phréatique sur l'homme et l'environnement: cas de la région d'El-Oued (SE Algérie)]. *Afrique Science* **161**, 170 161.
9. Chandoul, IR et al. 2015. Groundwater assessment using GIS-based DRASTIC models in Shallow aquifer of Gabes North (South East Tunisia). *Arabian Journal of Geosciences* **8**, 19–29.

10. Engel, B et al. 1996. Estimating groundwater vulnerability to non-point source pollution from nitrates and pesticides on a regional scale. *International association of hydrological sciences* **235**, 521–526.
11. Foster, SSD 1987. Fundamental concepts in aquifer vulnerability, pollution risk and protection strategy. In: Duijvenbooden W. van and Waegeningh H.G. van (eds): TNO Committee on Hydrological Research, The Hague. Vulnerability of soil and ground water to pollutants, Proceedings and Information **38**, 69–86.
12. Gogur, F and Dassargues, A 1998. A short review on groundwater vulnerability assessment, basic statements for use in the framework of the cost 620 action. *Workshop* 18-20 May. University of Neuchâtel.
13. Hadžić, E et al. 2015. The importance of groundwater vulnerability maps in the protection of groundwater sources. Key study: Sarajevsko Polje. *Procedia Environmental Sciences* **25**, 104 -111.
14. Murat, V. et al. 2000. Etude comparative des méthodes d'évaluation de la vulnérabilité des aquifères à la pollution : application aux aquifères granulaires du Piémont Laurentien, Quebec. [Etude comparative des méthodes d'évaluation de la vulnérabilité des aquifères à la pollution : application aux aquifères granulaires du Piémont Laurentien, Québec]. *AIH-CNC et SCG*, 411-418.
15. Ribeiro, L 2000. Development of an index to assess the susceptibility of aquifers to contamination. [Desenvolvimento de um índice para avaliar a susceptibilidade dos aquíferos à contaminação]. *(não publicada), ERSHA-CVRM*, 1-8.
16. Rizka, M 2018. Comparative studies of groundwater vulnerability assessment. *Environmental Earth Sciences* **118**, 012018.
17. Samake, M et al. 2011. Groundwater vulnerability assessment in Shallow aquifer in Linfen basin, Shanxi province, China, using DRASTIC model. *Journal of Sustainable Development* **4**, 53-71.
18. Sinan, M and Razack, M 2007. An extension to the DRASTIC model to assess groundwater vulnerability to pollution: application to the Haouz aquifer of Marrakech (Morocco), special issue: *Environment: Survival and Sustainability*. 247-348.

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