Desalination and Water Treatment
www.deswater.com
doi:10.5004/dwt.2018.22737

124 (2018) 211–222
August

Assessment of groundwater risk to Plio-quaternary aquifer's contamination: semi-arid climate case (central Tunisia)

Kaouther Ncibi[a,c,*], Mohamed Mosbahi[b], Noureddine Gaaloul[c]

[a]*University of Tunis El Manar, Faculty of Sciences of Tunis (FST), Department of Geology, Campus Universitaire, 2092 Tunis – El Manar, Tunisia, email: nkawther@yahoo.fr (K. Ncibi)*
[b]*Laboratory of Georesources, CERTE, BorjCedria, BP 273, 8020 Solimen, Tunisia, email: mohamedmosbahi1@gmail.com (M. Mosbahi)*
[c]*Rural Engineering Laboratory. National Institute of Research in Rural Engineering, Water and Forestry (INRGREF), Hédi Karray Street, B.P.10, 2080 Ariana, Tunisia, email: gaaloul.nouredine@iresa.agrinet.tn (N. Gaaloul)*

Received 3 November 2017; Accepted 11 July 2018

ABSTRACT

In the Sidi Bouzid plain in Tunisia, the use of chemical fertilizers in irrigated perimeters is commonly accentuated. However, in the absence of regular monitoring in this region, the pollution affected the water table. Here, we aimed to reduce the danger of fertilizer usage through a qualitative water management tool using geographic information system (GIS) and to create a pollution risk map. A model evaluating groundwater risk index to pollution was established, using vulnerability index of pesticide DRASTIC and SI models modified applying weighting parameter techniques such as Single-parameter sensitivity analysis (SPSA) and linear regression (LR). These techniques were validated using chemical pollutant (nitrate concentrations). Our calculations demonstrate that the coupling of two models is much more effective than either each used alone. In conclusion, our study shows three risk classes (moderate, high and very high), the high class occupies the majority part of the study area. According to risk map, there are considerations to be taken into account: making sure to avoid leakage or spillage of contaminants. In addition to regular inspections and maintenance, well water must be analyzed and ensured containment of pesticides. These models coupling helps decision-making in areas occupied by irrigated perimeters.

Keywords: Risk index; Vulnerability; Pollution; Geographic information system; Tunisia

1. Introduction

Environmental impact of agriculture was a problem in perpetual growth. Groundwater was systematically threatened by agricultural activity and associated pollution created by pesticide use [1]. Assessment of groundwater contamination was a necessary topic mobilizes hydrogeologists and environmental experts to propose various modeling and management tools including assessment and mapping of groundwater vulnerability to contamination [2]. This later was introduced by Margat in the late 1960s [3]. It is based on the fact that naturally, ecosystems protect groundwater against several pollution sources (human, animal and natural) [4].

Groundwater vulnerability assessment identifies and combines geomorphological, geological and hydrogeological parameters and allow to obtain groundwater vulnerability index. Some specifications were assigned to groundwater vulnerability (intrinsic and specific). The intrinsic vulnerability was used in cases where natural ecosystems characteristics were used [5], while the specific vulnerability was used when the pollutant nature and its attenuation scenario into the system were considered [6]. The first vulnerability map was published in 1970 by Albinet for French territory [4]. As a result, many methods for estimating and mapping groundwater vulnerability has been developed. These publications became generalized around the world in the late 1980s. The most diffused models are DRASTIC [7], SINTACS [8], EPIK [9], PaPRIKa [10], the European Approach [11], COP [12]. There are also some country-specific models,

*Corresponding author.

such as Swiss models [13] and the Slovenian model [14]. The popular approach evaluating vulnerability is parametric index method. These methods were later modified using several parameter weighting techniques [15–17]. The choice of techniques used to evaluate vulnerability index will be verified and validated by nitrate concentrations.

Comprehensive knowledge of groundwater management provided by the vulnerability. In addition, there are several studies on this subject in the world [18–21]. Notably, in Tunisia, many research projects were executed in this topic [6, 22–25], typically these researches were focused on assessing vulnerability using one or more models separately, followed by validation using water quality data and/or the comparison among themselves.

The aquifer of Sidi Bouzid plainface many challenges from potential pollution. Intense agricultural activity facilitated groundwater pollution. Nitrates have become a significant source of groundwater pollution in this region. This paper proposes an approach to ensure a water quality management in order to achieve the sustainability. The aim of this study is the establishment of groundwater contamination risk map of Sidi Bouzid plain based on the combination of intrinsic and specific models. For this intention, two modified models were used: the pesticide DRASTIC and the SI (Susceptibility Index), and are determined one combining GIS tools.

2. Description of the study area

2.1. Location and anthropogenic activities

Sidi Bouzid plain located in central Tunisia has an area covering approximately 640 km² (Fig. 1). A semi-arid climate characterizes this region. The mean annual rainfall and mean temperature during the period between 1975 and 2015 were of the order of 240 mm and 19°C respectively, and the mean annual evaporation was about 1506 mm [26]. The altitude in this region varies between 325 m and 550 m, with slopes between 0 and 20%. It was, therefore, a relatively low topography, similar to a plain.

Principle activity in Sidi Bouzid plain is agriculture. As water wells in this region were used mainly for agricultural activity. Based on land use map, the most of this area was occupied by irrigated perimeters (annual crops) divided into public and private sectors followed by permanent crops. Orchards, discontinuous urban regions and aquatic environments were scattered in limited areas throughout the region (Fig. 2a). Agricultural activity in Sidi Bouzid plain needs a high use of water and pesticides leading to groundwater contamination.

2.2. Geology

Sidi Bouzid plain occupies the eastern termination of central Atlasic of Tunisia. It was bounded by several mountains: (1) to the east by the north-south axis, which separates it from the pelagian platform, (2) to the north by the eastern dipping of the Kasserine Fault and the Jebel Lessouda, (3) to the south by the Jebel Al Hfay- Jebel Kebar alignment and (4) to the west by the Jebel Hamra-Rakhmet alignment.

The study area was an asymmetric synclinal oriented NE-SW and formed by a Mio-Plio-Quaternary continental deposit. It was the result of the compressive phase that affected central Tunisia at Miocene.

The Tunisian geological map at 1: 500 000 scale shows a sedimentary series ranging from Triassic to Quaternary (Fig. 2b) [27,28]. Secondary formations outcrop at the high structures bordering the plain. Triassic outcrops were located at Jebel Hamra. They were formed by gypsum, dolomitic limestone and red and green clays. The Jurassic was outcrop by calcareous-dolomitic deposits at Jebel faydh. On the massifs of Jebel Kebar, Al Hfay, Rakhmet, Hamra, Lessouda, Bou-zar and Gsayra, the upper and lower Cretaceous were present by dolomites, marl and limestone deposits. Tertiary formations were represented by complete sedimentary series ranging from Paleocene to continental

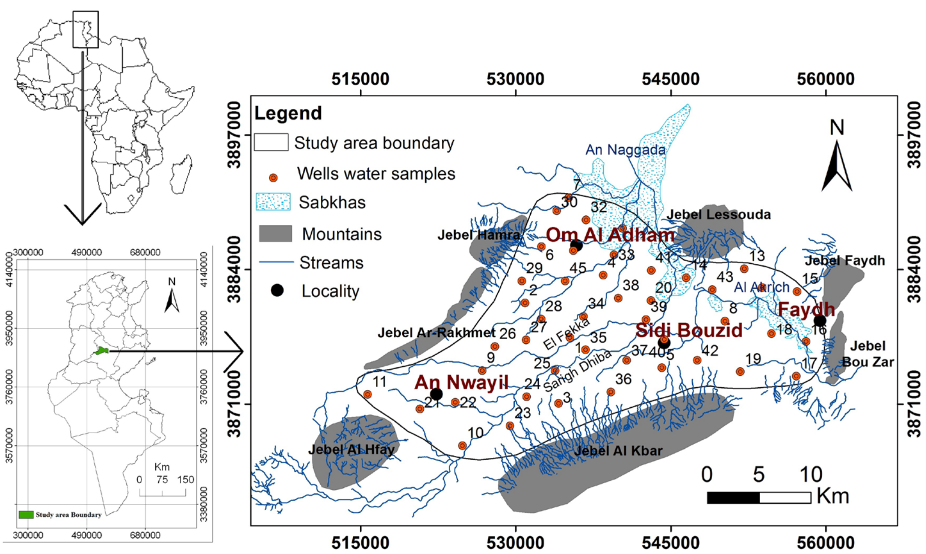

Fig. 1. Location of the Sidi Bouzid plain and wells water samples.

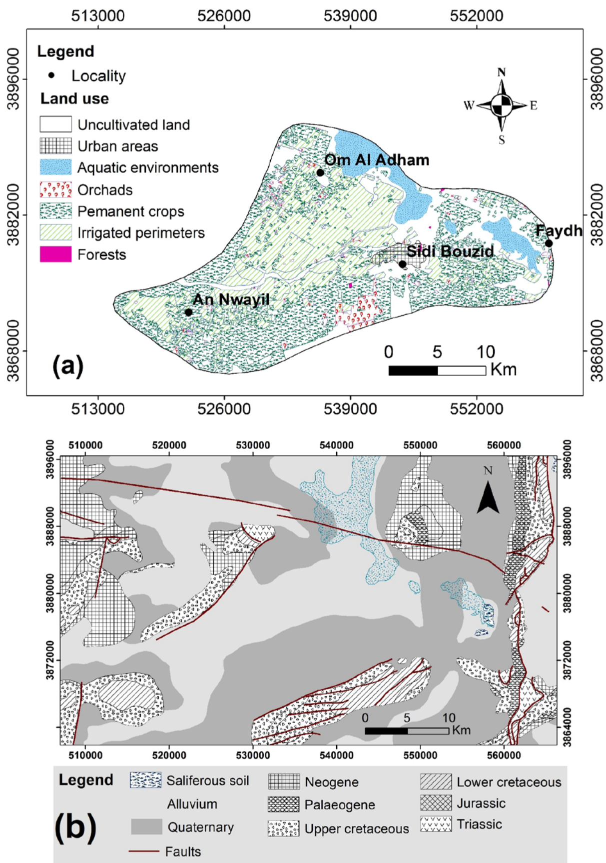

Fig. 2. Maps of: (a) Land use; (b) geology (Extract of the geological map of Tunisia; 1/500000); of Sidi Bouzid plain.

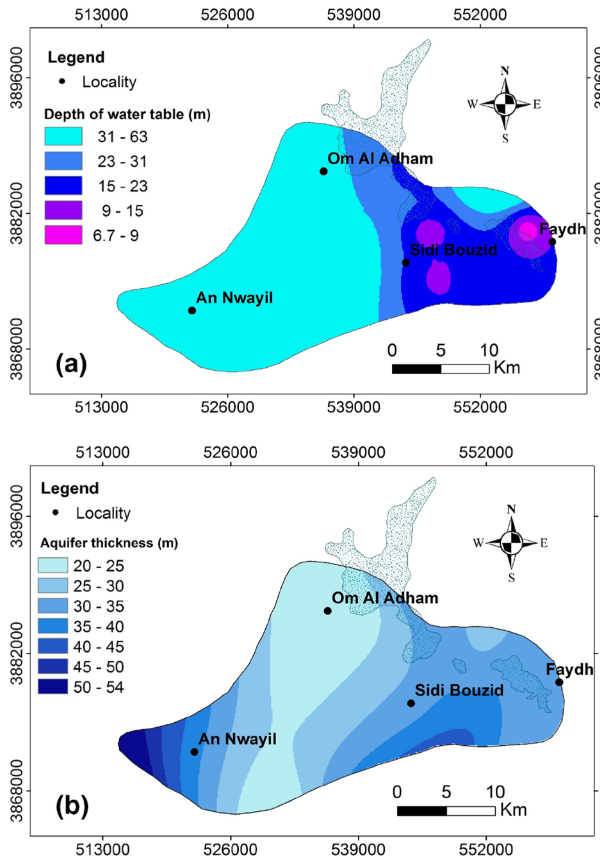

Fig. 3. Maps of: (a) groundwater depth; (b) groundwater thickness; of Sidi Bouzid plain.

Mio-Pliocene. These deposits were located at mountains piedmont [29–31].

The plain connects with surround reliefs by faults [29]. These are NW-SE faults bordering anticlines of Jebel Kebar, Jebel Rakhmet and Jebel Hamra, then the N-S fault series related to the north-south axis limiting the studied area to the east. These tectonic accidents were the cause of the basin's Sidi Bouzid plain subsidence, which began in Miocene and continued until Quaternary. Thus, the large deposits thickness was favorable to the presence of aquifers.

2.3. Hydrology and hydrogeology:

With the exception of wadi Al Fakka, in the Sidi Bouzid plain,all wadis draining the region were intermittent. Wadi Al Fakka is born in Foussanagraben, with NE-SW direction, this wadi runs the northwestern part of the study area. In the southeastern part, of the study area, runs the wadi of SaregEdhiba, which oriented from NE to SW and occurs at Jebel kebarpiedmont. These wadis were spread out in the depressions of Naggada and Akarich, where the waters have been transferred to the saliferous area of the sabkhas [32] (Fig. 1).

The hydrogeological reserves of central Tunisia consist of detritic sediments of Mio-Plio-Quaternary age [33–37]. Such the case of Sidi Bouzid plain, it was an area clearly defined by its natural conditions and hydrogeological limits. Hydrogeology cross section of Sidi Bouzid plain's aquifer presented in Fig. 3 shows a considerable variation in depth and thickness. The depth of the water table shows a lateral variation. Highest depth was located west of the study area which had values equal to 63 m. Water table depth decreases towards north and east of the region until attaining 6 m (Fig. 3a). Aquifer thickness map shows the highest level varies between 45 m and 50 m to the SW and NE of the study area. Towards to the aquifer central part, thickness levels decrease to achieve values between 20 m and 30 m (Fig. 3b).

Mio-Plio-Quaternary aquifer of Sidi Bouzid plain had a water reservoir which rests on clay and clayey sand substratum with lenticular formations. The aquifer system of the study area was identified by a single multi-layer aquifer [38], characterized by a vertical heterogeneity of deposits and alternations of sand, clayey sand and sandy clay. In the downstream and upstream of Sidi Bouzid plain's aquifer the deposits dominated by sandy lithologic, while the central part was dominated by sandy clay (Fig. 4).

This aquifer has long been the subject of intensive exploitation [39]. The renewable water resources were determined by the infiltration mainly from the contributions of Wadi El Fekka. The high use of water caused a pie-

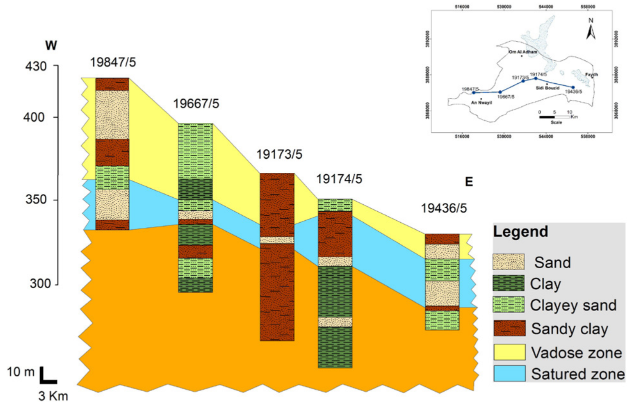

Fig. 4. Hydrogeology cross section of Sidi Bouzid aquifer.

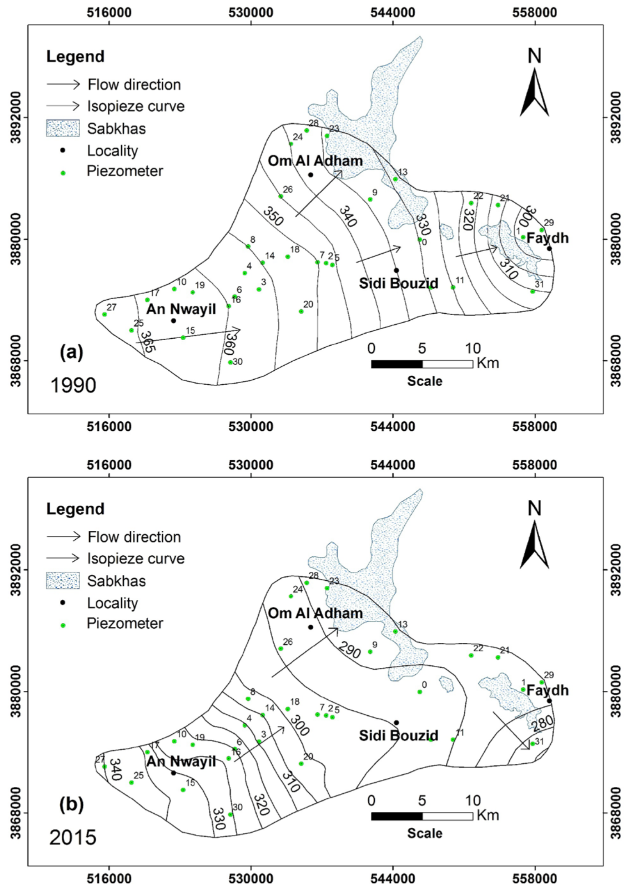

Fig. 5. Piezometric maps of the phreatic aquifer of Sidi Bouzid plain for: (a) 1990, (b) 2015.

zometric decrease. Two piezometric maps of 1990 and 2015 are used to characterize the history of their development.

Water flow, in the period 1990–2015, keeps almost the same direction from the south-west to the north and north-east of the plain. The piezometric map of 1990 shows an intensive piezometric value ranging between 295 m and 365 m (Fig. 5a). The water level decreases further to the northeast of the aquifer (small hydro potential area). The isopiezes curves show a uniform flow with constant direction oriented to Neggada and Akarich sabkhas. In 2015, the value of isopiezes curves ranging from 275 to 345 m showing a decrease in water levels, which provides Akarich Sabkhas to contribute to groundwater recharge (Fig. 5b).

Salinity in water samples of Sidi Bouzid plain ranges from 1218 mg/l to 6199 mg/l. The spatial distribution (Fig. 6a) of salinity values shows a highest concentrations in the downstream part of the aquifer (north and north-east of the study area), towards to the upstream the aquifer has become less mineralized.

Nitrate concentrations of Mio-Plio-Quaternary aquifer of Sidi Bouzid plain vary between 32.4 mg/l and 109.5 mg/l. According to World Health Organization (WHO), if nitrate levels in water exceed 10 mg/l, their origin was considered anthropogenic. Therefore in the study area, nitrate concentrations were found mainly from agricultural activity. The distribution map of nitrate concentrations shows high levels to the south and south-west of the plain. Highest nitrate levels can be explained by the coincidence of two types of land use: irrigated perimeter and permanent crops. The lowest nitrate concentrations were located in the west and the north of the study area in the vicinity of sabkhas where agricultural productivity is low (Fig. 6b).

3. Materials and methods

3.1. The DRASTIC model

The DRASTIC model is a parametric model of vertical vulnerability, developed by Aller et al. 1987 [7]. This model has been created taking into account the main elements of the hydrogeological system. There are two versions of the DRASTIC model: pesticide DRASTIC and generic DRASTIC. The pesticide DRASTIC model is applied in the case where the contaminants were considered pesticides and reflect the agricultural use of pesticides, the case of our work. Generic DRASTIC was applied where the pollutants are inorganic [40,41]. The difference between generic and pesticide DRASTIC models occurs when assigning weights [22].

Pesticide DRASTIC model had seven parameters, each first letter of the parameters is the model name: Depth of water table (D), net Recharge (R), Aquifer media (A), Soil media (S), Topography (T), Impact of the vadose zone (I) and hydraulic Conductivity (C). A parametric weight between 1 and 5, reflects the degree of influence of each parameter [42]. At each parameter rating is assigned ranging from 1 to 10 [43]. The lowest rating reflects the lowest vulnerability to contamination.

A numerical value of vulnerability index applying pesticide DRASTIC model denoted PDI was determined; it describes the degree of vulnerability of each hydrogeological unit. This index was calculated by summing the parameters multiplied by the weights and ratings of the corresponding parameters [18], which determined using the following equation:

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

where w: is the weight of the parameter, r: is the rating of the parameter.

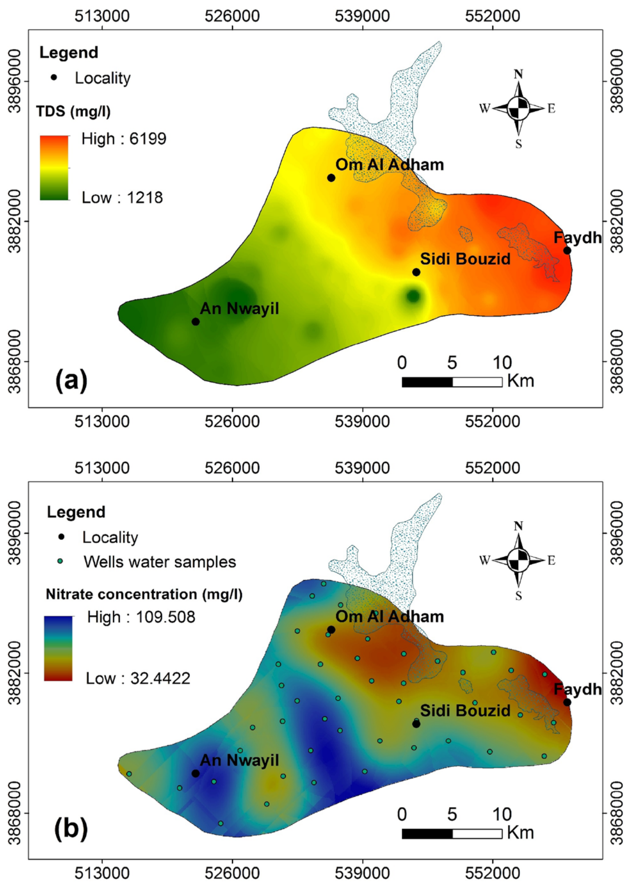

Fig. 6. Spatial distribution of: (a) salinity (m/l) and (b) nitrate concentrations (mg/l); of Sidi Bouzid plain aquifer.

The values of the vulnerability index using pesticide DRASTIC model (PDI), range from 26 to 256. The values obtained are grouped into four classes, each corresponding to a level of vulnerability. The vulnerability index intervals used in this study to determine the degree of vulnerability are those proposed by Engel et al. [42] (Table 1). The ratings, weights, and classes of the DRASTIC model were used by various authors [22,23].

3.2. The SI model

The SI (Susceptibility Index) model is a parametric vulnerability model developed in Portugal by Ribeiro [22,43]. This is a specific vertical vulnerability model applied in the assessment of vulnerability to agricultural pollution disseminated mainly by nitrates, in medium and large scales. This model takes into account five parameters: D (Depth of water table), R (net Recharge), A (Aquifer media), T (Topography) and LU (Land Use). The classes and ratings for the first four parameters are identical to those used in the DRASTIC model. The ratings of the land use range from 0 to 100 [22,43]. The weight parameter varies between 0 and 1 according to the importance of the parameters in vulnerability [22]. The SI vulnerability index is calculated as the sum of the products of ratings by weight of the corresponding parameter, using the following equation:

Table 1
Land use categories and degrees of vulnerability [42,43]

Parameters	Range/feature	Rating
Land use	Uncultivated land (sand, rock, foresters	0
	Aquatic environments	50
	Permanent crops	70
	Rural communities	70
	Urban areas	75
	Arboriculture	90
	Irrigated perimeters	90
Criteria for the evaluation of vulnerability in the DRASTIC and SI model		
Vulnerability degree	Pesticide DRASTIC model [42]	SI model [43]
Low	<100	<45
Moderate	101–140	45–64
High	141–200	65–84
Very high	>200	85–100

$$SI = Dw * Dr + Rw * Rr + Aw * Ar + Tw * Tr + LUw * LUr \quad (2)$$

where D, R, A, T, and LU: the five parameters of the SI model; W: the weight of parameter; r: the associated rating.

The SI index has four degrees of vulnerability according to the values of vulnerability index (Table 1).

3.3. Weights modification

To minimize the doubts and increase the reliability of the vulnerability index results and in order to determine the real weights, the assessment of groundwater vulnerability to pollution requires further experimental analysis and weighting adjustment. Single-parameter sensitivity analyses and Linear Regression were performed.

3.3.1. Single-parameter sensitivity analysis (SPSA)

The Single-Parameter Sensitivity Analysis is performed to assess the impact of input parameters on the vulnerability index [16]. It is based on the comparison between theoretical weights assigned to the input parameters with the effective weights [16,20]. The effective weight is obtained using the following equation:

$$W = (Pw * Pr / V) * 100 \quad (3)$$

where W: is the effective weight for each parameter, Pr and Pw: are the notes and the weights assigned respectively for each parameter, V: represents the total of undisturbed vulnerability index calculated.

3.3.2. Linear regression (LR)

Linear regression was used to establish statistical models. It quantifies a relationship between several independent variables (DRASTIC and SI parameters) and a dependent variable (Nitrates) [44]. LR Suppose that a response variable Y can be predicted by a linear function of a regressor variable X.

$$Y = \beta_0 + \beta_1 X_i + \varepsilon_i \quad (4)$$

where Y: is the response variable, β_0: is the intercept, β_1: is the slope coefficients for the environmental variables (D, R, A, S, T, I, C and LU),: ε is the remaining unexplained noise in the data.

3.3.3. Weighting approach comparison using nitrates

Nitrate concentrations were used to validate models. A Pearson correlation carried out between nitrate value and modified vulnerability index using single-parameter sensitivity analysis and linear regression approaches for both pesticide DRATSIC and SI models. The model which has the best correlation between modified vulnerability index and nitrates will be chosen to evaluate groundwater pollution risk.

In order to make an excellent representative results, water samples were chosen for covering the entire studied area. Water samples are analyzed for nitrates in the laboratory of the National Institute of Agronomic Research of Tunis (INRAT).

3.4. Risk index (RI)

The usable pure water usually comes from underground sources. Everything must be done to protect them from contamination. Agricultural contaminants can threaten the quality of groundwater if not properly managed; [45,46]. Many factors affect the risks of groundwater contamination such as soil media and aquifer media. For this reason, the assessment of the vulnerability index does not seem sufficient [47]. Therefore, we determined the Risk Index based on the coupling of models used in the agricultural areas: modified pesticide DRASTIC (MPD), Modified Susceptibility index (MSI), and by adding the parameters, which have the highest weight of two models. The risk index is determined by the following equation:

$$RI = MPDI + MSI + XrXw + YrYw \quad (5)$$

where $XrXw$ highest parameter weight of the modified DRASTIC model, $YrYw$ highest parameter weight of modified SI model.

Fig. 7 shows the different steps to obtain the RI: data collection, groundwater vulnerability RI mapping.

3.5. Data processing and sources

The data used to determine the vulnerability and risk maps were summarized in Table 2. The processing of the data was performed using the Geographic Information System (GIS). The different maps produced in this work were carried out by the kriging geostatistical method of the ArcGIS10.2.2® software. All maps are in raster mode. The reclassification (according to the vulnerability and risk classes), and the crossing of the raster maps was executed by applying the Spatial Analyst tool of ArcMap10.2.2® software.

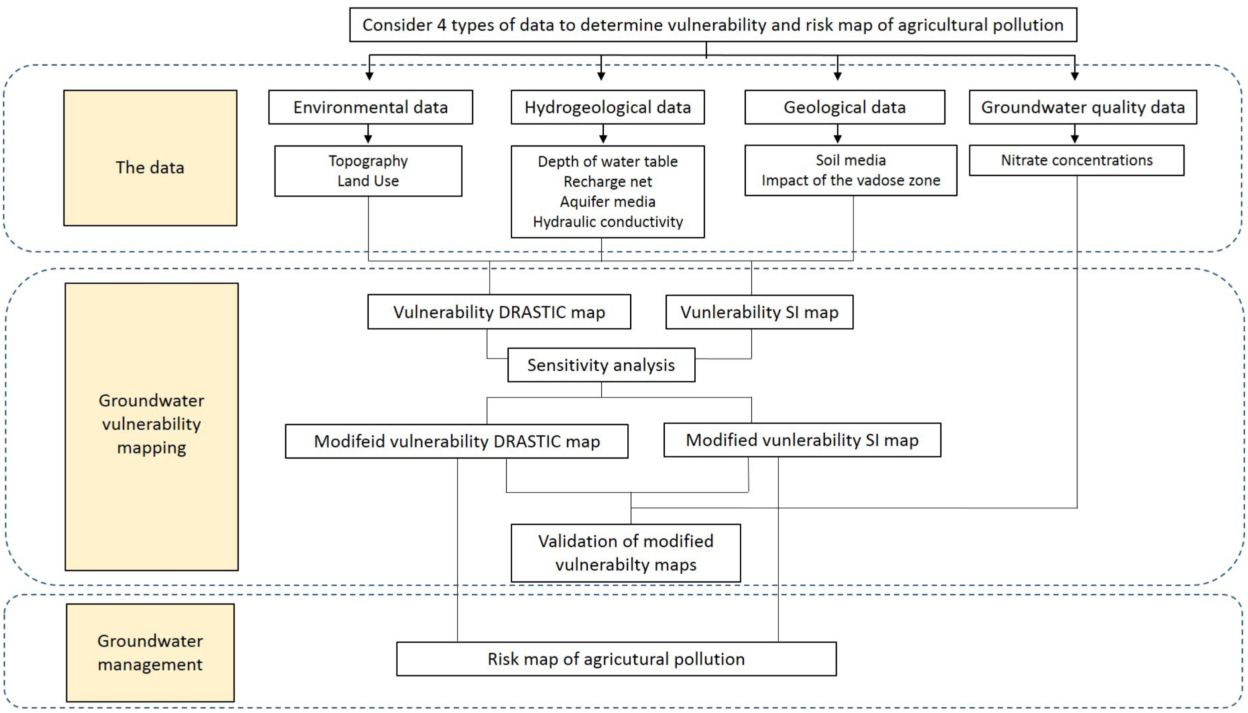

Fig. 7. Flowchart of methodology to obtain groundwater Risk Index (RI).

Table 2
Data sources of pesticide DRASTIC and SI parameters

Parameters	Sources of data	Processing
D	Data for the static level of 32 water points including 3 monitoring wells and 29 piezometers, our measures in 2015	Interpolation
R	Historic piezometry (1990–2015)	Calculated using piezometric level fluctuations method
A	Geological information, well logs (DGRE).	Digitalization
S	Soil maps (scale 1:50 000) (CRDA Sidi Bouzid, 2013).	Digitalization
T	Topographical maps (scale 1:50 000) (CRDA Sidi Bouzid, 2013).	Interpolation
I	Water logs and geological maps (DGRE)	Interpolation
C	Pumping tests (DGRE)	Interpolation

4. Results

4.1. Parameter weights and vulnerability indices

The result of adjusted parameters weight for pesticide DRASTIC and SI models are shown in Table 3. Fig. 8 shows the spatial distribution of VI for both pesticide DRASTIC and SI models using two methods of weighting parameters adjustment (SPSA and LR). Original weight of pesticide DRASTIC and SI models, used as a reference for the comparison.

LR used to adjust the weight parameter for pesticide DRASTIC model was decreased weight values compared with original weights. For SI model this technique was decreased all weight values except aquifer media (A) and topography (T) parameters.

Using SPSA,the pesticide DRASTIC model decreased weight values of D and R parameters and increased the other weight values of A, S, T, I and C giving much importance to aquifer media parameter. SPSA techniques used to adjust parameter weights of SI model, decrease A and LU parameters and increase D, R and T parameters.

The application of SPSA and LR methods on the pesticide DRASTIC model shows vulnerability indices range varying between 105 and 174 and 68 to 126 successively. Vulnerability index (VI) using SI model shows a VI range varied from 29 to 109 for SPSA technique model and 43 to 85 for LR technique.

The spatial distribution maps (Fig. 8) of vulnerability classes varied from one technique and model to another. Highest vulnerability index of all models remarkably includes an area in the center of the plain.

4.2. Validation with nitrates

The validation of models was achieved by Pearson correlation between vulnerability indices obtained using weighing adjustment techniques (SPSA and LR) and nitrate concentrations. For this purpose, 45 samples were analyzed in the dry season in 2015. A significant correlation with the vulnerability indices estimated applying SPSA on pesticide DRASTIC and SI models with a correlation coefficient higher than 0.6 for both models. Vulnerability index assessed using LR adjustment technique was not correlated with nitrate concentrations with correlation coefficient lower than 0.4 (Fig. 9). Based on these correlations, SPSA provided better results than LR. SPSA can be applied in the study area and will be used to calculate the risk index

Table 3
Results weighting parameter techniques using single parameter sensitivity analysis and linear regression applied to the pesticide DRASTIC and SI models

Parameter	Theoretical weight	Modified weight	
		Single-parameter sensitivity analysis	Linear regression
Pesticide DRASTIC model			
D	5	3.67	3.49
R	4	2.72	3.27
A	3	4.28	2.93
S	5	5.60	4.65
T	3	3.42	1.93
I	4	4.48	1
C	2	2.10	2.61
SI model			
D	0.186	0.15	0.08
R	0.212	0.16	0.19
A	0.259	0.40	0.40
T	0.121	0.01	0.24
LU	0.222	0.28	0.09

4.3. Risk map

Following the choice of vulnerability indices assessed using SPSA, the Risk Index (RI) can be expressed by Eq. (5):

$$RI = MPDI + MSI + 5.60Sr + 0.40Ar \quad (6)$$

where *S*: as the soil media parameter of modified pesticide DRASTIC model, *A*: as the aquifer media parameter of SI model respectively, *w*: weights assessed by single-parameter sensitivity analysis.

The risk map thus produced shows three degrees (moderate, high and very high). The moderate degree occupies 18.72% of the study area near to the sabkhas of Naggada

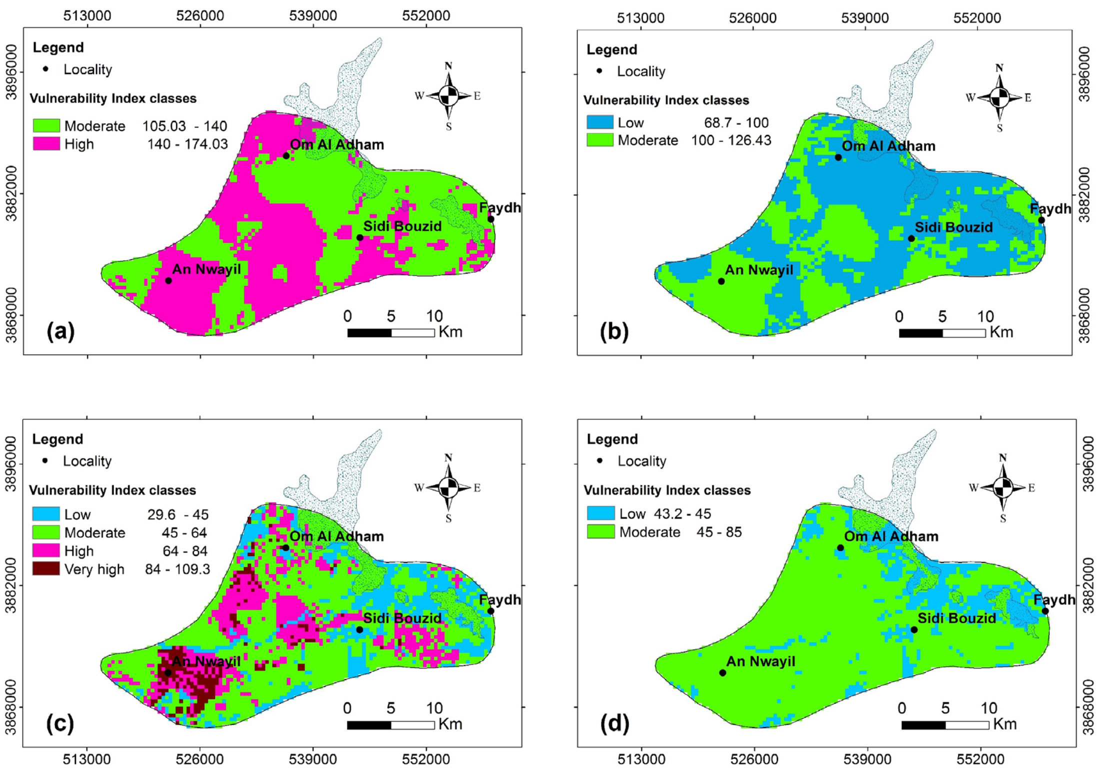

Fig. 8. Vulnerability index distribution of pesticide DRASTIC and SI models based on SPSA and LR weighting adjustment techniques: (a) pesticide DRASTIC using SPSA, (b) pesticide DRASTIC using LR, (c) SI using SPSA and (d) SI using LR.

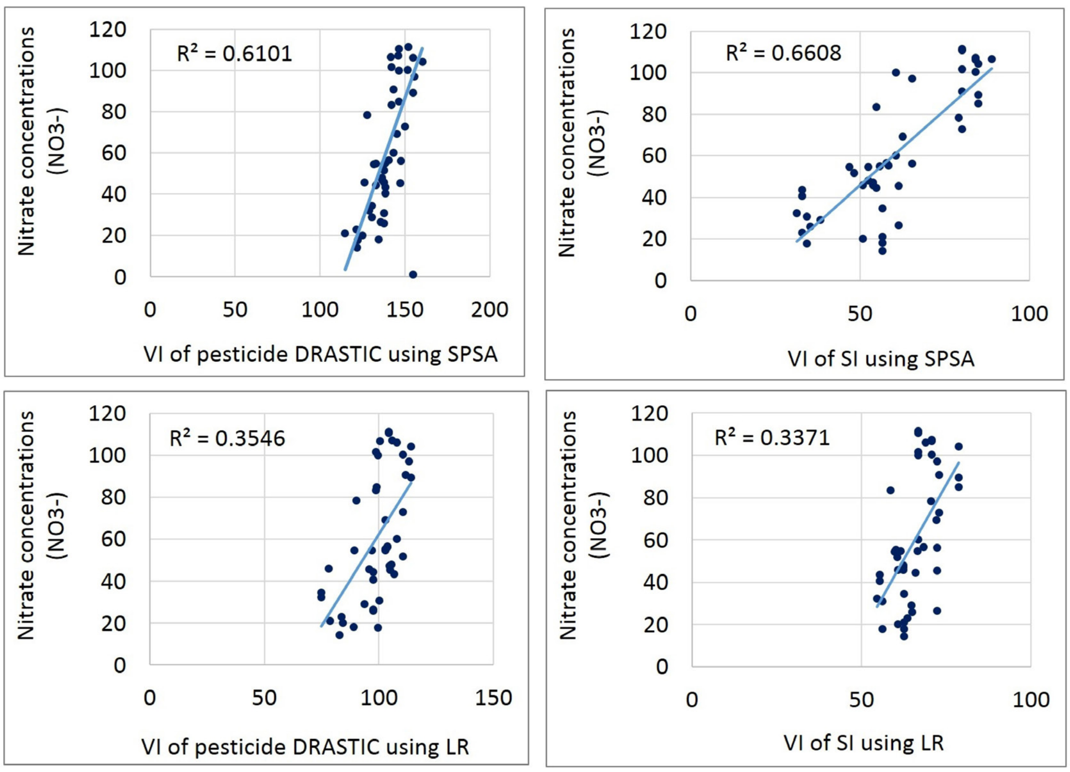

Fig. 9. Correlation between vulnerability indices of modified pesticide DRASTIC and SI models and nitrate concentrations of the aquifer of Sidi Bouzid plain.

and Akarich. The majority of the study area was held by a high-risk degree; 77.98% of the study area. A very small part (3.30% of the study area) is occupied by a very high degree dispersed in different zones of the study area (Fig. 10)

5. Discussion

The assessment of groundwater risks using vulnerability index in central Tunisia has permitted the identification and description of vulnerable areas to pollution in the aquifer of Sidi Bouzid plain. The results of this study highlight the usefulness of the intrinsic (modified pesticide DRASTIC) and specific (modified SI) vulnerability indices in studies to evaluate groundwater risk.

The comparison between VI executed in 2013 [23] and 2016 shows a decrease. It is due mainly to the net recharge parameter. Moreover, recharge shows problems with its estimation on a regional scale, once all anthropogenic activities change the aquifer recharge. The difference in the vulnerability degree was probably associated with the not absolute parameters used to assess groundwater vulnerability index. These are the main reasons why the VI has been changed.

Furthermore, similarly to other vulnerability studies of different common, this study has shown that results can vary from one model to another in the same region, from one study to another or from one region to another [17,19–21]. This confirms the application of the weights parameters adjustment techniques (e.g., Single Parameter Sensitivity Analysis and Linear Regression) to increase the reliability of results of groundwater vulnerability to pollution. It is expected that the modified models parameter will be specific for the considered study site indeed, and will depend on many local specific factors such as hydrogeological settings and the selection of the monitoring data as reference pollution data, etc.

The case study of the Sidi Bouzid plain also shows that some of the modified parameters of pesticide DRASTIC and SI models have a low weight as hydraulic conductivity and topography. This does not reflect that those parameters have no effect on groundwater pollution and cannot explain their remove as in the case of the study of Jmal et al. [15]. It should also be highlighted the influence of soil media and

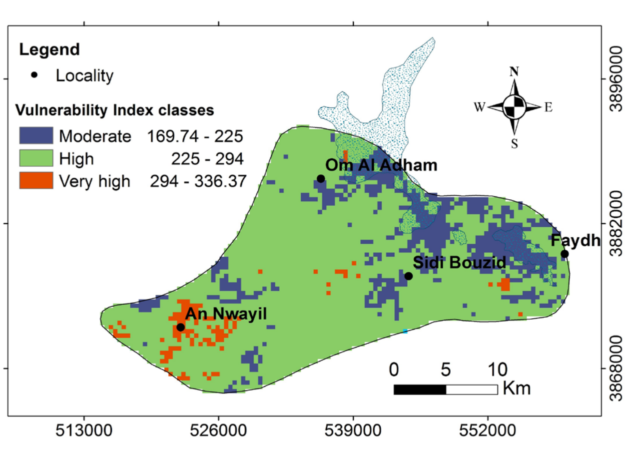

Fig. 10. Risk Index (RI) Spatial distribution of Sidi Bouzid plain.

aquifer media parameters in the pesticide DRASTIC and SI models. These parameters consider the impact of water infiltration and flow within vulnerable areas. There was implied that some regions of aquifer receive the pollutants.

Its location explained the moderate risk near to the sabkhas of Naggada and Akrich. On the other hand, the highest-risk degrees were located on areas lacked agricultural activity, the use of chemical fertilizers and the fertile soils. And it's coincided with irrigated perimeters.

Given the significant costs arising from the remediation of contaminated aquifers. It is important that measures are taken to protect the aware while pollution: human activities are a necessity in society; drought has a vital role in the natural degradation of the water quality. Considering the importance of the application of these two models in the study area the establishment of risk map by the combination of the two vulnerability indices gave an idea of the areas that require protection. The protective zones coincide with the high degree of risk (77.98% of the study area). The protection is manifested mainly through: avert any activity with a risk of contamination and minimize any source of pollution in order to limit its effects on the groundwater quality. Aquifer risk assessment of Sidi Bouzid plain is a scientific tool basis for water management and the decision-maker contribution.

6. Conclusion

We assess in this study groundwater risk to pollution for the Sidi Bouzid plain, combining specific and intrinsic model (pesticideDRASTIC and SI model). Considering the poor results of the original model we propose to modify the pesticide DRASTIC and SI models. We adapt the weighting parameter adjustment techniques, SPSA and LR, and it will be validated by observed nitrate concentration data. In a model used, we consider SPSA to modify weighting parameter and to assess vulnerability indices. For the mapping of groundwater risk to pollution, we add modified vulnerability index for pesticide DRASTIC and SI models with parameters having the highest weights of two models. We consider the dominating effect of aquifer media and soil media parameters on the groundwater pollution risk. The risk index map is, therefore, a suitable tool for supporting groundwater resource management, groundwater quality protection, and land use planning at the scale of the Sidi Bouzid plain. Weighting techniques in vulnerability modeling is a challenging enterprise because different methods may produce markedly different results. Several methods must be tried to know the most robust to the studied area. However, the integration of chemical data makes it possible to give better results understanding about the risk that affects the region.

References

[1] S.S.D. Foster, Fundamental concepts in aquifer vulnerability, pollution risk and protection strategy, Netherlands Organization for Applied Scientific Research, Netherlands 1987, pp. 69–86.

[2] N. Gaaloul, E. Saeid, Artificial recharge experiences in semiarid areas, USA 2014, pp. 17–49.

[3] J. Margat, Vulnérabilité des nappesd'eausouterraine à la pollution: Base de la cartographie [Groundwater vulnerability to pollution: Basis of cartography], BRGM Orléans Report [Bureau of Geological and Mining Research], France, 1968, p. 78.
[4] M. Albinet, J. Margat, Cartographie de la vulnérabilité à la pollution des nappesd'eausouterraine [Mapping of Groundwater Vulnerability to Pollution], IAHS publication, Proc. Moscow Symposium, 1975, pp. 58–70.
[5] D. Allier, B. Vittecoq, V. Mardhel, Evaluation de la vulnérabilitéintrinsèque des eauxsouterraines de la Martinique [Assessment of the groundwater intrinsic vulnerability in Martinique], BRGM Martinique Report [Bureau of Geological and Mining Research], France, 2008, p. 78.
[6] J. Vrba, A. Zaporozec, Guidebook on mapping groundwater vulnerability, in International Contributions to Hydrology, vol. 16, Heinz Heise, Hannover, 1994, p. 131.
[7] L. Aller, T. Bennet, J.H. Lehr, R.J. Petty, G. Hacket, DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeologic settings, US Environmental Protection Agency Report (EPA/600/2-87/035), Robert S. Kerr Environmental Research Laboratory, (1987) p. 455.
[8] M.M.D.M. Citivà, SINTACS: A parametric system for evaluating and mapping the vulnerability of aquifers to pollution. Methodology and automation, Pitagora Publications, Italia, 1997.
[9] N. Doerfliger, F. Zwahlen, Groundwater vulnerability mapping in karstic regions (EPIK). Application to groundwater protection zone: practical guide. Office Fédéral de l'Environnement, des Forêtset du Paysage (OFEFP), Berne, Suisse, 1998.
[10] N. Doerfliger, V. Plagnes, K. Kavouri, J. Gouin, Cartographie de la vulnérabilitéintrinsèque des aquifèreskarstiques. Guide méthodologique de la méthodePaPRIKa [Mapping of intrinsic vulnerability of karstic aquifers. Methodological Guide to the PaPRIKa Method], BRGM Orléans Report [Bureau of Geological and Mining Research], France, 2009, p. 119.
[11] D. Daly, A. Dassargues, D. Drew, S. Dunne, N. Goldscheider, S. Neale, I. Popescu, F. Zwahlen, Main concepts of the "European approach" to karst-groundwater-vulnerability assessment and mapping, Hydrogeol. J., 10 (2002) 340–345.
[12] J.M. Vías, B. Andreo, M.J. Perles, F. Carrasco, I. Vadillo, P. Jiménez, Proposed method for groundwater vulnerability mapping in carbonate (karstic) aquifers: the COP method, Hydrogeol. J., 14 (2006) 912–925.
[13] N. Goldscheider, M.S.S.H.H. Klute, The PI Method - a GIS-based approach to mapping groundwater vulnerability with special consideration of karst aquifers, J. Appl. Geology, 46(3) (2000) 157–166.
[14] N. Ravbar, The Protection of Karst Waters: A Comprehensive Slovene Approach to Vulnerability and Contamination Risk Mapping. Ph.D. Thesis, University of Nova Gorica, 1970.
[15] I. Jmal, A. Bachaer, B. Emna, A. Nabila, S. Salwa, H. Monji, B. Salem,Assessing groundwater vulnerability to nitrate pollution using statistical approaches: a case study of Sidi Bouzid shallow aquifer, Central Tunisia, Arab. J. Geosci., 10 (2017) 1–15.
[16] S. Saidi, S. Bouri, H. Ben Dhia, Sensitivity analysis in groundwater vulnerability assessment based on GIS in the Mahdia-KsourEssaf aquifer, Tunisia: a validation study, Hydrol. Sci. J., 56 (2011) 288–304.
[17] D. Thirumalaivasan, M. Karmegam, K. Venugopala, AHP-DRASTIC: software for specific aquifer vulnerability assessment using DRASTIC model and GIS, Environ. Model. Softw., 18 (2003) 645–656.
[18] D. Raj Pathak, A. Hiratsuka, I. Awata, L. Chen, Groundwater vulnerability assessment in shallow aquifer of Kathmandu Valley using GIS-based DRASTIC model, Environ. Geology, 57 (2007) 1569–1578.
[19] R. Li, J.W. Merchant, Modeling vulnerability of groundwater to pollution under future scenarios of climate change and biofuels-related land use change: A case study in North Dakota, USA, Sci. Total Environ., 447 (2013) 32–45.
[20] A. VictorineNeh, A. AkoAko, A.R. Richard Ayuk, T. Hosono, DRASTIC-GIS model for assessing vulnerability to pollution of the phreatic aquiferous formations in Douala–Cameroon, J. Afr. Earth Sci., 102 (2015) 180–190.
[21] M. Arauzo, Vulnerability of groundwater resources to nitrate pollution: A simple and effective procedure for delimiting Nitrate Vulnerable Zones, Sci. Total Environ., 575 (2016)799–812.
[22] M.H. Hamza, A. Added, A. Francés, R. Rodriguez, Validitée de l'application des méthodes de vulnérabilité DRASTIC, SINTACS et SI à l'étude de la pollution parles nitrates dans la nappe phréatique de Metline–Ras Jebel–Raf Raf, C. R. Geosci., 339 (2007) 493–505.
[23] W. Aydi, S. Saidi, M. Chalbaoui, S. Chaibi, H. Ben Dhia, Evaluation of the groundwater vulnerability to pollution using an intrinsic and a specific method in a GIS environment: application to the plain of Sidi Bouzid (Central Tunisia), Arab. J. Sci. Eng., 38 (2013) 1815–1831.
[24] A. Zghibi, A. Merzougui, I. Chenini, K. Ergaieg, L. Zouhri, J. Tarhouni, Groundwater vulnerability analysis of Tunisian coastal aquifer: An application of DRASTIC index method in GIS environment, Groundwater for Sustainable Dev., 2–3 (2016) 169–181.
[25] N. Allouche, M. Maanan, M. Gontara, N. Rollo, I. Jmal, S. Bouri, A global risk approach to assessing groundwater vulnerability, Environ. Model. Softw., 88 (2017) 168–182.
[26] INM (InstitutNationale de la Météorologie) [National Institute of Meteorology], Tableaux climatologiquesmensuels (1975–2015) [Monthly Climate Tables (1975–2015)], stations of Sidi Bouzid, 2016.
[27] M. Mosbahi, M. Khlifi, A.Tlili, F. Jamoussi, Influence of the halokinesis on the clay mineral repartition of upper Maastrichtian – Ypresian in the Meknassy-Mezzouna basin, center-western Tunisia, Arab. J. Geosci. 7–9 (2014) 3881–3899.
[28] M. Mosbahi, M. Khlifi, F. Jamoussi, A. Tlili, Valorization of Coniacian - middle Campanian clay minerals of the Meknassy-Mezzouna region (center-western Tunisia) in the clinker manufacturing, Arab. J. Geosci., 10 (2017) 349–357.
[29] A. Kadri, Evolution tectonosédimentaire (Aptien-Quaternaire) des JebelsKoumine, Hamra et Lessouda (Tunisie centrale) [Tectonosedimentaryevolution (Aptian-Quaternary) of JebelsKoumine, Hamra and Lessouda (Central Tunisia)]. Ph.D. thesis, University of Paris-Sud, France 1988, p. 183.
[30] M. Rabhi, Contribution à l'étudestratigraphique et analyse de l'évolutiongéodynamique de l'Axe Nord-Sud et des structures avoisinantes (Tunisiecentrale) [Contribution to the stratigraphic study and analysis of geodynamic evolution of the North-South axis and neighboring structures (Central Tunisia)]. Ph.D.Thesis, University of Tunis El Manar, Tunisia, 1999, p. 226.
[31] H. Azaiez, H. Gabtni, I. Bouyahya, D. Tanfous, S. Haji, M. Bedir, Lineaments extraction from gravity data by automatic lineament tracing method in Sidi Bouzid Basin (Central Tunisia): Structural framework inference and hydrogeological implication, Int. J. Geosci., 2 (2011) 373–383.
[32] H. Smida, Apports des Systèmesd'InformationsGéographiques(SIG) pour uneapprocheintégréedansl'étude et la gestion des ressourceseneau des systems aquifères de la région de Sidi Bouzid (Tunisiecentrale) [Contributions of Geographic Information Systems (GIS) for an integrated approach in the water resources study and management of aquifer systems in the region of Sidi Bouzid (Central Tunisia)]. Ph.D. thesis, University of Sfax, Tunisia, 2008, p. 283.
[33] Y. Hamed, R. Ahmadi, R. Hadji, N. Mokadem, H. Ben Dhia, W. Ali, Groundwater evolution of the continental intercalaire aquifer of southern Tunisia and a part of southern Algeria: use of geochemical and isotopic indicators, Desal. Water Treat., 52 (2013) 1990–1996.
[34] Y. Hamed, R. Ahmadi, A. Demdoum, S. Bouri, I. Gargouri, H. Ben Dhia, S. Al-Gamal, R. Laouar, A. Choura, Use of geochemical, isotopic, and age tracer data to develop models of groundwater flow: A case study of Gafsa mining basin-Southern Tunisia, J. Afr. Earth Sci., 100 (2014) 418–436.
[35] N. Mokadem, A. Demdoum, Y. Hamed, S. Bouri, R. Hadji, A. Boyce, R. Laouar, A. Sâad, Hydrogeochemical and stable isotope data of Groundwater of a multi-aquifer system: Northern Gafsa basin - Central Tunisia, J. Afr. Earth Sci., 114 (2015) 174–191.

[36] H. Riheb, B. Abderrahmane, L. Yacine, B. Mustapha, C. Abd el Madjid, D. Abdeslem, Geologic, topographic and climatic controls in landslide hazard assessment using GIS modeling: A case study of Souk Ahras region, NE Algeria, Quat. Int., 302 (2013) 224–237.
[37] H. Besser, N. Mokadem, B. Redhouania, N. Rhimi, F. Khlifi, Y. Ayadi, Z. Omar, A. Bouajila, Y. Hamed, GIS-based evaluation of groundwater quality and estimation of soil salinization and land degradation risks in an arid Mediterranean site (SW Tunisia), Arab. J. Geosci., 350 (2017) 1–20.
[38] H. Yangui, Z. Kamel, T. Rim, R. Kazimierz, Recharge mode and mineralization of groundwater in a semi-arid region: Sidi Bouzid plain (central Tunisia), Environ. Earth Sci., 63 (2011) 969–979.
[39] DGRE (Direction Générale des Ressources en Eaux) [General Directorate of Water Resources], Annuaires annuels d'exploitation des nappes phréatiques [Annual directories for the exploitation of groundwater], Tunisia 2015.
[40] H. Baalousha, Assessment of a groundwater quality monitoring network using vulnerability mapping and geostatistics: A case study from Heretaunga Plains, New Zealand, Agric. Water Manage., 97 (2010) 240–246.
[41] L. Bai, Y. Wang, F. Meng, Application of DRASTIC and extension theory in the groundwater vulnerability evaluation, Water Environ. J., 26 (2012) 381–391.
[42] B. Engel, K. Navulur, B. Cooper, Estimating Groundwater Vulnerability to Non-point Source Pollution from Nitrates and Pesticides on a Regional Scale. Proceedings of the conference on HydroGIS: Application of geographic information systems in hydrology and water resources management, IAHS, Vienna 1996, pp. 521–526.
[43] L. Ribeiro, J.C. Pindo, L. Dominguez-Granda, Assessment of groundwater vulnerability in the Daule aquifer, Ecuador, using the susceptibility index method, Sci. Total Environ., 574 (2000) 1674–1683.
[44] A. Mair, A.I. El-Kadi, Logistic regression modeling to assess groundwater vulnerability to contamination in Hawaii, USA, J. Contam. Hydrol., 153 (2013) 1–23.
[45] A. Pisciotta, G. Cusimano, R. Favara, Groundwater nitrate risk assessment using intrinsic vulnerability methods: A comparative study of environmental impact by intensive farming in the Mediterranean region of Sicily, Italy, J. Geochem. Explor., 156 (2015) 89–100.
[46] G. Bartzas, F. Tinivella, L. Medini, D. Zaharaki, K. Komnitsas, Assessment of groundwater contamination risk in an agricultural area in north Italy, Info. Process. Agri., 2 (2015) 109–129.
[47] N. Allouche, M. Maanan, M. Gontara, N. Rollo, I. Jmal, S. Bouri, A global risk approach to assessing groundwater vulnerability, Environ. Model. Softw., 88 (2017) 168–182.

Supporting information