Advanced Journal of Environmental Science and Technology Vol. 1 (1), pp. 001-012, September, 2013. Available online at www.advancedscholarsjournals.org © Advanced Scholars Journals

Full Length Research Paper

Assessment of groundwater pollution by nitrates using intrinsic vulnerability methods: A case study of the Nil valley groundwater (Jijel, North-East Algeria)

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Accepted 9 August, 2013

Scientists are deeply concerned with the state of vulnerability of groundwater reservoirs. It is a complex task because of the difficulties in determining the degree of pollution of the ground water. Many methods have been adopted like DRASTIC, GOD, SI, SINTACS, etc. The present article targets the determination of the vulnerability of groundwater reservoirs of a climatic Mediterranean region (Nil valley region, Jijel). The excessive use of fertilizers in agriculture has been the main reason behind the increase of the Nil valley groundwater pollution with nitrates (Jijel, North-East Algeria). In fact, the use of fertilizers in high quantities relatively to the needs of the plants lead to the leaching and infiltration of the excess fertilizers into groundwater which increases the nitrates percentage; as a result, the allowed norms of water consumption are exceeded. Relevant to this, the aim of this study was to assess the aquifer vulnerability caused by pollution with nitrates using DRASTIC, GOD and SI methods. The spatial distribution of the found nitrates in groundwater shows that the DRASTIC method is the most appropriate method in this case with a percentage of 71% vs. 54 and 63% for GOD and SI methods, respectively. Moreover, it was found that the studied water is characterized by a medium to high degree of vulnerability. Pertinent to this, it is highly recommended to find solutions to better protect and preserve the Nil valley groundwater.

Key words: Aquifer vulnerability, pollution, nitrate, agriculture, groundwater protection.

INTRODUCTION

Groundwater reservoirs are easily affected by pollution. The process is slow but its effects are very dreadful (Baghvand et al., 2010) (from the ground to the unsaturated zone). Thus, whatever the nature of the physical pollution (radioactivity), be it chemical (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), the aquifers are affected.

In agricultural areas, in particular, an excessive use of fertilizers has directly or indirectly affected the groundwater quality (Huang et al., 2012). But beyond the quantitative aspect, it is also advisable to remain vigilant on the level of the water quality consumed by the populations (Diodato et al., 2013).

Nitrate is a common compound, naturally generated from the nitrogen cycle. However, anthropogenic sources have greatly increased the nitrate concentration, particu-

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larly in groundwater (Chand et al., 2011). Nitrate losses from non point agricultural sources, mainly originated by fertilizers application, have been recognized as one of the most serious threats for pollution of groundwater (Salemi et al., 2012). An improvement of knowledge is however essential to make the water services more powerful and to reinforce the policy for the access to safe water in the country (Diodato et al., 2013).

However, the prevention against groundwater pollution constitutes an important phase to which scientists are doing their best notably in studying the vulnerability of the groundwater. They therefore, created classical scientific methods (Etienne et al., 2009) and numerical (Boufekane and Saighi, 2010), to facilitate the identification of the state of these groundwaters and to control the pollutants in the reservoirs such as DRASTIC, GOD, SINTACS, etc. These different methods are presented under the form of numerical quotation systems based on the consideration of the different factors influencing the hydrogeological system (Rouabhia, 2004, in Attoui et al., 2012).

Prevention of aquifers pollution is considered as an important factor in the management of groundwater resources; also, the assessment of aquifer vulnerability by scientists is an essential factor which gives us solutions to protect groundwater resources. The Nil valley ground-water (Jijel, Algeria) which is characterized by a favorite vegetables and greenhouse gardening activity undergo a contamination by nitrates due to the use of fertilizers in agriculture. In order to prevent groundwater resources pollution, the present work studies the aquifer by using three parametric methods named DRASTIC, GOD and SI, by examining the surface activities which characterize the aquifer. The obtained vulnerability maps via the three methods are validated by comparison with the observed nitrates in the groundwater.

Description of the studied area

The studied area is located in the north-east of Algeria. The alluvial aquifer of this area forms part of the coastal plains region of Jijel (Figure 1); it covers an area of 83 km^2 and opens to the north of the Mediterranean Sea. It corresponds to the lower Nil valley and its two tributaries, Boukaraa valley (left bank) and Saayoud valley (right bank). This region is characterized by a few natural lakes and swamps, the most notable are downstream of the plain: Ghedir Beni Hamza in the north-east and Ghedir el Merdj in the north-west.

The maritime location of this region gives to it a mild and damp climate. The average air temperature is 17°C/year, while rainfall, relatively high, reaches 900 mm/year. In addition, the geological substratum of the area consists of gneiss and the schist. However, the parts of swallow, sedimentary formations mainly marly Oligocene age, Miocene and Pliocene cover these metamorphic facies. Finally, the depressions and valleys are filled with quaternary alluvial deposits which are interstation terraces aquifers.

The groundwater recharge is mainly directed by infiltration of rainfall and the low water situation by the various rivers which cross the plain. The aquifer forms part of the socio-economic development of the region by the exploitation of the domestic wells and boreholes (36 million m^3/year).

MATERIALS AND METHODS

Working environment

The study is based on the obtained measurements from the field surveys that were conducted during the hydrological year, 2010-2011 and supplemented by the compilation of the information collected from various technical services of the willaya of Jijel (National Agency Resources Water, Direction of the Water Resources, Direction of the Agricultural Services). The data was collected from:

1. Piezometric campaign conducted in September 2010,
2. Results from pump tests in 36 wells; in fact, these results allow to deduce the transmissivity values (T ranging between 10^{-3} m^2/s and 10^{-2} m^2/s) and permeability values (K = 10^{-4} to 10^{-3} m/s).
3. Data sheets and logs of the geological drilling.
4. Results of geophysical interpretations (maps of apparent resistivity, resistance transversal, cuts geoelectrical).
5. Cartographic documents on the scale 1/50 000 (geological map and soil map, topographic maps of Jijel, Sidi Merouane) and with the 1/25 000 (topographic maps of Jijel and Texanna).
6. Digital maps of land at 1/10 000 (Chekfa, Taher and EL Kennar),
7. Slope map and Digital Elevation Model (DEM).
8. The meteorological data (hydrological year 2010/2011) in order to assess the water balance and estimate the blade infiltrated water.

Data preparation

The documents of the different parameters allowing the map development of vulnerability by groundwater pollution have been created accordingly to values grid by using regular grid of 25 x 25 m by cutting the 83 km^2 of the study area (elementary units of this size).

Presentation of the used methods for vulnerability assessment

DRASTIC method

DRASTIC method was developed by the staff of the U.S. Agency for Environmental Protection USEPA (Aller et al., 1987). It allows the assessment of vulnerability of the vertical aquifer pollution caused by parametric systems. It is based on the estimation of 7 parameters in particularly, the percentage of the effective recharge, the soil type and the characteristics of the saturated and unsaturated zones of the aquifer. Each parameter, divided to an interval of significant values, is assigned by a numerical rating based on its growing importance in the vulnerability. These seven

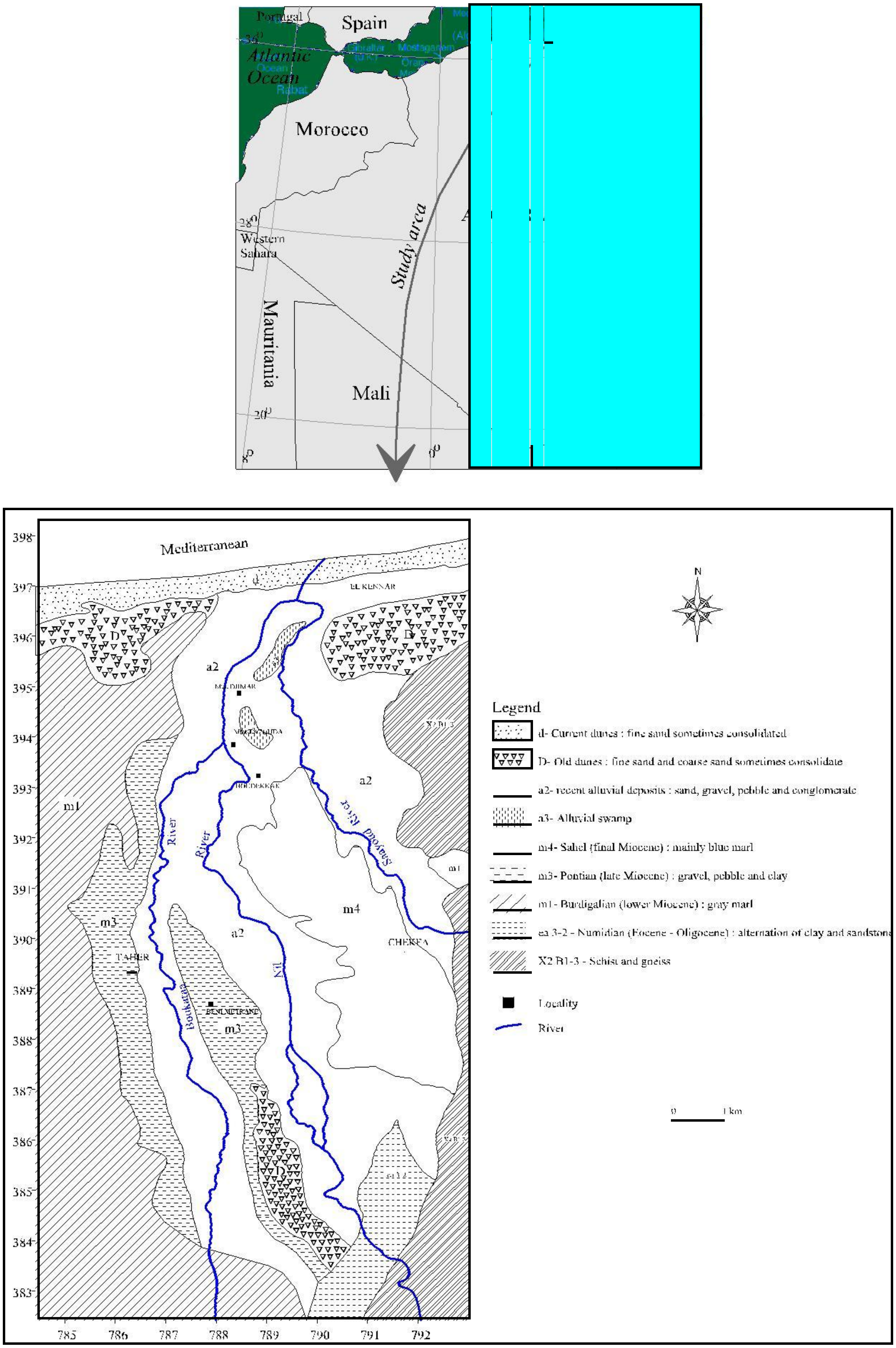

Figure 1. Map showing geology of the studied area.

Table 1. Weight settings of DRASTIC (Aller et al., 1987).

Symbol	Parameter	Weight
D	Water depth	5
R	Effective recharge	4
A	Middle aquifer	3
S	Soil type	2
T	Topography	1
I	Impact of the vadose zone	5
C	Hydraulic Conductivity	3

Source: Aller et al. (1987).

Table 2. Criteria of the vulnerability assessment by using DRASTIC method (Engel et al., 1996).

Class vulnerability	Low	Average	High	Very high
Index	<101	101-140	141-200	>200

Source: Engel et al. (1996).

parameters are used to define the different hydrogeological units, variously influenced by transport processes and attenuation of contaminants in the soil. Numerical value called a weight parameter, between 1 and 5 is assigned to each parameter and reflects its influence degree. Each parameter is listed based on the associated scores ranging from 1 to 10, the lowest score represents the conditions of the lower vulnerability contamination; also, to describe the vulnerability degree of each hydrogeological unit, the numerical value called DRASTIC vulnerability index should be determined.

The DRASTIC vulnerability index was calculated by addition of the different products (score × weight of the corresponding parameter):

DRASTIC Index = $D_w D_r + R_w R_r + A_w A_r + S_w S_r + T_w T_r + I_w I_r + C_w C_r$

Where: D, R, A, S, T, I and C are the seven parameters and the subscripts r and w are the corresponding rating and weights, respectively.

The partial index of each parameter is then calculated using the equation:

Partial index = weight × rating

So, the DRASTIC index is defined by the scores of the all vulnerability parameters multiplied by their respective weights.

The DRASTIC weight parameters, defined according to Aller et al (1987), are shown in Table 1.

The extent of vulnerability of the aquifer hydrogeological is defined by the indices DRASTIC. These indices are divided into four classes and vary between the extreme values ranging from 23 to 226 (Engel et al., 1996), (Table 2).

GOD method

This method is characterized by a rapid assessment of the aquifer vulnerability; it was developed by Foster in 1987 and 1998 (Ferreira, 2004) for studying the vulnerability of the aquifer against the vertical percolation of pollutants through the unsaturated zone, without considering their lateral migration in the saturated zone.

The approach used in this model takes in consideration three parameters:

1. Groundwater occurrence
2. Overall aquifer class
3. Depth table of the groundwater.

The GOD index which is used to evaluate and map the aquifer vulnerability caused by the pollution, was calculated by multiplication of the influence of the three parameters using the followed equation:

GOD Index = $C_l \times C_a \times C_d$

Where: Ca is the type of aquifer, Cl is the lithology of the unsaturated zone and Cd is the depth on the water surface.

The GOD indexes are divided into five classes and vary between the extreme values ranging from 0 to 1 (Table 3).

SI method

The SI method (Susceptibility Index) was developed in 2000 in Portugal by Ribeiro; it is used to assess the vulnerability of vertical agricultural pollution generated mainly by nitrates and secondarily by pesticides. This method is based on five parameters:

The first four (D: water depth, R: effective recharge, A: middle aquifer, T: topographic slope of the land) are identic with those used in the DRASTIC method. The fifth parameter (LU) represents Land. The dimensions of five parameters and their corresponding individual classes are given in Table 4.

The lands are classified accordingly to the Corine Land Cover (European Community, 1993). Each land class is assigned by a factor land use (LU) ranging from 0 to 100 (Table 5). The assigned values to the parameters of the different classes have been multiplied by 10 to facilitate the reading results, they range from less

Table 3. Intervals values of GOD index and corresponding classes.

Class vulnerability	Very low	Low	Average	High	Very high
Index	0 - 0.1	0.1 - 0.3	0.3 - 0.5	0.5 - 0.7	0.7 - 1

Source: Murat et al. (2003).

Table 4. SI method parameters and their corresponding weight.

Symbol	Parameter	Weight
D	Water depth	0.186
R	Effective Recharge	0.212
A	Middle aquifer	0.259
T	Topography	0.121
LU	Land Use	0.222

Source: Ribeiro (2003).

Table 5. Main soil occupation classes and their correspondant land use (LU) values.

Land classification according to the Corine Land Cover	LU (land use factor)
Industrial waste discharges, landfill	100
Irrigated rice fields	90
Caries, shipyards, open-air mines	80
Areas covered artificial, green spaces	75
Permanent crops (vine yards, orchards, olive, etc.)	70
Discontinuous urban areas	70
Pasture and agro-forestry	50
Aquatic environments (salt marshes, salinas, etc.)	50
Forests and semi-natural zones	0

Source: Ribeiro (2000) .

Table 6. Criteria for the evaluation of vulnerability in the SI method.

Class vulnerability	Low	Average	High	Very high
Index	< 45	45 - 64	65 - 84	85 - 100

Source: Ribeiro (2000)

vulnerable to most vulnerable. The assigned weights to the SI parameters vary from 0 to 1 depending on the size of the parameter in vulnerability.

According to their index values, the SI method has four degrees of vulnerability (Table 6).

Validation of vulnerability maps

The developed vulnerability maps by each method are then compared with the results of the hydrochemical analyzes of pollutants. In this study, we are only interested in studying the nitrates percentage and their distribution in the aquifer. For this purpose, 35 samples are analyzed and compared with respect to the nitrates map in the water with the distribution of the vulnerability classes obtained by the three methods.

RESULTS

DRASTIC method

The obtained values of the DRASTIC index vulnerability

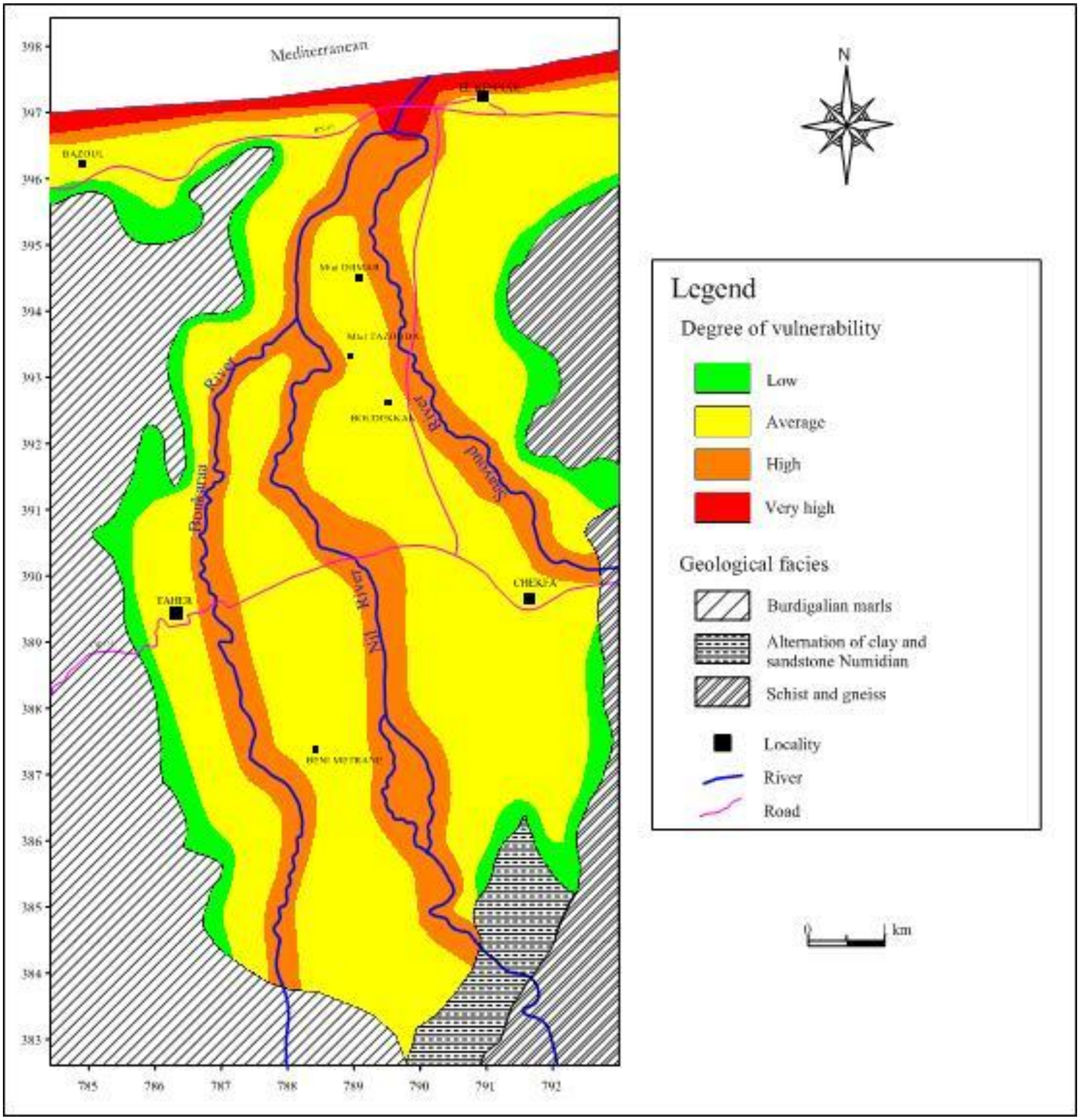

Figure 2. Aquifer vulnerability map (DRASTC method).

by this method vary from 85 to 210. Their spatial distribution allows distinguishing, within the studied area, four zones with different degrees of vulnerability (Figure 2), closely related to the hydrographic network.

a. The zone with very high vulnerability at the coast affects more particularly the mouth of Nil valley. It occupies around 3% of the studied plain. This high degree of vulnerability can be explained by the shallow aquifer as well as the existence of a permeable massif of dunes, allowing the infiltration of pollutants present at the surface.

b. The zone with high vulnerability encompasses the previous one and penetrates inside the land along the topographic drains of the Nil valley and its two tributaries, Saayoud and Boukaraa. This second zone represents 26%

26% of the plain surface area, and juxtaposes the extended areas of the major waterways, where the major sediments composing the alluvial terraces are dominant, and the piezometric level is shallow (1.5 to 5 m). Such characteristics favor the penetration of pollutants to the aquifer, particularly in the depressed parts.

c. The zone with an average vulnerability covers about two-thirds (2/3) upstream the plain, where, despite the importance of gravelly and sandy fraction of the aquifer, it is less protected from pollution because of its shallow depth from the surface (generally more than 5 m).

d. The zone which is a bit vulnerable corresponds to the edges of the plain and covers 10% of the area. Its low vulnerability is due first to the depth of the aquifer (about 10 m) and secondly, to the low permeable covering soil and the unsaturated zone.

GOD method

GOD indices show values ranging from 0.16 to 0.54. Their low dispersion allow differentiating just three zones of vulnerability (Figure 3), whose spatial distribution, somewhat different from the DRASTIC case, is as follows:

a. The highest degrees of vulnerability are located, as before, in coastal areas, especially at the Nil river. However, they remarkably invade inland up along Boukraa and Saayoud valley, around 4 km. This area covers 18% of the plain area and, as already mentioned, corresponds to shallow-aquifer areas (1.5 to 5 m), associated with a highly permeable sediments at surface (dune, sandy and gravelly aquifer, etc.).

b. Moderate vulnerability zones contain the previous one and go up further along the valley, until covering 47% of the plain surface area. The aquifer is situated between 5 and 9 m deep and consists of gravel and sand that promote the spread of pollutants, despite the sporadic presence, in the airy area, clay and marly intercalations.

c. Regarding DRASTIC case, though somewhat wider, low-vulnerability band surrounds the plain. On the other hand, the valley intervals also indicate low vulnerability levels because the underground water there is more than 12 m deep, and saturated and unsaturated zones are a bit permeable. The cumulative surface area of low vulnerability areas reaches 35%.

SI method

As a result of its analogy with DRASTIC method (DRST parameters identity), it is sufficient in this case to define the land use parameter (LU) in order to immediately deve-lop the vulnerability map, SI. The results reveal index values ranging from 33 to 91, defining four (4) areas on the vulnerability map (Figure 4). The configuration of this map exhibits similarities with both GOD map in highly vulnerable areas (coast and Nil valley mouth) and the Drastic map, concerning the rest of the plain. This third map highlights the particular behavior of the major valley beds which act as preferential paths of contamination. According to a descending vulnerability degree, the four individualized cover areas of 21, 25, 44 and 10% respectively.

Vulnerability maps validation to nitrate pollution

Nitrate spatial distribution into groundwater

Nitrate concentrations spatial variation into groundwater depends on agricultural activities, covering soil lithology and airy area thickness. Recorded contents in 35 samples (19 drillings and 16 wells) collected in September 2010 (Figure 5) show the following:

1. The highest values are observed in the northeast corner of the plain. These values frequently exceed the threshold of 50 mg/l tolerated by the WHO (World Health Organization) for drinking water. Nitrate high-concentration in this corner is attributed to dense market and greenhouse gardening activity. Furthermore, this northeast area is characterized by shallow groundwater and permeable aquifer.
2. Outside this corner area, nitrate contents progressively decrease upstream, while still remaining relatively high at the Nil valley mouth (40 mg/l) and along two of its tributaries, Saayoud and Boukeraa, revealing leaching bands of highly fertilized agricultural fields.
3. In the rest of the plain, nitrate concentrations are close to 20 mg/L. Traditional soil fertilization practices and clay covering soil, allow protection of groundwater against pollution. It is in this area, and more precisely, between Djimar and Tazouda, where the main field of water gathering area is found. Further upstream, nitrate levels are below 20 mg/l.

Nitrate distribution and vulnerability maps comparison

Comparison of nitrate-concentration distribution map and that vulnerability levels obtained by each approach, shows the following:

a. DRASTIC map case

i. The three samples whose concentrations exceed 45 mg/l correspond to average-vulnerability area;
ii. From nine samples whose contents vary between

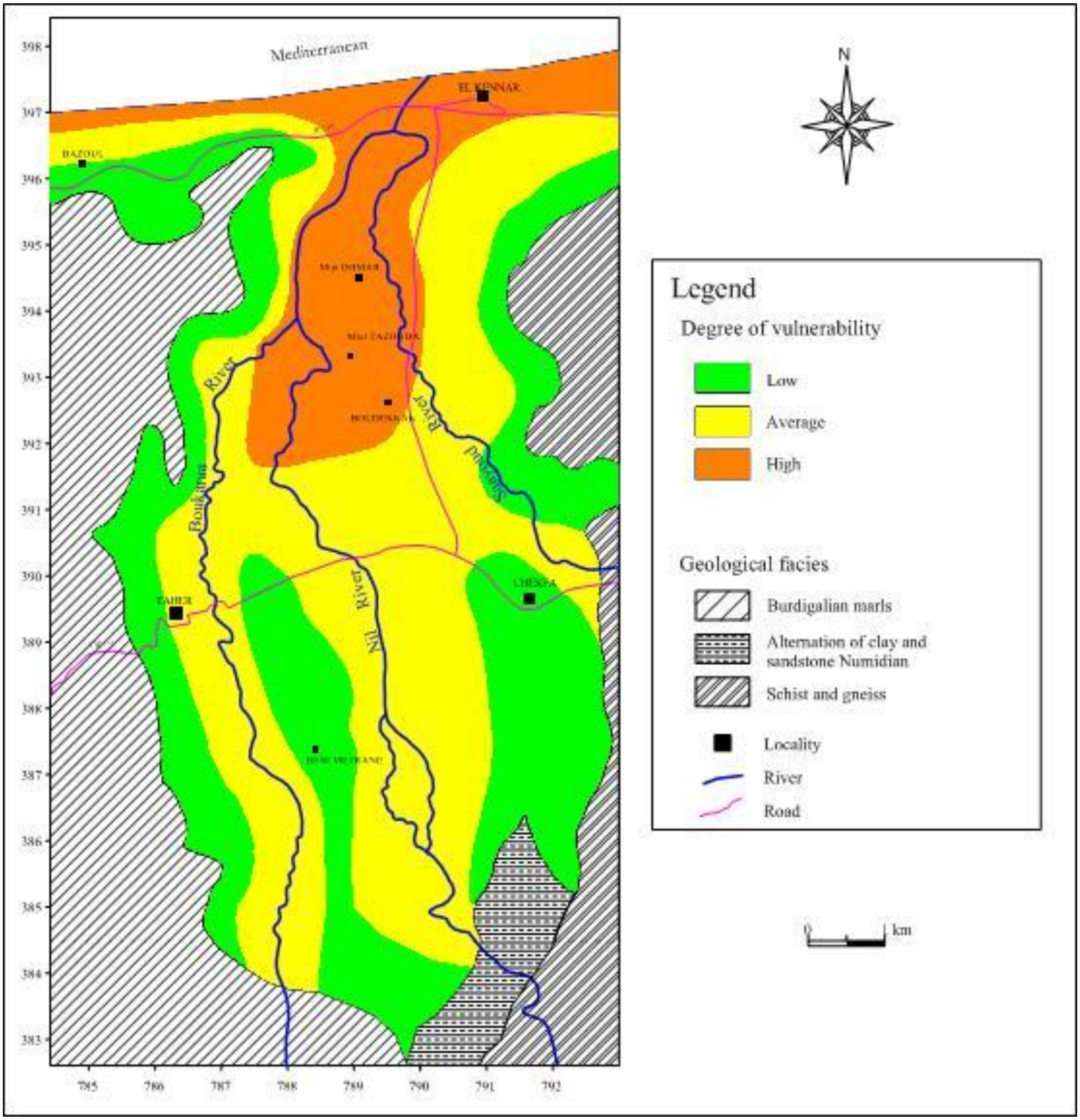

Figure 3. Aquifer vulnerability map (GOD method).

15 and 30 mg/l, two (2) samples coincide with average-vulnerability area, and seven (7) left, with high-vulnerability zone;

iii. Concerning the twenty-two (22) samples with contents below 15 mg/l, water point lies in the low-vulnerability zone, 15 in the average and six (6) in the high one.

b. GOD map case

i. The three samples with contents exceeding 45 mg/l correspond to the average-vulnerability zone;

ii. The nine samples exhibit contents ranging between 15 and 30 mg/l, equally spread among the three vulnerability

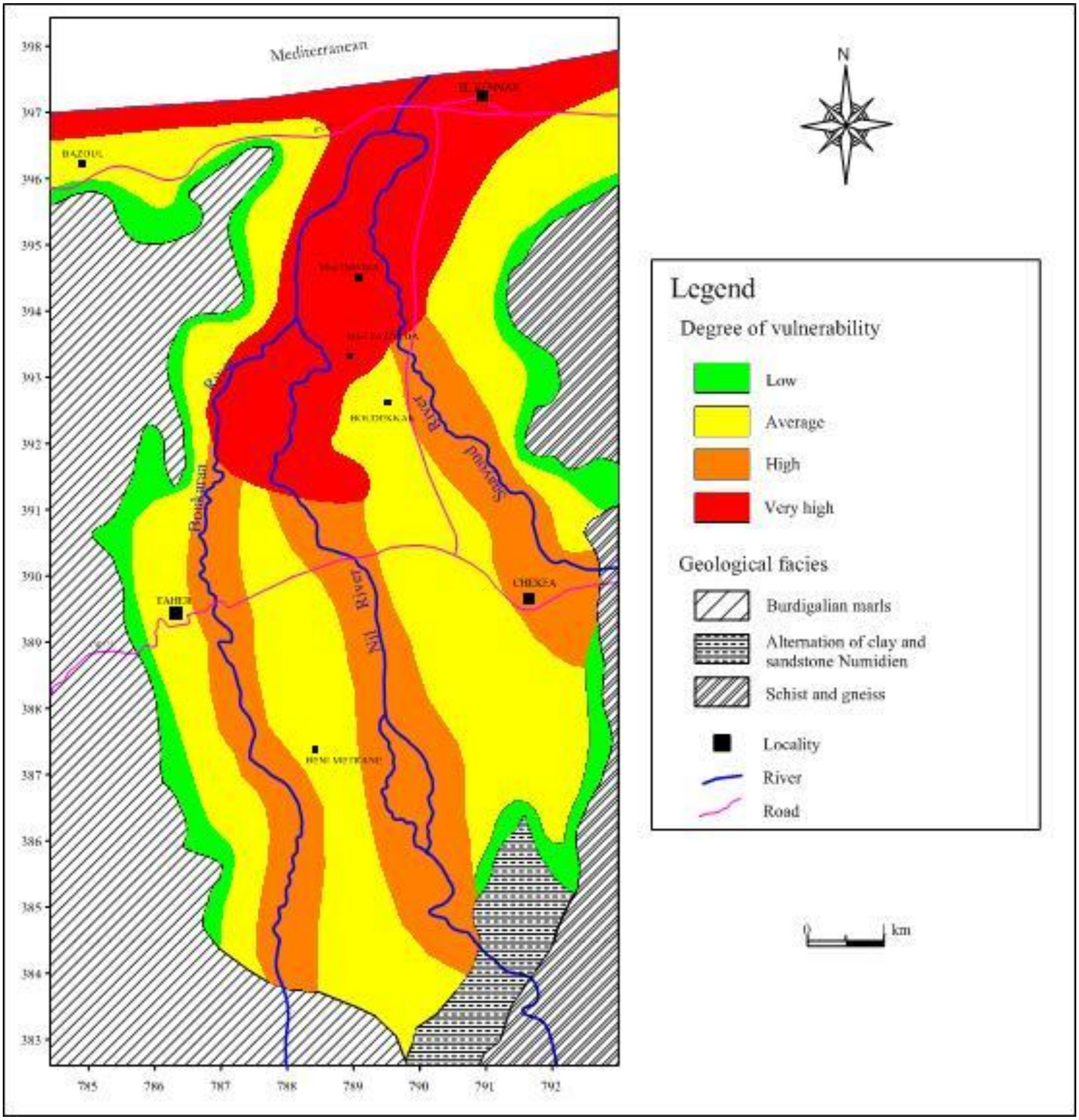

Figure 4. Aquifer vulnerability map (SI method).

zones being identified by this method (low, average and high) ;

iii. As for the 22 samples with low concentrations, five samples belong to low-vulnerability area, eight to the average, and nine to the high one.

c. SI map case

i. Of the three samples with contents above 45 mg/l, only one sampling point belongs to very high vulnerability zone. However, for the others, they fall within medium-

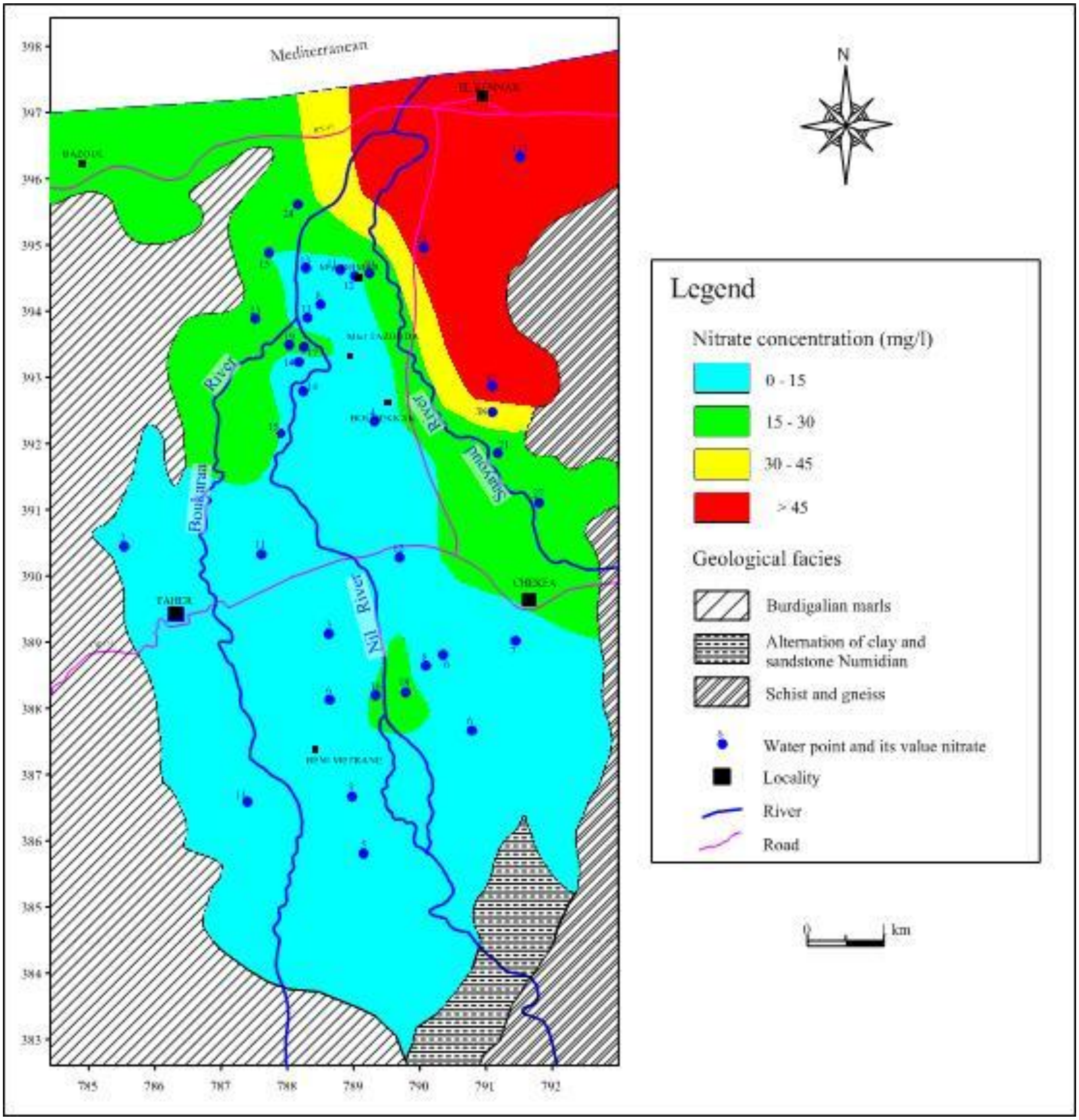

Figure 5. Nitrate distribution map.

vulnerability area;

ii. Of the nine samples displaying contents varying between 15 and 30 mg/l, the third belong to very high vulnerability area, four fall within the high, and the others in the average one;

iii. Finally, concerning 22 samples with low contents, eight samples correspond to high-vulnerability area and 13 to the average one.

Table 7 shows, firstly, that average-vulnerability class is predominant whatever the approach used. Secondly, the table results reveal that DRASTIC method seems to be the most reliable in reflecting reality on the ground, with coincidence rate of 71% (25 of 35 values), against 63% for SI method (22 values of 35) and 54% for GOD method

Table 7. Nitrate spatial distribution into groundwater, with respect to vulnerability classes being defined by the three methods.

Vulnerability	DRASTIC Method				GOD Method				SI Method			
	Samples number per nitrate content class (mg/l)											
	0-15	15-30	30-45	> 45	0-15	15-30	30-45	> 45	0-15	15-30	30-45	> 45
Low	1	0	0	0	5	3	0	0	1	0	0	0
Average	15	2	1	3	8	3	1	3	13	2	0	2
High	6	7	0	0	9	3	0	0	0	4	1	0
Very high	0	0	0	0	0	0	0	0	8	3	0	1
Total	22	9	1	3	22	9	1	3	22	9	1	3

Vulnerability: Low, average, high, very high. Nitrate concentration (mg/l): 0-15, 15-30, 30-45, > 45. Samples number: 0, 1, 2, 6, 15.

method (19 values of 35).

DISCUSSION

This study was done in an area clearly defined by natural conditions and hydrogeological limitations. However, the studied field is characterized by intensive agricultural activity, using chemical fertilizers which are potential sources of groundwater pollution.

The combined use of three approaches allows better understanding of mechanism and representativeness of pollution vulnerability in the examined area. This leads also to the distinction, depending on the case, between sometimes three, sometimes four classes, ranging from low to very high vulnerability degree. The difference in classes' number is linked to the fact that class boundaries and dimensions that are assigned to different parameters are not absolute, but instead relative. This implies that standard classes' limits may not reflect reality on the ground where a class can encompass different hydrogeological units within. Moreover, different works in literature showed that the limits may vary from one method to another, from one study to another or from one region to another. For example, GOD method does not give enough importance to recharge parameters and aquifer permeability.

Despite the deficiencies noticed in development of pollution-vulnerability maps using these intrinsic methods, reliability of results is slightly altered. Obtained results help to acquire a good idea regarding the most sensitive areas, and to subsequently prescribe necessary protection measures. Vulnerability maps validation would have been more representative if the number of nitrate measurements was greater and well distributed over the whole plain. Finally, analysis of other pollutants would have provided extra values for validation.

In the case of Nil valley groundwater, DRASTIC method proves to be the one that best reflects reality on the ground. However, it takes into account seven parameters including reliability that depends on data used for their implementation. Many of them as recharge, hydraulic conductivity and vadose zone impact, are either approximate or produced via scaling-up. This would conse-quently generate errors during parameters assessment process.

After validation using nitrate contents observed in groundwater, we have noticed the following:

1. GOD method provides results largely different from that generated by the other ones, and can define three vulnerability classes: low, average and high, with a matching rate of 54%.
2. DRASTIC and SI methods raise four vulnerability classes and provide relatively similar results, particularly for high, average and low-vulnerability areas (Table 7). By contrast, they differ in very high-vulnerability areas (3.1% for DRASTIC against 21.4% with SI).
3. Finally, with a matching rate of 71%, DRASTIC approach seems to better reflect reality on the ground where average vulnerability class (61%) predominates.

From the results of this work, the authors concluded that the DRASTIC method could be adequate for vulnerability mapping in this region. It confirms the results of the work already completed by several authors in the countries of the basin of the Mediterranean Sea. For example, Salemi et al. (2012) in Italy, Hamza et al. (2010) in Tunisia, Stigter et al. (2006) in Portugal.

Conclusion

Vulnerability-study results of Nil valley groundwater show that vulnerability degree increases upstream and downstream due to rising of the aquifer and the important sandy fraction in the airy zone. In addition, this relates to intensive anthropogenic soil-activity. High index areas are on the coast where groundwater is shallow and agricul-tural activity is dense. DRASTIC approach is more reliable in representing nitrate distribution into water, with a matching rate of 71%, against 63% in SI approach case and 54% in that of GOD. Nevertheless, whatever the method used, results reveal that Nil valley groundwater, mainly downstream, is highly vulnerable. Indeed, very high-vulnerability class covers 20% of the plain, while that having a high level reaches 30%. GOD method is less accurate and, less alarmist, however. Comparison of results provided by the three methods applied to the aquifer, clearly defined by its geometry and natural conditions, evidences discrepancies in the phenomenon assessment. Variations results from differences between the scoring systems of parameters.

Since it has been proved that this vital groundwater reservoir is vulnerable and present a risk of pollution, the following protection measures must be taken with the results of the vulnerability:

1. Protection perimeters of groundwater must be installed.
2. Protection perimeters supported by a general evacuation plan of used water must be installed.
3. Continuous monitoring of fertilizer use in agriculture.

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