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Research article

Assessing vulnerability to agricultural pollution of groundwater Bou Arada-Laroussa according to SI method applied by GIS

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Abstract

Groundwater of Laroussa Bou Arada is located in an agricultural area characterized by using increasingly important chemical fertilizers and especially nitrates. A study of vulnerability to nitrate pollution of the aquifer has been performed by applying the SI (Susceptibility Index) parametric method by Geographic Information Systems represented by the softwares Idrisi Andes and Cartalinx. The results were validated by measurements of nitrates in the groundwater. Three vulnerability classes (low, medium and high) were obtained showing an uneven spatial distribution. Much of the study area belongs to the class of medium vulnerability (70% of the total area), followed by the class of high vulnerability (29.86 %) and the low vulnerability class that covers only 0.14 % of the total area of the study area. The total coincidence rate between nitrate concentrations and different vulnerability classes is 71 %, which allows the validation of the vulnerability map obtained. This card can be used as a tool for decision support in planning and thus better protect the groundwater in the study area.

Key words: Vulnerability, Groundwater, Pollution, Nitrates, SI method, GIS, Siliana-Tunisia.

1. Introduction

The groundwater of Bou Arada Laroussa is located in an agricultural area characterized by using increasingly important chemical fertilizers and especially nitrates. A study of vulnerability to nitrate pollution of the aquifer has been performed by applying the SI (Susceptibility Index) parametric method by Geographic Information Systems. Indeed, the vulnerability maps allow the location of the most sensitive to pollution and thus help the establishment of protection zones of groundwater.

The exploitation of water resources of the groundwater Bou Arada Laroussa (North West Tunisia Siliana) which covers an area of 170 km ², is an economic imperative, considered as priority because the region in which localizes this groundwater is an excellent agricultural region, and a large part of the population of this area is active in the field of agriculture. The resources of this aquifer are threatened by the use of increasingly chemical fertilizers (mainly nitrates) and pesticides.

As part of this work, we conducted a study of vulnerability to agricultural pollution of groundwater Bou Arada Laroussa using SI parametric method (Ribeira, 2000) applied by the Geographic Information Systems (GIS). This method is a modified version of the DRASTIC method (Aller et al., 1987) adapted to agricultural pollution. The verification of the validity of the vulnerability's card obtained is based on the measurement data of nitrate in the water was carried out in this study.

2. Material and methods

2.1. Presentation of the SI method

The SI (Susceptibility Index) method was developed in Portugal by Ribeiro (2000) in order to address two major flaws related to the DRASTIC method : the redundancy of some parameters and the default weighting schemes which is more or less arbitrary. The term susceptibility used in the name of this method was defined by Verba and Zoporozec in 1994. It refers to " lack of ability to resist to the change in the quality of water in an aquifer as a result of contaminants".

This method is a specific vertical vulnerability that has been designed to be applied mainly in assessing vulnerability to diffuse agricultural pollution, mainly by nitrates, medium and large scales. This method takes into account five parameters are :
- D : the depth of the water,
- R : effective recharge of the aquifer,
- A : the lithology of the aquifer,
- T : the topographic slope of the land.
- O.S : land use.

2.2. Presentation of the study area

The plain of Bou Arada Laroussa (Fig. 1) which is located the studied groundwater covers 170 km² and belongs to the great watersheds Mejerda and Meliane. It is located about 100 km SW of Tunis in a narrow sedimentary basin that is bounded on the north by a band of hills. It belongs geographically to "Grand Tell" precisely in its northern part. Its climate is semi-continental mediterranean. The towns of Bou Arada and Laroussa are the main towns in the study area.

The Quaternary occupies the entire plain of Bou Arada Laroussa (Fig. 2). It is represented by :
- Topsoil ;
- A thin limestone crust ;
- Alluvial terraces ;
- Scree rounded or angular elements ;
- An alluvial filling containing groundwater.

It appears from the study that the stratigraphic study area is located at the southern limit of the Tunisian furrow, leaving the clay marl series to expand significantly on the edges of the plain. These sets are made waterproof by Souar formations, El Haria and Aleg. Fine particles (clay) from the erosion of these waterproof series are carried by floodwaters from the plain to accumulate in the plains. The permeable series that can be aquifers are relatively small and appear in the syncline of Er-Rmil. They are Eocene and Campanian limestones ; the miopliocene filling and Oligocene sandstones (Oueslati, 1990).

The annual rainfall average in the two stations Bou Arada and Laroussa during the period 1998-2008 is 440 mm (DGRE, 2008). The annual temperature average of the period between 1998 and 2008 is around 18 ° C (INM 1998-2008).

The groundwater extends over the plains of Bou Arada and Laroussa. It is obvious that the tank will depend on the lithology of these two plains. The boreholes show that the portion of the aquifer in the area Laroussa has coarse detrital inputs from erosion of Oligocene formations of the syncline of Jebel Er R'mil and Lahmar and southern borders of the plain, while one belonging to the region of Bou Arada seems composed of detrital purposes (sandy clays), tuff, silt, and sometimes rollers near Oued Bou Arada. The piezometric study showed that the water flow from the plain of Bou Arada is directed from south to north to El Gouraet Hmada and Sebkhet EL Kourzia. The waters of the western part of the region of Bou Arada flow into the region Laroussa and seem to be drained by Oued Siliana (Oueslati, 1990).

The plain of Bou Arada Laroussa is an area characterized by an important agricultural activity. Framers practice the permanent crops such as tree crops and olive trees that occupy 26.45 % of the total area, and annual crops such as cereal crop occupying 62.5 %.

3. Results

3.1. Application of the SI method

3.1.1. The map of depths of the water

This map was based on data from the depth of water (static level) recorded in 149 shallow wells evenly distributed over the study area (CRDA Siliana, 2006).

3.1.2. Map of slopes

The slope map was drawn up following a series of treatments by the softwares IDRISI ANDES and Cartalinx on both topographic maps covering the study area : Teboursouk card 1/50000 (sheet 33) and Bou Arada card 1/50000 (sheet 34).

Both cards were joined with the RasterStitch software. This software allows to quickly assemble, two images just to make one (Fig. 4).

3.1.3. Net recharge card

The method used to develop the map of the net recharge of groundwater Bou Arada Laroussa is that of Williams and Kissel (1991). This method has been adopted for the valuation of the net recharge in many semi-arid regions in the U.S. and it has been applied and verified in Tunisia groundwater Metline -Ras Jebel-Raf Raf (Hamza et al., 2006) and that of the Oued Gueniche (Hamza et al., 2007). Net recharge, R, is calculated according to this method with the following equations corresponding to different hydrologic soil groups :

$R = (P - 10.28)^2 / (P + 15.43) \rightarrow$ hydrologic group A.

$R = (P - 15.05)^2 / (P + 22.57) \rightarrow$ hydrologic group B.

$R = (P - 19.53)^2 / (P + 29.29) \rightarrow$ hydrologic group C.

$R = (P - 22.67)^2 / (P + 34.00) \rightarrow$ hydrologic group D.

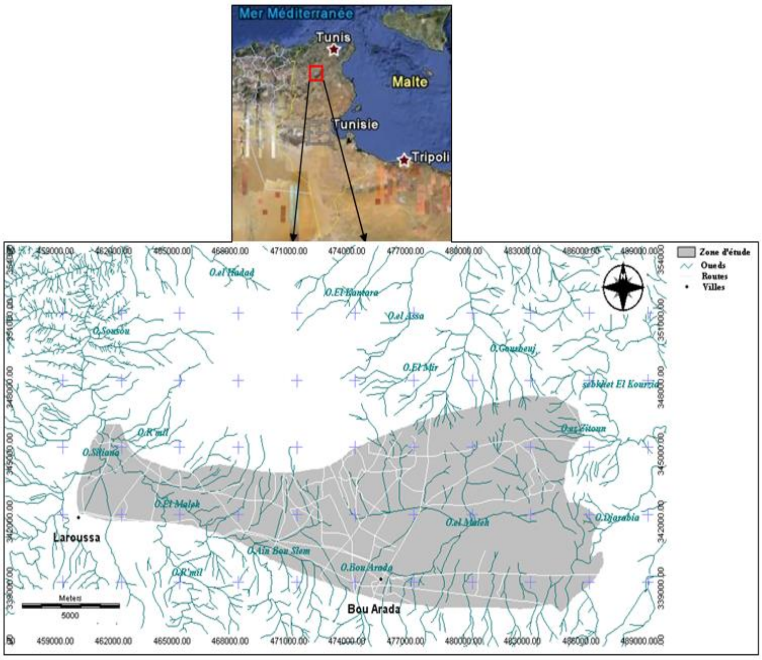


Fig. 1. Location of the study area

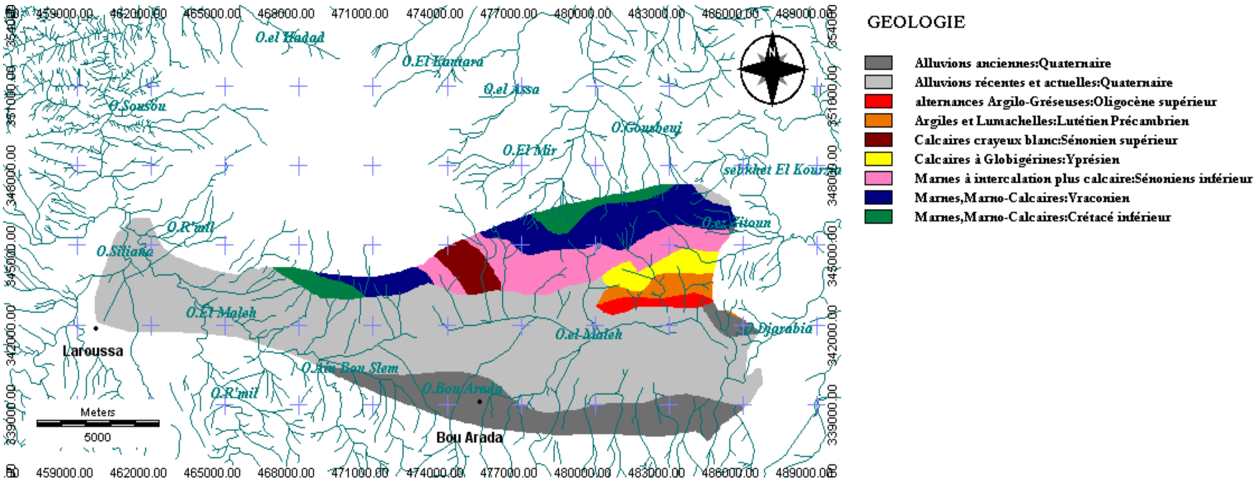


Fig. 2. Geological map of the study area. Extract from geological maps of Bou Arada and Teboursouk 1/50000 (ONM, 1998)

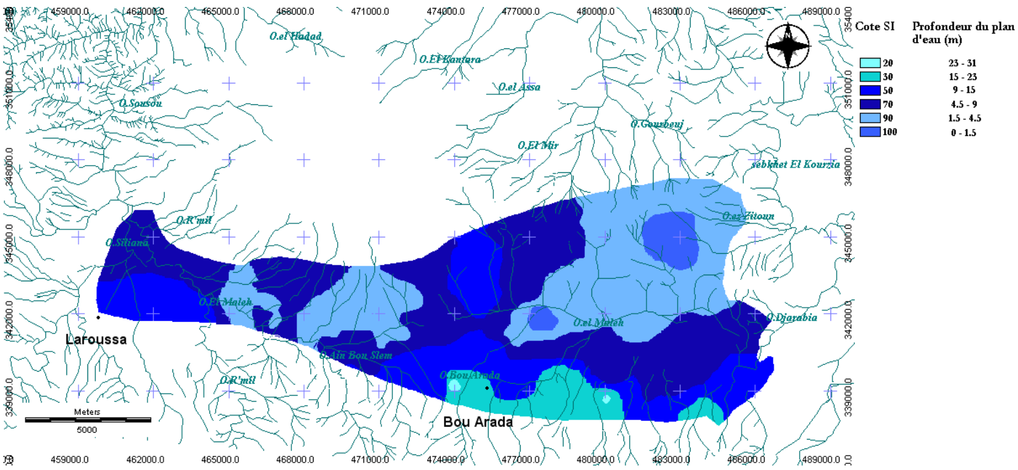


Fig. 3. Map of the water's depth of groundwater Bou Arada Laroussa classified according to the SI method

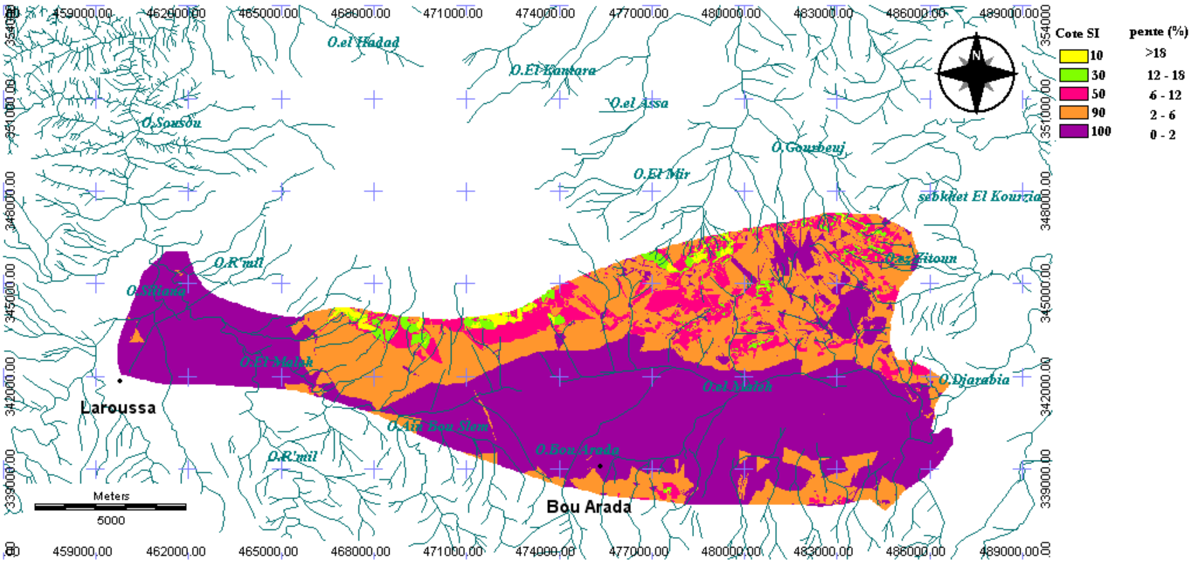


Fig. 4. Slope map classified according to the SI model

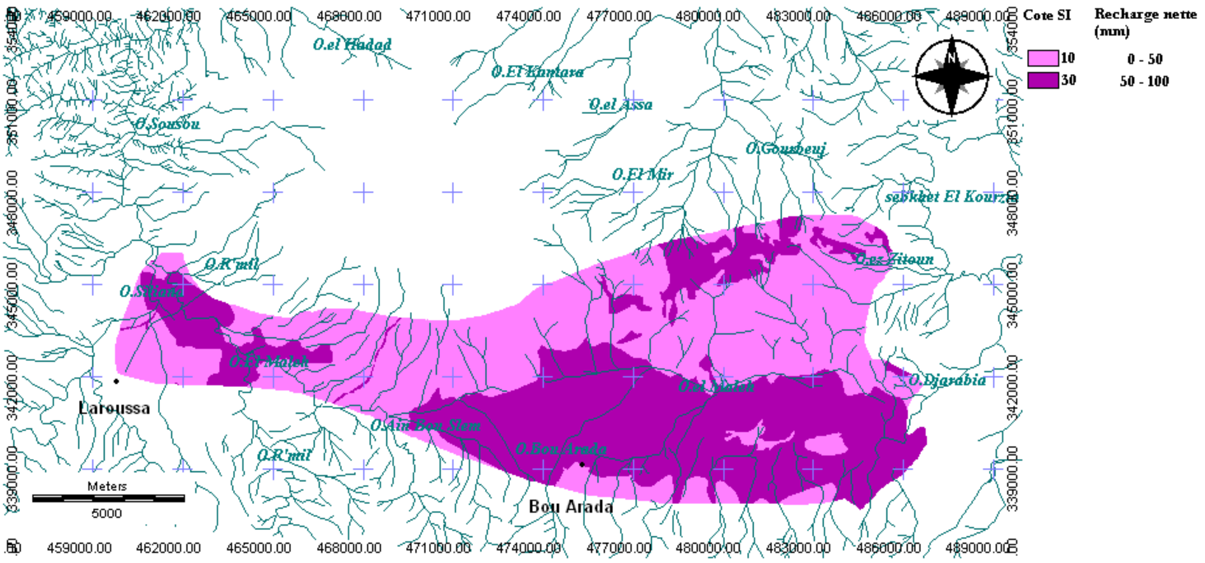


Fig. 5. Map of the net recharge of groundwater Bou Arada - Laroussa classified according to the SI method

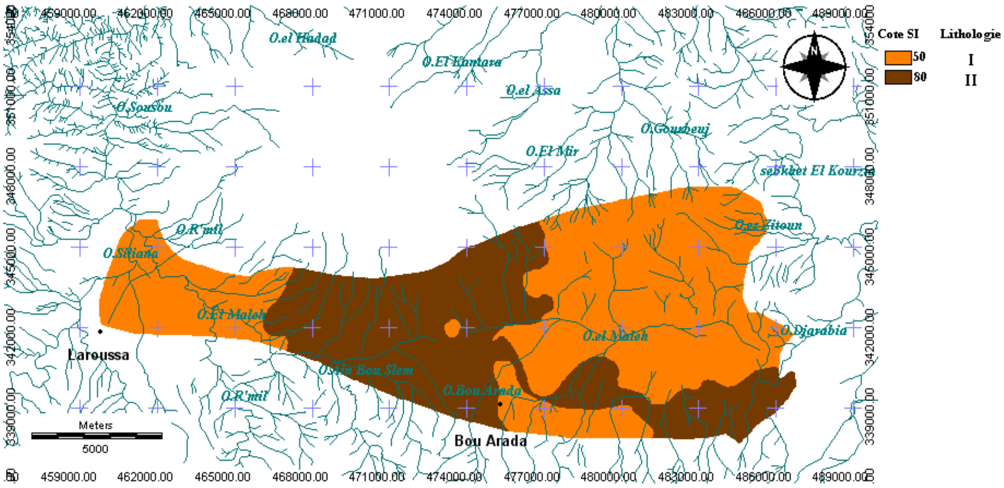


Fig. 6. Map of lithologie of groundwater Bou Arada Laroussa classified according to the SI method with:

I: sandy red clay, sandy clay, sand and clay

II: gravel, slightly sandy gravel, gravel and rubble, sand, red sand

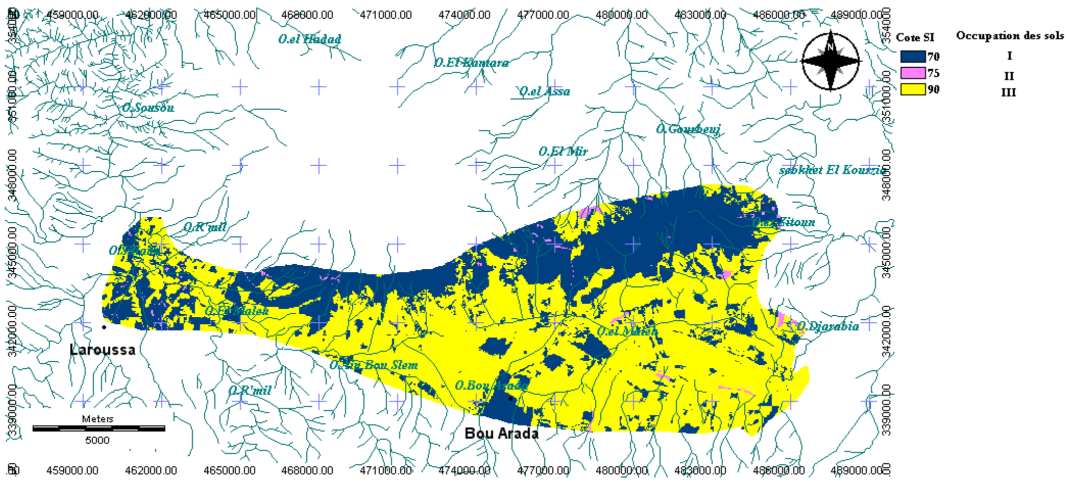


Fig. 7. Map of land use of the study area classified according to the SI method with:

I: Vegetable Crops, Olives, Industrial Crops, discontinuous urban areas

II: Non-Agricultural Land

III: Crops cereals

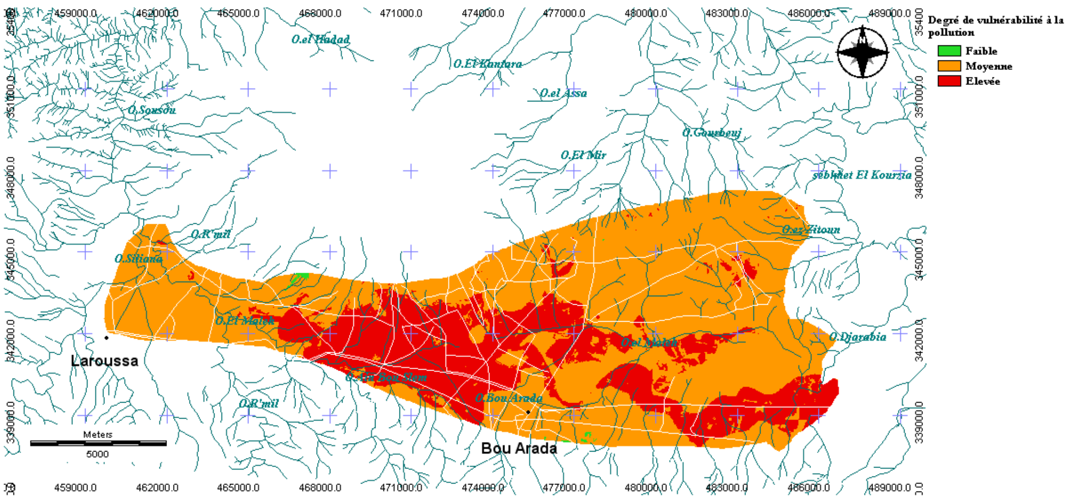


Fig. 8. SI vulnerability map of growndwater Bou Arada Laroussa

where P is the sum of the annual rainfall and irrigation, expressed in inches.

The hydrological four groups A, B, C and D (Viessmann et al., 1977) correspond to the soil types classified according to their infiltration:

- Hydrological Group A: Soils having high infiltration rates even if they are completely wet. They consist mainly of deep soils well to excessively drained, formed of sand or gravel. These soils are characterized by high transmission rates of water.
- Hydrological Group B: Soils with medium infiltration speeds when fully wet. They are moderately deep to deep soils, moderately well drained drained and having a moderately fine to moderately coarse texture. Their water transmission speeds are medium.
- Hydrological Group C: Soils having low infiltration rates when they are completely wet. They mainly consist of soil formed by impermeable layers; the texture is moderately fine to fine. Their water transmission rates are low.
- Hydrological Group D: Soils having very low infiltration rates when they are completely wet. These soils are basically formed of swelling clay, soils with shallow or subsurface clay layers, and shallow soils located over waterproof materials. Their water transmission rates are very low.

The parameter P includes the annual rainfall average which is approximately 440 mm (DGRE, 2008) and the annual amount of irrigation water., which is of the order of 125 mm distributed over the three irrigation perimeter established at the area of Bou Arada Laroussa (CRDA Siliana, 2008).

The hydrological groups map was extracted from the soil map (1/50000) of the study area (CRDA Siliana, 2007). The three types of identified hydrological groups are:

- Hydrologic Group B: sandy soil and sandy loam;
- Hydrologic Group C: sandy loam, sandy clay soil, balanced soil, clay loam, sandy clay soil, clay loam and clay soil;
- Hydrologic Group D: urban area.

The development of the net recharge card was made with IDRISI ANDES (Fig.5).

3.2. Lithology card of the aquifer

The development of the lithological map of the aquifer Bou Arada Laroussa was established not only based on four lithostratigraphic correlations between 7 surveys in the study area by the services of CRDA Siliana (1987-1992) but also based on the depth data of the water. Ten lithological classes of the aquifer were extracted. For each of these classes, we assigned a score ranging between 50 and 80, to finally have the lithological map SI.

3.3. Map of land use

The land use's of the study area was extracted from the agricultural map (1/50000) covering the region of Siliana (CRDA Siliana, 2007). The digitization of this map was made under the Cartalinx software. The resulting map was transferred to IDRISI ANDES according to reclassify the land of the SI method classes.

3.4. Elaboration of the vulnerability map of SI

To establish the SI card, specific vulnerability card to nitrate pollution of the groundwater Bou Arada Laroussa, the maps for each parameter (card odds) were first multiplied by the values of their corresponding weights instead. Then the five parametric maps were summed to obtain the map of vulnerability indices ISI (ISI is equal to the sum of the products of the weight of each parameter with the value of its rating).

$$\mathbf{SI = PPE_p \times PPE_c + Rn_p \times Rn_c + A_p \times A_c + T_p \times T_c + Os_p \times Os_c}$$

with:

PPE_p: the weight of the depth of the water

PPE_c: the map of the depth of the water classified according to the dimensions (SI)

Rn_p: the net weight of the aquifer recharge card

Rn_c: the net Recharge card aquifer classified according to the dimensions (SI)

A_p: the weight of the lithological map of the aquifer

A_c: the lithological map of the aquifer classified by grade (SI)

T_p: the weight of the slope map

T_c: the slope map classified by grade (SI)

The resulting map (Fig. 8), 1/50000 scale, shows the presence of three classes or degrees of vulnerability to pollution: low, medium and high. Much of the study area belongs to the class of medium vulnerability (70% of the total area), followed by the class of high vulnerability (29 %) and the low vulnerability class that covers only 1% of the total area of the study area.

Land with high vulnerability are mainly distributed:

- To the east of the town of Bou Arada;
- North of the town of Bou Arada: around Hir Banania and Hir Bija;
- To the west of the town of Bou Arada: around Tarf ech Chena and Hir er Raim.

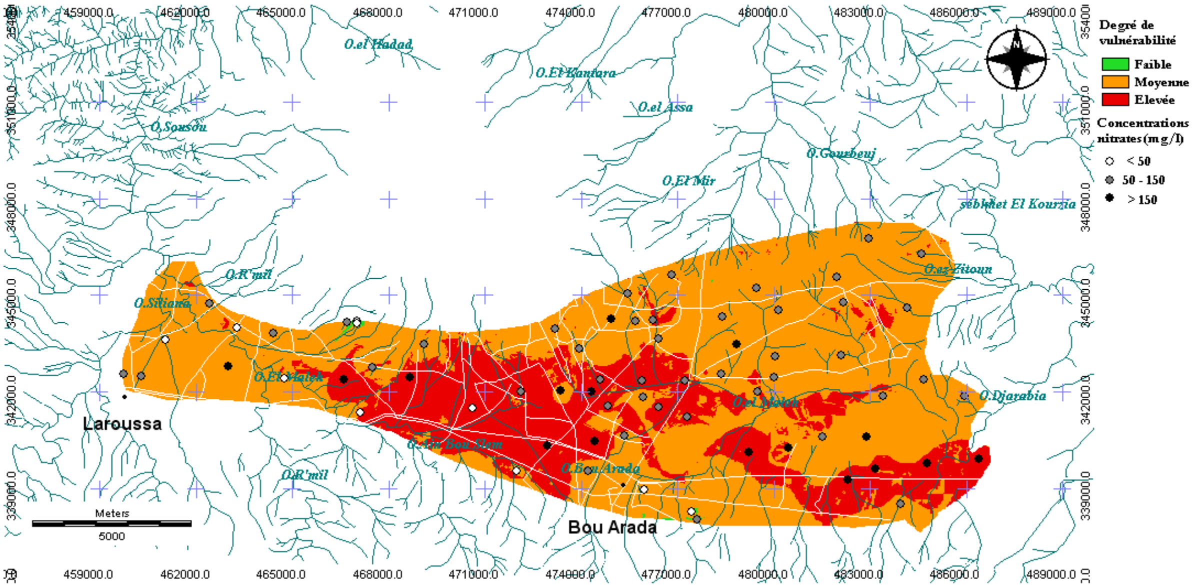


Fig. 11. Map of coincidence between the interpolated and classified map of nitrates and the SI vulnerability map

Fig. 9. Map of the distribution of nitrate concentrations in groundwater Bou Arada Laroussa

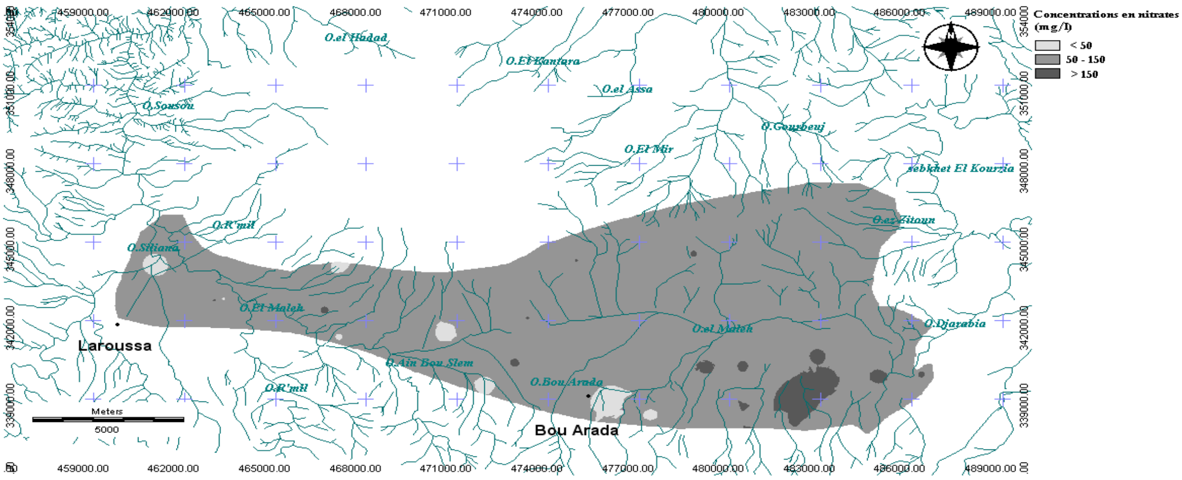
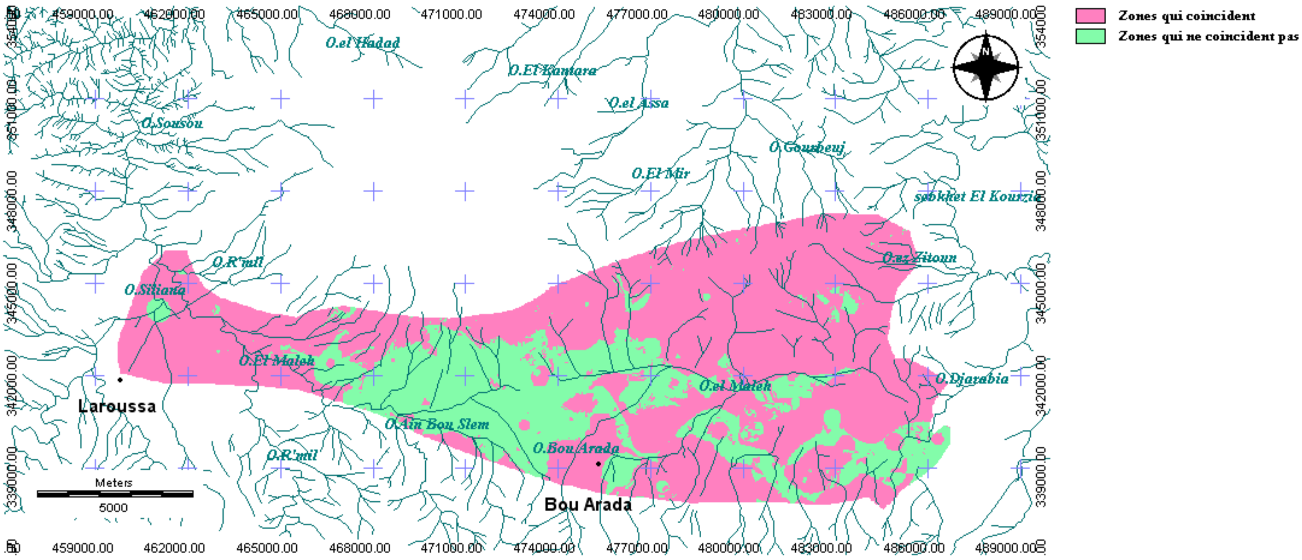


Fig. 10. Map of nitrates interpolated and classified



These lands are mainly irrigated perimeters and annual crops characterized by shallow depth of the plan of water between 1.5 and 9 m, a net recharge of aquifer between 50 and 100 m , an aquifer lithology formed by gravel, gravel, gravel and sand, and a gentle slope between 0 and 2%.

3.5. Checking the validity of the SI vulnerability map

The validity of the SI method vulnerability in the groundwater of Bou Arada Laroussa was tested by a comparison between the distribution of ponctual measurements of nitrate available and the distribution of vulnerability classes. 69 measures nitrate $NO3^-$ recorded in 69 wells which are well distributed over the studied area (DGRE, 2006) were used (Fig. 9).

Ribeiro (2000) defined the low nitrate concentrations as those below 50 mg/l, the medium concentrations as those between 50 and 150 mg/l, and the highest concentrations as those greater than 150 mg/l.

Table 1 shows the coincidence between nitrate concentrations and SI vulnerability classes. From this table we can deduce that the values of nitrate concentration are as follows:

- Among the 16 above 150 mg/l, 11 (69% of these values) coincide with the area of SI high vulnerability.
- Among the 43 values between 50 and 150 mg/l, 31 (72% of these values) coincide with the area of medium vulnerability.
- Among the 10 values below 50 mg/l, 3 (30% of these values) coincide with the area of low vulnerability.

Tab.1: Coincidence between nitrate concentrations and classes of SI vulnerability

	High Vulnerability	Medium Vulnerability	Low Vulnerability
Number of high values of [$NO3^-$] (Above 150 mg / l)	11	5	0
Number of medium values of [NO_3^-] (between 50 and 150 mg/l)	10	31	2
Number of low values of [NO_3^-] (lower than 50 mg/l)	2	5	3

The total rate of coincidence between nitrate concentrations in the different classes and vulnerability is 65% (45 of 69 values).

The validity of the SI vulnerability map can also be verified by comparing the classified map with a map interpolated from ponctual measurements of nitrates classified into three classes of map values: low: 0 to 50 mg/l; medium 50-150 mg/l and elevated above 150 mg/l (fig. 10).

The superposition of two maps: map of vulnerability and map of nitrate interpolated and classified can detect a coincidence rate of about 71% (Fig. 11).

4. Conclusion

The present study on the vulnerability to pollution of groundwater Bou Arada Laroussa was performed by applying the SI method (Ribeiro, 2000), specific method for the vertical vulnerability to nitrates, by the Geographic Information Systems GIS.

The SI map shows that groundwater Bou Arada Laroussa is characterized by high to medium vulnerability to poluution of nitrate.

The validity of the results was verified by a comparison between the distribution of vulnerability classes in the SI card and measures of nitrates available in the waters of the studied groundwater. The obtained rate of coincidence is 71 % which is an acceptable rate.

The SI method considers the "land use" which is not considered in other methods of intrinsic vulnerability parameter. This parameter, involving different types of occupation (agriculture, industry, urban areas, etc..). Its is important in the study of specific vulnerability to pollution by nitrates which are the most serious pollutants in the study area.

The results are consistent with those obtained for the same climatic conditions, by other authors in Portugal (Ingles et al., 2002. Ribeiro et al., 2003. Batista, 2004; Oliveira Ferreira and Lobo, 2005; Stigter et al., 2006) and Tunisia (Hamza et al., 2007; Hamza et al., 2009; Maalej, 2008).

Conflict of Interest

The authors declare that they have no conflict of interest.

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