International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Assessment of Nitrate Pollution of Groundwater by Vulnerability Methods (DRASTIC, GOD and SI): Application to the Alluvial Aquifer of the West of Mitidja (Sidi Rached -Tipaza)

Sbargoud Saida[a], Djeddou Rabia[b]*

[a, b] National Institute of Agronomic Research of Algeria (INRAA), 02, Avenue des Frères Ouaddek, BP 200- El Harrach-Alger-Algeria.

A B S T R A C T

The Sidi Rached basin is a plain which constitutes the western part of the large irrigated perimeter of Mitidja covering an area of 15,640 ha. Mitidja contains the largest aquifer in the country. The available resources of this aquifer are estimated at 300 hm3. Their exploitation is an economic imperative deemed a priority due to the fact that surface water resources are becoming increasingly scarce due to the combined effects of drought and the increase in the population and its needs. Given that this region is primarily agricultural, farmers are forced to intensify their production to ensure their income. This intensification results in an increase in nutrient inputs (fertilizers and others). This excessive input causes losses of pollutants, particularly nitrates, to the water aquifer and the hydrographic network. This nitrate pollution reduces the potential of good quality water resources, generates a health risk for the rural population and compromises the socio-economic development of the country. Therefore, and in order to protect the groundwater of Mitidja, a study of the vulnerability to pollution of the water aquifer by nitrates was carried out using two intrinsic vulnerability methods DRASTIC standard and GOD, and the specific vulnerability method to nitrate pollution SI. These different methods were applied by the geographic information system (GIS) software ArcGis10.22. The objective is to demonstrate the contribution of the combined use of GIS and these models to delimit areas at risk of nitrate pollution of this aquifer for better management of water resources. The validity of the application of these methods to the study of nitrate pollution of the aquifer in question was tested, by establishing a comparison between the distribution of nitrates in the waters of the aquifer and the distribution of vulnerability classes. This showed that the most valid methods are the intrinsic methods (DRASTIC and GOD) where the degrees of coincidence are 74.3% and 51.4% respectively. The different published maps can be used as decision support and spatial analysis tools for all future projects in the region.

Keywords: Vulnerability, pollution, nitrates, DRASTIC, GOD, SI, GIS, groundwater, water quality.

1. Introduction

The groundwater of the Sidi Rached aquifer is subject to multifaceted pollution which weakens this vast and rich plain. Mainly fed by rainwater but also by the infiltration of water from the wadis crossing the plain and permanently communicating with the alluvial water aquifer. The groundwater resources of this aquifer are increasingly in demand to cover the ever-increasing water needs in various areas (food, irrigation, industry, etc.). However, these groundwater resources are threatened by several factors linked to mismanagement, overexploitation and the intensive use of fertilizers and pesticides. The process is slow, but its effects are very dangerous (Baghvand et al., 2010) (from the ground to the unsaturated zone). Thus, whatever the nature of the chemical pollution (mineral pollutants) (Lain et al., 2007 in Attoui et al.2012, Lake et al., 2003), organic (pesticides) (Worrali et al., 2004) or bacteriological (bacteria, viruses) (Schijven et al., 2010), groundwater is affected. The nitrate level of 28.6% of water points (drills and wells) located in the Sidi Rached basin far exceeds the admissible WHO limit (50mg/L). The major question that arises is then, how can we manage and protect our water resources? For this, prevention and protection measures are required. This protection begins with the demarcation of so-called vulnerable or risk areas. With the aim of preserving groundwater resources and improving its management, this work consists of mapping its vulnerability to pollution by the application of three methods DRASTIC, GOD and SI which are considered as tools to help with decision regarding the management of groundwater pollution risks in the area in question and land use planning.

2. Materials and methods

2.1 Study area

The Sidi Rached watershed is located in the extreme west of the Mitidja plain and crosses two (02) wilayas (Tipaza and Blida). It is limited to the north by the Sahel and the wilaya of Tipaza, to the east by Attatba and El Affroun, to the west by Hadjout and to the south by the Blidén Atlas barrier. It occupies an area of 156.4 km2 and a population of 54,000 inhabitants. The main cities of the watershed are Sidi Rached, Ahmer El Ain and Bourkika. The Sidi Rached basin is subject to a coastal sub humid regional climate characterizing all of the coastal plains. As we move away from the coast, the climate becomes more and more continental and there is a significant drop in temperatures.

From a rainfall point of view, the rains are often irregular from one year to the next, they are characterized by a decreasing gradient from the East (625 mm in Sidi Rached) to the West (510 mm in Sidi Ghiles), and 'an increasing gradient from the coast towards the South, where stations in regions such as Menacer, Ahmeur el Ain located at the limits of the Bliden Atlas record average rainfall greater than 580 mm. The hydrographic network of the Sidi Rached basin is characterized by a set of watercourses which drain alluvium outcrops. To (from) the East we find Wadi Bouziane, to the South East Wadi Ahmer el Ain, to the West Wadi Ouriane and to the South-West the Wadi Guenidha and Wadi Saffah.

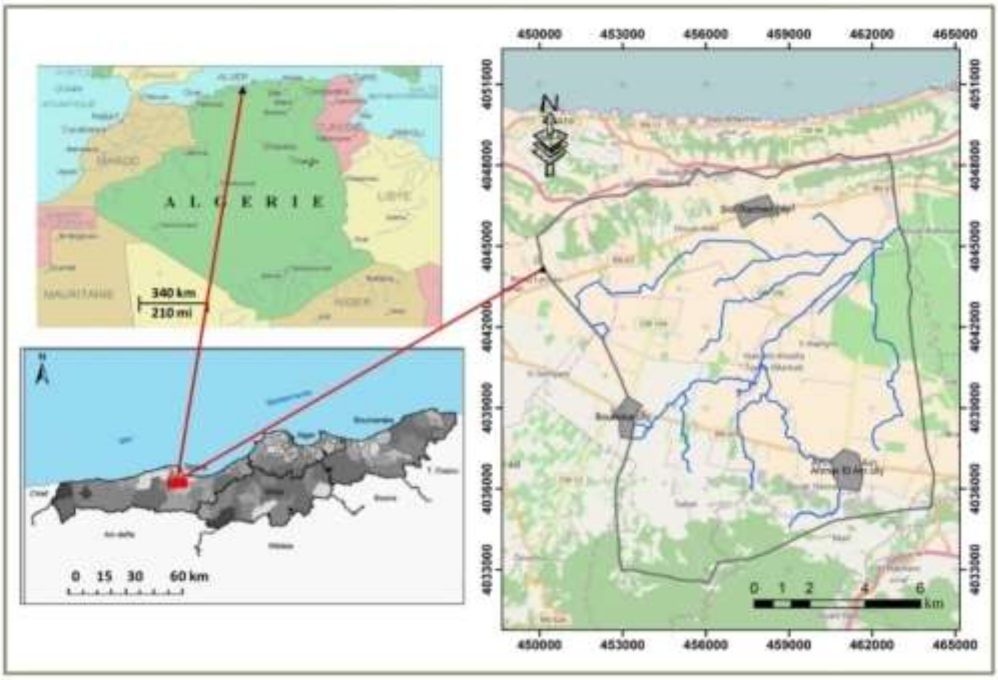


Fig. 1- Situation map of the study area (Sidi Rached-Mitidja west)

More than 200 boreholes and wells are currently exploited at the Sidi Rached aquifer for irrigation and drinking water. The Mitidja aquifer is recharged mainly by precipitation but also by underground inputs from the Blidèen Atlas. Geologically and hydrogeologically, the Sidi Rached basin contains two aquifer levels:

• The formation of Astien

• The Quaternary alluvium which rests on the boater's marls forming the watertight limit of almost the entire basin.

Between these two aquifers there is a semi-permeable clay-marl formation of the Villafranchian called el Harrach marl, the thickness of which is 100m in the center which decreases towards the south (Binnie and Atkins, 1983). The resources of this aquifer are threatened by the increasing use of chemical fertilizers in agriculture, as well as by urban and industrial discharges and the absence of water treatment plants. Indeed, nitrate levels exceeding standards have been observed in numerous boreholes and wells. This pollution is mainly due to agricultural intensification and urban discharges due to lack of sanitation network. The current situation is therefore critical. A major question that arises is, how to manage and protect this water resource? For this, prevention and protection measures are required. This protection begins by demarcating so-called vulnerable zones. It is with this aim in mind that this work is carried out and consists of mapping the vulnerability to pollution of the water aquifer in Sidi Rached (West Mitidja). As part of the present study, our choice focused on the application of three methods from the category of index mapping with weighting of criteria (Point County Systems Model PCSM), namely the standard DRASTIC method (Aller et al. A987) the GOD method and the SI (Susceptibility Index) method which is a specific vertical vulnerability method (developed in Portugal by Ribeiro (2000).

2.2 Data used

The application of the three methods DRASTIC, GOD and SI requires the collection of a set of data relating to hydrogeology, piezometrics, geology, morphology, pedology and topography of the natural environment. Each parameter requires a certain amount of data (Table 1).

Table 1 - Data used for calculation and mapping of DRASTIC and SI parameters.

Symbole	**Parameters**	**Source of Information**	**Summary of Process Followed**
D	Depth to water	Profiles of the borehole showing static and dynamic levels of the water aquifer within the study area; Topograohic map to the scale of 1/50,000 of Marengo N_62-B5-C15 and Tipaza N_40-B4-C15.	Static levels were interpolated using Arcgis 10 for the area of the study area
R	Net Recharge	Geology map, hydrogeological study and study of hydroagricultural development of the plain of Mitidja.	Net recharge was estimated by geology as a function of precipitation.
A	Aquifer Media	Geologic map to the scale of 1/50,000, geophysical map of Algiers and lithologic drill cuttings (National Agency of Hydraulic Resources and DHW of Tipaza).	The rock which serves as aquifer, pores or fractures related to the vulnerability to pollution.
S	Soil	Soil Map. Local soil taxonomy and textures	Soil taxonomy subgroups were linked to texture and translated into vulnerability ratings
T	Topography	Contour lines of Mitidja (ASTER GDEM version 2 of 30 m resolution—NASA and METI).	Contour lines were processed into a Global Digital Elevation Model. Using ArcGis 10.22, slope was calculated and translated to vulnerability ratings.
I	Impact of the vadose zone	Profiles of the borehole provided by ANRH and geologic map of Mitidja.	Reading of profiles from ANRH and confirmation with geology map.
C	Hydraulic conductivity	Direct data from works reporting local values and Geophysical prospecting	The values of the hydraulic conductivity were interpolated using Arcgis 10.22 for the study area.
LU	Land use	Land use map.	The land use map was established from the cadastral plan and field surveys using Arcgis 10.22.

2.3 Methods applied for assessing groundwater vulnerability

The precision of the estimation of the vulnerability of an aquifer depends mainly on the nature, quantity and reliability of the data used (Melloul et al., 2009), a very careful examination of the data was carried out with the aim of to highlight all available information. The compilation of the results of the field work (piezometry, flow tests and chemical analyses) and the available results made it possible to acquire usable data, which were prepared to apply the various calculations to the area studied. In the present study, the assessment of the degrees of vulnerability was made by applying the three methods DRASTIC, GOD and SI taking into account the availability of data relating to the required parameters.

2.3.1 Description of the DRASTIC method

The DRASTIC method was developed in the 1980s by the National Water Well Association, whose objective is to assess the risks of groundwater pollution (Suais and Durbar, 1993); (Vrba and Zaporozec, 1995). This method allows the establishment of vulnerability maps which constitute the synthesis of lithological, pedological and hydrogeological knowledge of a region.

The acronym DRASTIC corresponds to the initials of seven factors determining the value of the vulnerability index (Bézélgues et al. 2002):

D: Depth to water;

R: net recharge;

A: aquifer media;

S: soil;

T: topography;

I: impact of the vadose zone;

C: hydraulic conductivity of the aquifer.

Each of these parameters corresponds to a weight (predetermined value) between 1 and 5, which reflects the importance of the parameter in the transport processes and attenuation of contaminants. A predominant parameter is assigned a weight equal to 5 while a parameter having less impact on the fate of a contaminant is assigned a weight of 1. The weight values of the parameters of the DRASTIC method used are those defined by Aller et al. (1987). These values are shown in table (2).

Table 2 - Weight of DRASTIC parameters (Aller and al. 1987).

Parameters	**weights**
D: Depth to water;	5
R: net recharge;	4
A: aquifer media;	3
S: soil;	2
T: topography;	1
I: impact of the vadose zone;	5
C: hydraulic conductivity of the aquifer.	3

Each of the 7 parameters is associated with a rating varying from 1 to 10, defined according to intervals of values. The lowest rating represents the conditions of lowest vulnerability to contamination (Dc, Rc, Ac, etc.). For each DRASTIC parameter, we developed a parametric map based on the ratings and weighting coefficients given to the criteria. The ratings given to the DRASTIC parameters are illustrated in the following table (after Lallemand – Barrès 1994).

Table 3 - Ratings given to DRASTIC parameters (Lallemand-Barrès 1994)

D: Depth to water

Range (m)	Rating
0 à 2	10
2 à 4	9
4 à 6	8
6 à 8	7
8 à 11	6
11 à 14	5
14 à 18	4
18 à 25	3
25 à 33	2
> à 33	1

R: net Recharge

Range (cm)	Rating
0 à 5	1
5 à 10	3
10 à 15	6
15 à 25	8
>à 25	9

A: Aquifer media

Range	Rating
Karsts limestone	10
Basalt	9
Sand and gravel	8
Massive limestone	6
Massive sandstone limestone	6
Bedded sandstone	6
Glacial till	4
Metamorphic/igneous	3
Massive shale	2

S: Soil

Range	Rating
Thin or absent	10
Gravel	10
Sand	9
Shinking clay	8
Sandy loam	7
Loam	6
Silty loam	5
Clay loam	4
Muck	3
No shinking clay	1

T: Topography

Range (%)	Rating
0 à 2	10
2 à 6	9
6 à 8	8
8 à 10	7
10 à 12	5
12 à 18	3
>à 18	1

I: impact of the vadose zone

Range	Rating
Karsts limestone	10
Basalt	9
Sand and gravel	8
Sand and gravel and W. silt	6
Bedded limestone sandstone	6
Sandstone	6
Limestone	3
Shale	3
Silty clay	3
Confining layer	1

C: Hydraulic conductivity	
Range (m/s)	Rating
>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

The calculation of the DRASTIC vulnerability index noted ID specific to each hydrogeological unit is obtained by the sum of the products of the score by its weight according to equation (1) (Osborne et al. 1998):

$$ID = Dc \times Dp + Rc \times Rp + Ac \times Ap + Sc \times Sp + Tc \times Tp + Ic \times Ip + Cc \times Cp \qquad (1)$$

p. The weight of the parameter (varies from 1 to 5).

c. The associated rating (varies from 1 to 10).

The index thus calculated represents a measure of the level of contamination risk of the hydrogeological unit to which it is attached. This risk increases with the value of the index. It can take a maximum value of 226 (100%) and a minimum value of 23 (0%). The equation for converting ID index into percentages is then:

$$ID\ 5\% = (Idi - 1) \times 100 / 225 \qquad (2)$$

A classification was established by Engel et al 1996 which makes it possible to set the limits of the intervals of the calculated index and to match vulnerability classes to these index (Table 6). The assessment of this vulnerability index is only possible through comparative analysis between different hydrogeological units. To this end, a system for representing the degree of vulnerability has been developed to allow users immediate visualization of the latter.

2.3.2 Description of the GOD method

The GOD method is a parametric systems method developed by Foster in England in 1987 (Foster, 1987). It presents the vulnerability of the aquifer to the vertical percolation of pollutants through the unsaturated zone and does not address the lateral migration of pollutants in the saturated zone (Mardhel et al., 2005). It makes it possible to carry out a rapid assessment of vulnerability (Murat et al., 2003). It is based on three criteria: type of water aquifer (Ground water occurrence); type of aquifer in terms of lithological factors (Overall aquifer class) (Murat et al., 2000) and the depth of the water aquifer (Depth to groundwater aquifer).

Table 4 - Ratings assigned to vulnerability parameters according to the GOD method, Foster (1987); Foster and Hirata (1991) (in Draoui et al. 2007).

Aquifer type (G)	No aquifer					0	
	Confined and artesian aquifer					0.1	
	Confined and non-artesian aquifer					0.2	
	Semi-confined aquifer					0.3	
	Aquifer with fairly permeable surface cover					0.4-0.6	
	Unconfined aquifer					0.7-1	
Lithology of the Unsaturated Zone (O)	Residual soil					0.4	
	Alluvial silt, clay, marl, fine limestone					0.5	
	Aeolian sand, siltstone, tuff, fractured igneous and metamorphic rock					0.6	
	Sand and gravel, sandstone, tuff					0.7	
	Gravel (colluvium)					0.8	
	Limestone					0.9	
	Fractured or karst limestone					1	
Depth to water (D)	D (m)	0-2	2-5	5-10	10-20	20-50	50-100	>100
	Note	1	0.9	0.8	0.7	0.6	0.5	0.4

The ratings assigned to the classes of the different parameters are less than or equal to “1” (Table 4).

The determination of the GOD index (IGOD) is obtained by the multiplication of these three parameters, according to equation (3), where C is the rating assigned to the parameter (Murat et al., 2003, In Ake et al., 2009):

$$IGOD = IG \times IO \times ID \qquad (3)$$

After calculating the index, the vulnerability classes corresponding to the index intervals obtained are determined. The GOD Index has a minimum value of "0" (0%) and "1" (100%) as a maximum value. Generally speaking, the GOD index is divided into five vulnerability classes ranging from "very low" to "extreme" (Table 6).

2.3.3 Description of the SI method

The SI (Susceptibility Index) method is a specific vertical vulnerability method, developed by Ribeiro (2000) to take into account the behavior of pollutants of agricultural origin, mainly nitrates. To the parameters common to both methods is added a fifth which is land use (LU). The ratings assigned to the four parameters in the DRASTIC method have been preserved. A value called land use factor and denoted LU, varying from 0 to 100, is assigned to each land use class. Thus, the value "0" (less vulnerable) corresponds to forests and semi-natural areas while the value 100 (more vulnerable) is assigned to industrial landfills, garbage dumps and mines. The weights assigned to the SI parameters vary from 0 to 1 depending on the importance of the parameter in terms of vulnerability (Table 5).

Table 5 - Ratings given to DRASTIC parameters (Lallemand-Barrès 1994)

Land-use classes				**LU rating**	
Industrial discharge, landfill, mines				100	
Irrigated perimeters, paddy fields, Irrigated and non-irrigated annual culture				90	
Quarry, shipyard				80	
Artificial covered zones, green zones, continuous urban zones				75	
Permanent cultures (vines, orchards, olive trees, etc.)				70	
Discontinuous urban zones				70	
Pastures and agro-forest zones				50	
Aquatic milieu (swamps, saline, etc.)				50	
Forest and semi-natural zones				0	
Parameters	**D**	**R**	**A**	**T**	**OS**
Ratings	0.186	0.212	0.259	0.121	0.222

The calculation of the SI vulnerability index noted ISI specific to each hydrogeological unit is obtained by the sum of the products of each note by its weight according to equation (4). The calculation of the SI Index can be summarized by the formula:

$$ISI = Dc \times Dp + Rc \times Rp + Ac \times Ap + Tc \times Tp + LUc \times LUp \qquad (4)$$

In this procedure, inspired from the work of Jourda et al. (2007), the minimum rating that a parameter is available to have in the sector studied is 1 and the maximum rating is 26. The equation for converting the SI index into percentage is then:

$$ISI = \frac{(ISIi-1) X\ 100}{26} \qquad (5)$$

With ISIi = SI index to identify, ISImin = 1 and ISImax = 26.

Table 6 - Vulnerability index value intervals and corresponding classes.

DRASTIC vulnerability index	**GOD vulnerability index**	**SI vulnerability index (%)**	**Corresponding vulnerability classes**
/	0-0.1	0-30	Very low
<101	0.1-0.3	30-45	Low
101-140	0.3-0.5	45-60	Medium
140-200	0.5-0.7	60-75	High
>200	0.7-1	75-100	Very high

1.1. *Validation of vulnerability maps*

Any vulnerability map developed must be tested and validated through measurements and analysis of groundwater chemical data. Indeed, several authors Isabel et al. (1990); Champagne and Chapuis, (1993); Mohamed, (2001); Jourda et al., (2006); Hamza et al., (2007), Kouamé (2007), Gabriel Etienne et al (2009); verified the validity of methods for assessing vulnerability to pollution based on groundwater chemical data. In the case of our study, the validity of the assessment of vulnerability to pollution by the DRASTIC, GOD and SI methods was tested by the rate of nitrates in groundwater by establishing a comparison between the spatial distribution of nitrates. in groundwater and the distribution of vulnerability classes. For this purpose, the groundwater quality monitoring was carried out on agricultural boreholes for the years 2008 to 2010. 39 water samples were collected from the boreholes and analyzed and compared with regard to the rate of nitrates in the water with the distribution of vulnerability classes obtained by the three methods.

2.4 Comparison of vulnerability assessment methods

Comparing the results obtained by applying the three methods makes it possible to determine variations in vulnerability assessment in space. This comparison was carried out by the statistical analysis of the surfaces relating to the vulnerability classes and by the concordance test and the evolution of the vulnerability index.

2.4.1 The vulnerability classes concordance

The vulnerability classes evaluated by the three methods (DRASTIC, GOD and SI) will be subject to conformity testing to verify their concordance. The latter will be established by calculating the Kendall coefficient, the Kendall coefficient (aka Kendall W) represents the statistical index which measures the degree of agreement of an evaluation between three or more evaluators having to judge the same phenomenon.

$$W = \frac{12R}{m^2(K^3-K)} \qquad \textbf{(6)}$$

With

W: Kendall coefficient;

R: quadratic difference of classes;

k: vulnerability methods;

m: vulnerability classes.

This coefficient has a margin of variation between 0 and 1. It presents a degree of concordance which is all the higher as the value of the coefficient W is close to 1.

2.4.2 Statistical analysis of surfaces

The statistical analysis of the surfaces allows to know whether the three methods applied present an identical assessment of vulnerability or an overestimation of one in relation to the other. This analysis will focus on the area per class of the three vulnerability maps resulting from the three methods DRASTIC, GOD and SI.

3. Results and discussion

3.1 Level of vulnerability of the Sidi Rached aquifer according to DRASTIC

The DRASTIC method allowed us to calculate the vulnerability index, this index is between 72 and 150; the spatial distribution is illustrated in Figure 2a. Calculating vulnerability percentages using formula (2) and applying the classification of ENGEL et al. (1996), we have acquired us to obtain, in the Sidi Rached area, three (03) vulnerability classes (Figure 2a). The analysis of this map shows a dominance of areas with low and medium vulnerability in the majority of the water aquifer:

- The low vulnerability class occupying 65.4% (Figure 3a) of the study area. This class reflects a low vulnerability to pollution which can be explained by the low permeability and low recharge of the aquifer.
- The average contamination vulnerability class occupying 32.1% of the study area.
- The high vulnerability class is confined to the north of the basin. This class represents 2.5% of the area studied. This degree of vulnerability can be explained by the low thickness of the vadose zone (0 to 6m) associated with the gentle slope of the land. These conditions favor the infiltration of any contaminant present on the soil surface. These areas require special attention regarding future land use decisions.

3.2 Vulnerability level of the Sidi Rached aquifer according to GOD

The vulnerability index assessed by the GOD method range between 0.048 and 0.56 and represent four classes which vary from “very low” to “high”. The map resulting from this classification is presented in Figure 2b. His analysis revealed the spatial distribution of these classes, as follows:

- the “very low” and “low” classes are located mainly in the south of the basin and a little around the municipality of Bourkika, occupying respectively 3.4% and 64.8% of the mapped area. The low vulnerability index observed is explained by a very significant piezometric surface depth;
- the “middle” class is found in the center of the basin, in the northwest and southwest of the studied plain, and represents 31.8% (Figure 3b) of the study area. It causes less severe pollution in the event of contamination of the water aquifer. The average degree of vulnerability is linked to the lithology of the aquifer consisting of sand with clayey passage characterized by moderate hydraulic conductivity;

- the “strong” class occupies a very small part of the plain which extends from the south-east to the north, and represents the smallest proportion (0.4%). The high degree of vulnerability is explained by the lithological nature of the latter which is composed of gravel (colluvium), limestone and coarse sand.

3.3 Level of vulnerability of the Sidi Rached aquifer according to SI

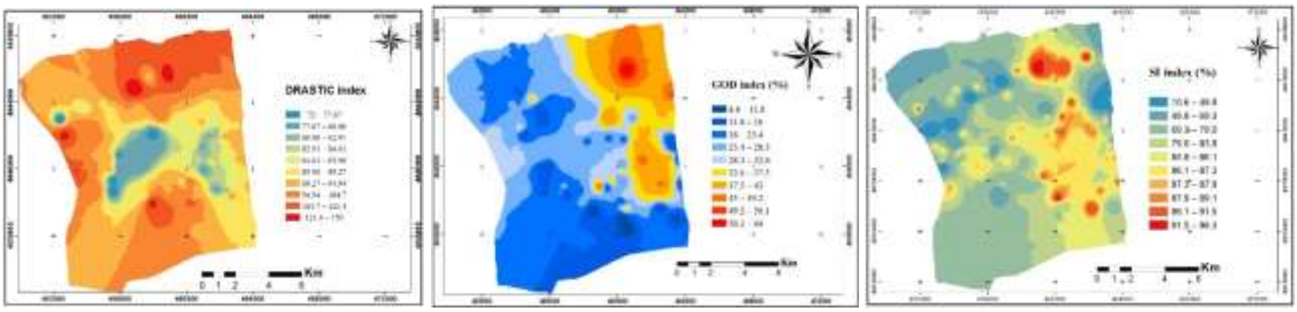
In Sidi Rached, the SI vulnerability map obtained after calculating the SI index indicates 10 classes which vary from 4.05 (minimum) to 26 (maximum). This index was divided into four (04) degrees of vulnerability to pollution (Figure 3): low, medium, high and very high.

- The “very low” classe is non-existent on the specific vulnerability map.
- The "low" and "medium" classes represent respectively 13.2% and 38.8% (Figure 3c) of the Sidi Rached region and meet to the south of the area studied (the Blidén Atlas barrier). In these areas, the intrinsic parameters of the aquifer considered are less favorable to pollutant penetration. Indeed, the slopes are high and the surface condition is dominated by dense forests. Thus, the anthropogenic activities carried out in these parts are less intense and therefore induce a specific vulnerability that is almost non-existent for the moment.
- As for the high and very high classes, they represent respectively 25.1% and 22.8% of the study area. Mostly located in the north and a little in the center of our study basin. They are characterized in terms of intrinsic parameters by sandy-clayey soils; low to medium slopes. The surface conditions are mainly made up of a mosaic of annual crops (cereals, vegetable crops, etc.) and permanent crops (fruit trees), crops that use fertilizer. These classes reflect the anthropic behavior of the region increasingly oriented towards agricultural intensification. These classes are linked to the characteristics of the area studied and qualitatively reflect the trend of local anthropogenic activities. However, in these areas, the intrinsic parameters of the water aquifer are favorable to the leaching of pollutants.

The SI index makes it possible to define the sensitivities of the Sidi Rached region in relation to nitrate pollution, just as the DRASTIC method has shown, these areas deserve particular protection attention.

Table 7 - Percentage of areas of vulnerability classes according to the DRASTIC, GOD and SI methods

Vulnerability class	DRASTIC		GOD		SI	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Very low	/	/	530	3.4	/	/
Low	10235	65.4	10129.7	64.8	2065.4	13.2
Medium	5020.3	32.1	4910	31.4	6076	38.8
High	384.7	2.5	70.3	0.4	3930	25.1
Very high	/	/	/	/	3568.6	22.9
Total	15640	100		100		100



a) DRASTIC method **b) GOD method** **c) SI method**

Fig. 2- Vulnerability maps of the DRASTIC, GOD and SI methods

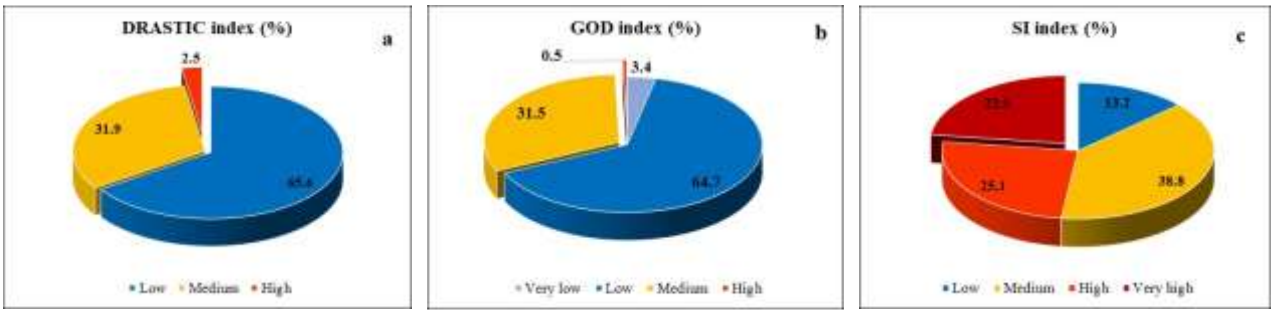


Fig. 3(a, b, c) - Graphical representation of vulnerability degrees of the alluvial aquifer of the West Mitidja (Sidi Rached), according to three methods.

3.4 Validation of vulnerability maps (DRASTIC, GOD and SI) to pollution

The validity of the application of the DRASTIC, GOD and SI methods to the study of nitrate pollution was verified at the level of the aquifer studied by comparing the distribution of nitrates in groundwater and the distribution of classes of vulnerability. We defined low nitrate concentrations as those below 50 mg/L, medium concentrations as those between 50 and 70 mg/L, and high concentrations as those above 70 mg/L. Figures 3a, 3b and 3c respectively represent the DRASTIC, GOD and SI pollution vulnerability maps, associated with the distribution of the three classes of nitrate concentrations. 35 boreholes and wells were the subject of chemical analysis in this present study. These analyzes indicate that the nitrate level in 28.6% of water points far exceeds the WHO admissible limit (50mg/L). We can deduct from the data in Table 8 that the nitrate concentration values are distributed as follows:

Table 8. Coincidence between nitrate concentrations and the different vulnerability classes of the DRASTIC, GOD and SI methods, case of Sidi Rached aquifer.

Method	Class	< 50mg/L	50mg/L<NO3<70mg/L	>70mg/L
DRASTIC	Low	**24**	4	4
	Medium	1	**1**	1
	High	0	0	0
GOD	Very low	0	0	0
	Low	**15**	2	4
	Medium	11	**3**	1
	High	0	0	0
SI	Low	0	0	0
	Medium	23	**3**	4
	High	2	2	0
	Very high	0	0	**1**

- For the DRASTIC map, among the 25 values below 50 mg/L, 24 coincide with the low vulnerability zone (96% of values), and one (4% of values) with moderate vulnerability. Among the 5 values located between 50 and 70 mg/L, 4 values (80%) coincide with the low vulnerability zone and only one (20%) with the medium vulnerability class. Finally, the 5 values above 70 mg/L coincide with the low vulnerability zone.
- For the GOD map, the 5 values exceeding 70 mg/L, 4 (80%) coincide with the low vulnerability zone and one value (20%) coincides with moderate vulnerability. Among the 5 values located between 50 and 70 mg/L, 2 (40%) coincide with the low vulnerability zone and 3 (60% of the values) with the medium vulnerability class. Finally, among the 25 values below 50 mg/L, 15 (60% of the values) coincide with the low vulnerability zone, and 10 (40% of the values) with moderate vulnerability;
- For the SI map, of the 25 values below 50 mg/L, 23 values (92% of the values) coincide with the medium vulnerability zone, and 2 (8% of the values) with the high vulnerability class. Among the 5 values located between 50 and 70 mg/L, 3 (60% of the values) coincide with the medium vulnerability class, and 2 values (40% of the values) with the high vulnerability class. Finally, 4 values (80%) exceeding 70 mg/L coincide with the zone of medium vulnerability, and one value (20%) with very high vulnerability.

3.5 Comparison of vulnerability assessment methods

The area obtained by class and by method (table 7) constitutes the basic element of comparison, whether for the Kendall test or for the statistical analysis of the area.

3.5.1 Kendall's test

The calculation of the Kendall's coefficient of concordance revealed that this test is reliable since the value of the Kendall's coefficient (W) is positive and therefore interpretable (W = 0.51) and the average correlation between the rows of table 9 is r = 35 %

3.5.2 Statistical analysis of risk areas by class

The comparison of the surfaces by classes, for the three methods, was made by subtracting the three vulnerability maps and resulted in the results illustrated in table 9. By assigning the values 1, 2 and 3, to the different vulnerability classes respectively low (very low + low), medium and high (very high + high) obtained by the three methods and by crossing the classes, we arrive at the results recorded in table 10.

Table 9. Comparison of areas by classes, for the three methods DRASTIC, GOD and SI.

	DRASTIC				
GOD	Classes	Low	Medium	High	Total
	Very low	530	00	00	**530**
	Low	8205	1540	384.7	**10129.7**
	Medium	1500	3410	00	**4910**
	High	00	70.3	00	**70.3**
	Total	**10235**	**5020.3**	**384.7**	**15640**
	DRASTIC				
SI	Low	2070	00	00	**2070**
	Medium	5910	145	00	**6055**
	High	1900	2045	00	**3945**
	Very high	355	2830.3	384.7	**3570**
	Total	**10235**	**5020.3**	**384.7**	**15640**

	GOD					
SI	Classes	Very low	Low	Medium	High	Total
	Low	530	1540	0	00	**2070**
	Medium	0	4720	1335	00	**6055**
	High	0	2311.1	1633.9	00	**3945**
	Very high	0	1558.6	1941.1	70.3	**3570**
	Total	**530**	**10129.7**	**4910**	**70.3**	**15640**

Table 10. Percentages of surfaces according to the index differences between the DRASTIC, GOD and SI methods.

DRASTIC et GOD						**Cohen's Kappa Index**
Index difference	-2	-1	0	+1	+2	
Percentage %	0	10.04	77.7	9.8	0	
Total		**10.04**	**77.7**	**9.8**		**K =0.51**
DRASTIC et SI						
Index difference	-2	-1	0	+1	+2	
Percentage %	14	69	16.6	0	0	
Total		**83**	**16.6**	**0**		**K = 0.07**
GOD et SI						
Index difference	-2	-1	0	+1	+2	
Percentage %	24.6	53.15	22.28	0	0	
Total		**78.75**	**22.28**	**0**		**K = 0.10**

The interpretation of the latter revealed that the "- 2" and "+ 2" classes have a zero percentage and that the "0" class represents the largest proportion (77.7%) and a kappa index of 0.51, where the DRASTIC and GOD methods are in concordance and have identical index. This confirms the concordance of the two methods also carried out by Murat and Fofana (2005). Although two thirds of the study area are evaluated with identical index (77.7%), we note some variations in index, in this case an undervaluation (10.04%) and an overvaluation (9.8%) index of the DRASTIC method compared to the GOD method. This difference is linked to the number of parameters used by the DRASTIC method, compared to the GOD method, because with 7 parameters the vulnerability by the DRASTIC method is more detailed than by the GOD method which only uses 3 parameters, which makes that the latter sometimes tends to underestimate vulnerability. The interpretation of the percentage of surfaces according to the differences in index between DRASTIC and GOD revealed that class "0" represents the lowest proportion (16.6%) and a very low kappa index (0.07) where the DRASTIC and SI methods do not match and have different index. We note an underestimation (83%) of the DRASTIC index compared to the SI method. Likewise, for the differences in index between GOD and SI, we note that class "0" represents a proportion of 22.28% and a kappa index of 0.10, which explains why these two methods do not agree and have different index. We also note an underestimation (78.75%) of the GOD index compared to the SI method.

2. Conclusion

The mapping of the vulnerability of the Sidi Rached aquifer carried out by the application of the DRASTIC, GOD and SI methods coupled with the geographic information system (GIS) reveals a trend of vulnerability to pollution low (48.9%), average (34.1 %) to high (17%), which allows us to say that this aquifer is threatened locally, by the infiltration of pollutants from the ground surface. Even if the high vulnerability class only represents 17% of the total area of the basin, the risk is significant given the presence of several sources of pollution in the region, namely: excessive inputs and domestic discharges from villagers. The comparison of the vulnerability maps (DRASTIC, GOD and SI) using the Kendall test (w) showed us that there is concordance between these three methods, since the value of the Kendall concordance coefficient (w) is positive. therefore, interpretable is 0.52. The comparative study of the DRASTIC, GOD and SI vulnerability maps and the available nitrate measurements shows that the least valid map for the assessment of vulnerability to nitrate pollution is that of SI, with a total percentage of coincidence between nitrate concentrations and different degrees of vulnerability is 14.3%. While for the DRASTIC and GOD vulnerability maps are 74.3% and 51.4% respectively. This comparison also shows that the GOD method is the most valid for the assessment of vulnerability to nitrate pollution because it better explains the comparison of the measured nitrate classes and the vulnerability classes with a degree of coincidence of 60% for the low vulnerability class and 60% for the medium vulnerability class. The analysis of the surfaces by classes of the two methods (DRASTIC and GOD) showed that 77.7% of the mapped area represents identical index. The DRASTIC method revealed an underestimation (10.04%) and an overestimation (9.8%) of index compared to the GOD method, which suggests that the two vulnerability maps are relatively close.

References

Achi K. Salem A., Combes, P. Couchot, A., Grenet B., Pradines D., 1973 : Carte hydrogéologique d'Alger au 1/200 000, ANRH d'Alger.

AGROCOMPLET/ENERGOPROJET, 1978 : Schéma général de l'aménagement hydraulique de la Mitidja.

Al Hallaq, A. & Abu Elaish, B., (2008) "Determination of Mean Areal Rainfall in the Gaza Strip Using Geographic Information System (GIS) Technique", Journal of Pure & Applied Sciences, University of Sharjah, UAE, Vol. 5, No. 2, pp. 105-126

Al Hallaq, A. & Abu Elaish, B., (2011) "Determination of Groundwater Vulnerability Zones to Contamination in Khanyounis Governorate, Gaza Strip, Using the DRASTIC Model within GIS", Journal of Social Sciences, Umm Al-Qura University, Vol. 4 - N0.1, 55p.

Aller L, Benett T, Lehr JH, *et al*. Drastic: a standardized system for evaluating ground water pollution potential using hydrogeologic settings. *National Water Well Association* 1987 ; Rapport EPA-600/2-87-035 ; 622 p.

A. T. Anani (2006): Evaluation et cartographie des zones vulnérables à la pollution de la nappe du Continental Terminal au niveau du District d'Abidjan (Sud de la Côte d'Ivoire), par les méthodes DRASTIC et GOD. Mémoire de DEA des Sciences de la Terre et des Ressources Minières, Université de Cocody, 71p.

CGG. Prospection géophysique de la plaine de Mitidja. ANRH d'Alger, 1967.

Ecrement Y., et Seghir B., 1971 : Etude Agro pédologique de la plaine de la mitidja. Rapport Direction des Etudes, milieu et Rech. Hydraulique.

F. Fofana (2005) : Evaluation et cartographie de la vulnérabilité à la pollution de la nappe d'Abidjan selon les méthodes DRASTIC et GOD. Mémoire de DEA, Université d'Abobo- Adjamé, 68p.

HAMZA M.H., A. ADDED, R. RODRIGUEZ, S. ABDELJAOUED, A. BEN MAMMOU (2007). A GISbased DRASTIC vulnerability and net recharge reassessment in an aquifer of a semi-arid region (Metline-Ras Jebel-Raf Raf aquifer, Northern Tunisia). *J. Environ. Manage*., 84,

Hamza M.A., A., Added, A. Frances, R., Rodriguez, M. Ajmi et S. Abdeljaoued (2008) : Évaluation de la vulnérabilité à la pollution potentielle de la nappe côtière alluvionnaire de Meltine-Ras Djebel-Raf Raf (Nord-est tunisien) selon les méthodes paramétriques DRASTIC, SINTACS et SI ». Revue des sciences de l'eau / Journal of Water Science, vol. 21, n° 1, 2008, p. 75-86.

Isabel D, Gelinas P, Aubre F. Cartographie de la vulnérabilité des eaux souterraines au Québec. *Rev Sc Tech Eau* 1990 ; 23 : 255-8.

J.P. Jourda, K. J. Kouamé, M. G. Adja, S. K. Deh, A. T. Anani, A. T. Effini, et J. Biémi (2007) : Evaluation du degré de protection des eaux souterraines : vulnérabilité à la pollution de la nappe de Bonoua (Sud-est de la Côte d'Ivoire) par la méthode DRASTIC. Session Environnement/Eau, 11p.

Mac Donald, M.et partners limited Cambridge, Anleterre en association avec W.S. Atkins et partners, BNEDER 1992 : Etude de l'aménagement hydro-agricole de la plaine de Mitidja.

Mac Donald, M.et partners limited Cambridge, Anleterre en association avec W.S. Atkins et partners, BNEDER 1997 : Etude de l'aménagement hydro-agricole de la plaine de Mitidja.

Menani MR. Étude hydrogéologique de la plaine d'El Madher (Algérie orientale) : géologie, climatologie, hydrogéologie et modélisation des écoulements souterrains de l'aquifère mio-plio-quaternaire. Thèse Doct. Univ. Nancy 1, Labo. GES, 1991 ; 409 p.

R. M. Mohamed (2001) : Evaluation et cartographie de la vulnérabilité à la pollution de l'aquifère alluvionnaire de la plaine d'El Madher, Nord-Est algérien, selon la méthode DRASTIC. Sciences et changement planétaires / sécheresse, vol. 12, n°

Saida, S., Tarik, H., Abdellah, A., Farid, H. & Hakim, B. 2017 Assessment of groundwater vulnerability to nitrate based on the optimised DRASTIC models in the GIS environment (Case of Sidi Rached Basin, Algeria). Geosciences 7 (2), 20.