

Assessing Vulnerability of groundwater with GOD model: a case study in Oran Sebkhah basin - Algeria

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Abstract

The vulnerability of groundwater is a relative, non-measurable and dimensionless property, which is based on the concept that some land areas are more vulnerable to groundwater contamination than others. Most groundwater vulnerability modeling has been based on current hydrogeology and land use conditions. However, groundwater vulnerability is strongly dependent on factors such as depth to water, recharge and land use conditions that may change in response to future changes in climate and/or socio-economic conditions. The evaluation of the aquifer vulnerability is one of the tools supporting decision making related to aquifer protection.

This study is a help approach to protect and prevent pollution of the Oran Sebkhah basin. It discusses the creation of a groundwater vulnerability map. This area of the aquifer is essentially occupied by agricultural areas characterized by an important use of chemical fertilizers, which are in addition to the discharge of industrial zones. The water resources are becoming increasingly scarce, over-exploited, poorly distributed and most especially polluted.

Information on the hydraulic confinement, overlying strata in terms of their lithological character and depth to groundwater table that is affect and control groundwater contamination were incorporated into the GOD model, to produce groundwater vulnerability maps.

The final map shows interesting results and stresses the need for the GIS to test and improve on the groundwater contamination risk assessment method. It was found that the studied water is characterized by a low to very high degree of vulnerability. A moderate vulnerability in area covering 71.5% of the extension of the shallow aquifer.

Keywords: Vulnerability, GOD, Nitrate, GIS, ARCGIS 10.

1. Introduction

Nowadays, groundwater resources play an important role in meeting demands on water supply because of regional climate change and scanty surface water source or their unsuitability (Alwathaf and El Mansouri 2011).

Pollution of groundwater is a major issue because aquifers and the contained groundwater are inherently susceptible to contamination from land use and other anthropogenic impacts (Thirumalaivasan et al. 2003), but because of the self purification function of the reservoir, groundwater is protected to the contamination. The infiltration and subsurface storage of rain and river water can reduce water stress. Artificial groundwater recharge, possibly combined with bank filtration, plant purification and/or the use of subsurface dams and artificial aquifers, is especially advantageous in areas where layers of gravel and sand exist below the earth's surface. Artificial infiltration of surface water into the uppermost aquifer has qualitative and quantitative advantages. The contamination of infiltrated river water will be reduced by natural attenuation. Clay minerals, iron hydroxide and humic matter as well as microorganisms located in the subsurface have high decontamination capacities (Balke and Zhu 2008).

Nevertheless, if the water resource is contaminated, it is not easy to modify its quality. Moreover, the groundwater quality is closely related to the lithology and the thickness of the vadose zone and the geometry of the reservoir.

All the hydrogeological aspects of the aquifer system such as recharge zone, groundwater flow and land use must be involved in the evaluation of the water resource quality.

Assessing the vulnerability of groundwater resource is a preventive tool for controlling groundwater contamination (Farjad et al. 2012). Aquifer system protection is necessary for a sustainable use and protection of the groundwater resources (Demiroglu and Dowd 2014; Gogu et al. 2003; Liggett and Talwar 2009).

In arid regions, over-exploitation of groundwater induced alarming declines in water levels (Edoulati 2013).

Generally, quality of water in arid regions is always changing due excessively factors: low rainfall, high evapotranspiration, structural and soil condition. Increasing populations and high living standards in most arid countries causes excessive water demands used in industries and urban needs (Ruopu and Merchant 2013).

Since detection, monitoring and treatment of groundwater pollution are relatively cost-prohibited;

management of groundwater quality has emphasized protection of the resource (i.e., prevention of contamination).

Protection strategies, however, need to be targeted so that staff, funds and technology can be focused upon those areas that are most threatened (Merchant 1994).

The concept of vulnerability of groundwater to contamination was introduced in the 1960s in France by Margat (1968). He used the term “vulnerability” to mean the degree of protection that the natural environment provides against the ingress of pollutants to groundwater. Since then, several definitions of vulnerability have been proposed. Groundwater vulnerability to contamination can be defined as the propensity or likelihood for contaminants to reach some specific position in the groundwater system after their introduction at some point above the top of the uppermost aquifer (Rao and Alley 1993). Generally speaking, the level of groundwater contamination is determined by the natural attenuation processes occurring within the zone between the pollution source and the aquifer (Fig. 1).

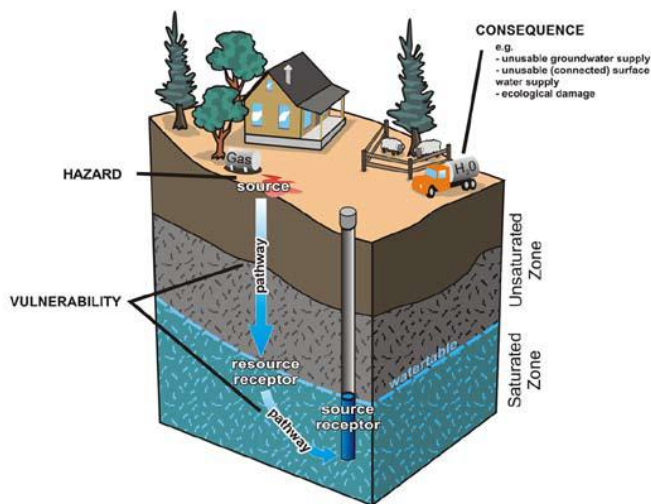


Figure 1: Source-pathway-receptor model for contaminants (Jessica and Talwar 2009).

The vulnerability is also identified as the hazard of the groundwater linked to the vadose zone lithology and the properties of the contaminant (Babiker et al. 2005; Demiroglu and Dowd 2014; Musekiwa and Majola 2013). The vulnerability of an aquifer to the pollution is related to many parameters such as lithology of the aquifer, geometry of the reservoir and hydrogeology (Varol and Davraz 2010; Moratalla et al. 2011).

Remediation of contaminated aquifers is expensive. To recognize the need to an efficient method to protect groundwater resources from contamination, scientists and managers develop aquifer vulnerability techniques to define, which areas are the most vulnerable (Pervinquer 1903).

The assessment of groundwater vulnerability to pollution has been the subject to intensive research during the past years and a variety of methods have been developed.

The available models for the assessment of the groundwater vulnerability are based on the combination of several hydrogeological parameters involved in the contamination process of groundwater.

The vulnerability concept was described based on the effect of the vadose zone to protect the groundwater quality. In fact, the vadose zone can play a key role to eliminate some pollutants infiltrated from surface water.

From 1980s, various models and approaches for the vulnerability assessment and mapping have been developed and tested all over the world (Haertle 1983; Aller et al. 1987; Foster 1987; Foster and Hirata 1988). The process of groundwater vulnerability mapping combines hydrogeological parameters of the aquifer to establish a map with a zoning related to the susceptibility of groundwater contamination by pollutant (Foster et al. 2002).

Many approaches have been developed to evaluate aquifer vulnerability. They include process based methods, statistical methods, and overlay and index methods.

Then, there were several approaches for developing aquifer vulnerability assessment maps. Conventional methods (i.e. DRASTIC, AVI, GOD, SINTACS) are able to distinguish degrees of vulnerability at regional scales where different lithologies exist (Vias et al. 2005).

From the evidence available, GOD approach was used to creating a vulnerability map (Groundwater hydraulic confinement/Overlaying strata/Depth to groundwater table) (Foster 1987). The objective of this study is to assess the vulnerability of groundwater to contamination in Oran Sebkhia basin area using a GOD model combined with a Geographic Information System (GIS). This method considers the soil and unsaturated zone without taking into account the transport processes in the saturated zone.

2. Morphological and structural presentation

The zone of study covers: the great Oran Sebkhia basin (with an area of 1,878 km²); the Sebkhia itself (with an area of 298 km²) and the stretches (over 40 km long and 6-13 km wide). The zone is located in the Central Coastal Oran basin and is bound by: the Djebel Murdjadjo (530 m) in the north, the Mount Tessala (1,061 m) in the south, the plain oued Tlelat in the east, and oued Mellah in the west (Fig.2) (Boualla et al. 2013).

The basin of the Great Sebkhia of Oran extends over an estimated area of about 1890 km². According to Petroleum Geologists (Perrodon 1957), it would be part of the western extremity of the Neogene basin of Lower Cheliff. This area subsided with a sedimentation load rate (largely exceeding 300 meter/million years) (Thomas 1985), presumably presents a major continental alluvial

sedimentation in the axial area. It is also asymmetrical due to the difference in dip of the outcrops (gentle in the North, steep in South). The basin is delimited by faults, especially to the South, similar to a "collapsing rift". The basin is this composed of three main areas: the southern slopes of Jebel Murdjadjo in the north, the northern slopes of Tessala Mountains in the south and the Sabkha Mlèta in the central area of the basin, where are accumulated soluble and insoluble products that come from reliefs (Fig.3).

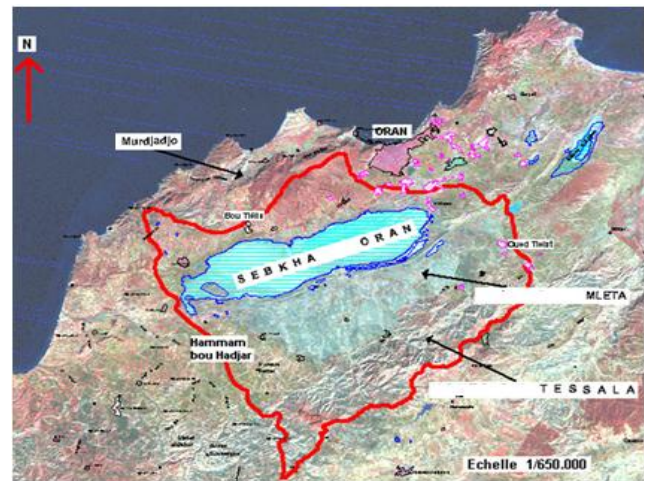


Figure 2: Location map of the great Sebkhia basin of Oran.

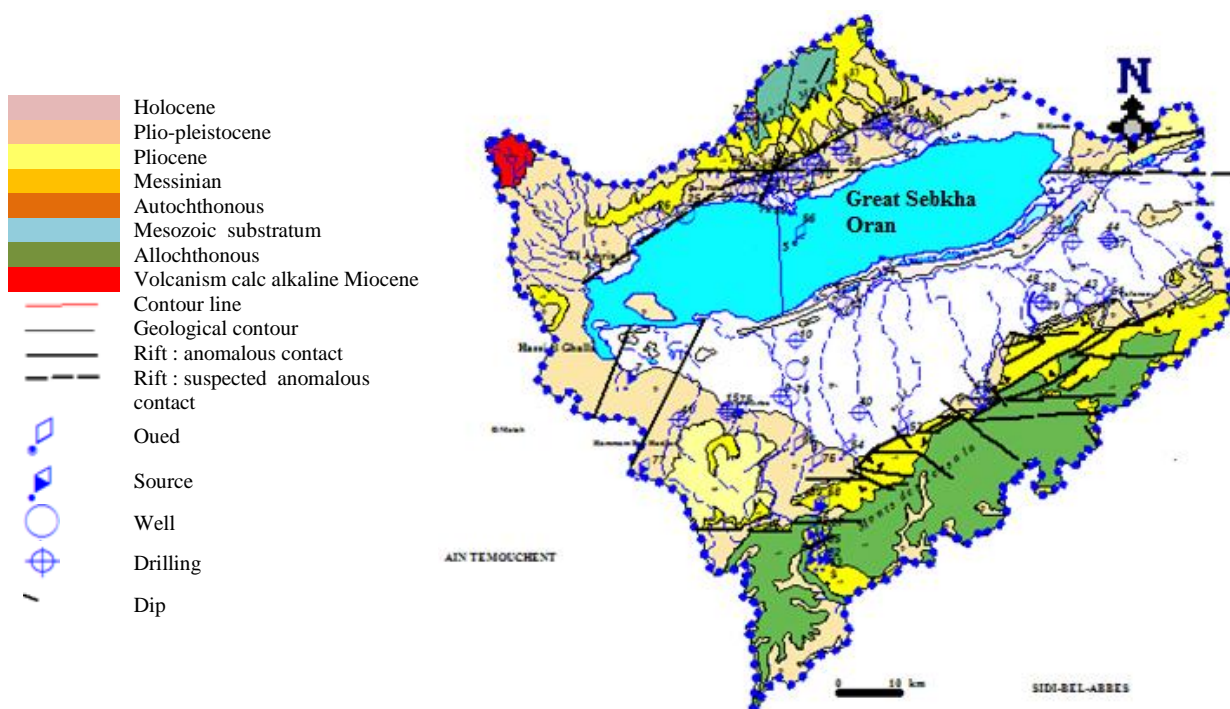


Figure 3: Aquifer system map of the Great Sebkhia of Oran (Benziane 2013).

The Neogene basin of the Great Sebkhia of Oran is characterized by a stack of two or three aquifers layers at the central area. The bedrock formations are characterized by water circulation of minor importance in some permeable layers, or in fracture networks. Neogene formations constitute the best groundwater reservoirs of the basin.

The Messinian consists of algae limestone outcropping on the southern slopes of Jebel Murdjadjo and on northern slopes of the Tessala Mountains.

These reef limestones are developed on both sides of the Sabkha-Mlèta area and constitute the peak of Jebel Tessala. Their extension underneath the lake remains hypothetic. The Pliocene outcrops in the El Kerma area and in the south of Aïn El Arba. These Outcrops are formed of sandstone hills characterized by a good infiltration capacity, easily absorbing rainfalls. The infiltrated water is not drained by water springs, but has to flow northward underneath the Figuier Plaine, and southward in the Mlèta Plaine. In depth, the Pliocene

sandstones contain abundant ascending water-table, of which the quality varies depending to the geographical areas. At the south of the M'lèta Plain, the Pliocene outcrops form, along the rupture line of the slope of Tessala Mountains, a more or less narrow band underneath carbonate facies. Under the plains of M'lèta and Maflak, the Pliocene sandstone, associated with the Miocene, form an aquifer complex recognized and captured by deep drilling (300–500 m); this relatively powerful set (150 m) lies locally on impermeable allochthonous formations. The Quaternary consists of alluvium extended in plains of the periphery of the Great Sebkhah of Oran. They contain a groundwater table fed by its own catchment and infiltration of runoffs issued from the reliefs. Water from this aquifer generally has a high concentration of solutes and its mineralization increases gradually, when we get close to salt lake. This groundwater layer, which flows generally towards the Sebkhah, is captured by farmer wells used for irrigation (Benziane 2013).

3. Methodology

Many approaches have been developed to assess groundwater vulnerability and it can be divided into three major categories: overlay and index methods, process based methods, and statistical methods. The method chosen for vulnerability assessment will depend on factors such as the scale of the study area, data availability, and the specific results desired (Tesoriero et al. 1998). In this work the GOD method was used to assess the Oran Sebkhah basin vulnerability. This is an easy and quick assessment method to map the groundwater vulnerability for contamination as the classical models assume some generic contaminants. This model has relatively lesser parameters in comparison to pragmatic models such as DRASTIC, SEEPAGE, and SINTACS.

This method has a simple and pragmatic structure. It is a rating system that assesses vulnerability by means of three

variables: groundwater occurrence (G), overall lithology of aquifer (O) and depth to groundwater table (D) (Foster 1987).

In developing GOD, the method's authors have given particular consideration to the likelihood of fractures or fracture systems to develop in the soils, overburden, or overlying geologic units of the aquifer. Although this method uses smaller number of parameters than other approaches, this does not imply that it is a less convincing method. It doesn't consider the heterogeneities in the used parameters. The model is described pictorially in figure 4.

The governing equation of the calculation of vulnerability index for the GOD model is given as below:

$$IGOD = Gr * Or * Dr$$

Gr is the rating assigned to the groundwater occurrence parameter; Or is the rating assigned to the overlying lithology parameter; and Dr is the rating assigned to the depth to water table parameter (tab.1).

Following the GOD flowchart, the area vulnerability index is computed by choosing first the rating of groundwater occurrence parameter and then multiplying by the overlying lithology rating as well as with the depth to water parameter rating. The overlying lithology parameter contributes to the vulnerability index only in the case of unconfined aquifers. The parameters can only take values from 0 to 1 (tab.2), the computation result is usually a value less than the score assigned to each parameter.

The overlying lithology contributes to the vulnerability index only in the case of unconfined aquifers (in other words, is equal to one for other types of aquifers).

In the particular case where two parameters have a value equal to 1, the vulnerability score is equal to the score of the third parameter (Gogu et al. 2003). For this, geology map 28 boreholes boreholes were considered.

To indexing spatial information a variety of GIS analysis and geo-processing framework has been applied using ArcGIS 10 software.

Table 1: Attribution of notes for GOD model parameters (Khemiri et al. 2013).

Aquifer type Gr	Note	Depth Dr (m)	Note	Lithology Or	Note
None aquifer	0	<2	1	Residual soil	0.4
Artesian	0.1	2-5	0.9	Limon alluvial, loess, shale, fine limestone	0.5
Confined	0.2	5-10	0.8	Acolian sand, siltite, tuf, igneous, rock	0.6
Semi-confined	0.3	10-20	0.7	Sand and gravel, sandstone, tufa	0.7
Free with cover	0.4-0.6	20-50	0.6	Gravel	0.8
Free with cover	0.7-1	50-100	0.5	Limestone	0.9
		>100	0.4	Fracture or karstic limestone	1

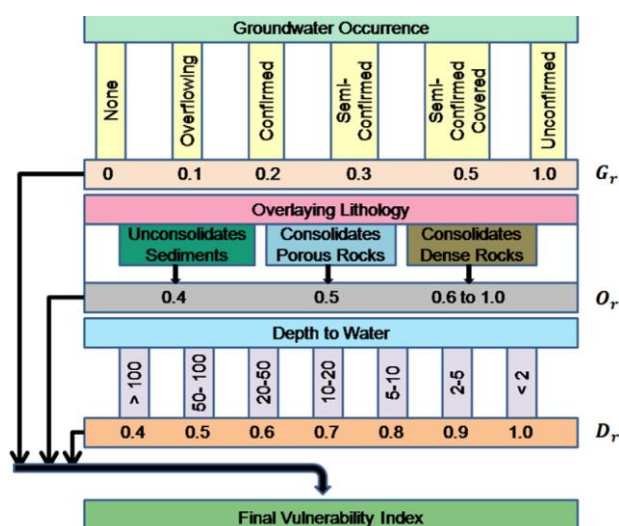


Figure 4: GOD model (Foster 1987).

Table 2 Reclassification of the methods in order to carry out the comparison (Khemiri et al. 2013).

Vulnerability	Class	GOD
Very high	A	0.7-1
High	B	0.5-0.7
Intermediate	C	0.3 – 0.5
Low	D	0.1-0.3

4. Result and discussion

This work can be greatly eased by using a GIS for overlaying the different data sources. GIS allows spatial data gathering, at the same time, gives a means for data processing such as geo-referencing, digitizing and spatial analysis.

Groundwater Contamination Risk Mapping is carried out by overlay of layers representing the different parameters in the par-metrics models.

After mapping all the parameters, the vulnerability maps were obtained by overlaying the individual maps. The spatial mapping in Raster format by interpolation of these parameters is a necessary step in this work. In this case, we obtain the result shown in (Fig.5). The vulnerability index for GOD model is calculated and the final vulnerability map was subdivided into classes related to vulnerability degrees of according to the classification. All the realized maps are projected in “WGS 1984 UTM Zone 32N”.

According to the previous discussion Classification of groundwater vulnerability, the study area was divided into

four vulnerable classes these classes indicate areas of higher, moderate, and low groundwater vulnerability. Low and moderate vulnerability covers about 7.1 % and 71.5% of the study area. They are essentially due to the deep groundwater, the low permeability and the vadose zone sediments, added to that the low hydraulic conductivity. The recharge and the depth of groundwater are two parameters having an influence on vulnerability degrees to pollution. The groundwater in these areas is most protected from pollutants so these areas are the most suitable areas for sustainable development. High vulnerability assigned to 1.12% of the study area. The north-west part of basin (Amria, Hassi El Ghella, Messerghin and south part of Sebkha) is the most exposed part to contamination with very high vulnerability is assigned 0.56 % . The region is an area of high agricultural activity with an intense use of chemical fertilizers.

The combination of quaternary alluvium, shallow groundwater, high recharge and high hydraulic conductivity. Results in a low capacity to attenuate the contaminants. A high vulnerability is linked with the type of soil, a permeable vadoze zone, and a slight slope.

Coarse texture of the soil zone and high downward flows which permit infiltration of more pollutants from the upper Holocene to the underlying Pleistocene aquifer, the risk of vulnerability of groundwater pollution in that area is high (Feumba and Ngoumou Ngatcha 2014).

In order to investigate the effect of over-farming on groundwater quality and to identify an appropriate methodology for pollution risk management, we have carried out a comparative study on the potential risk of contamination from nitrate of agricultural origin, combined with the GOD aquifer vulnerability methods. All parameters used in this risk assessment were prepared, classified, weighed, and integrated in a GIS environment. For calibrating the models and optimizing and/or weighing the examined factors, the modeling results were validated by comparing them with groundwater quality data, in particular nitrate content. The criterion for checking this method was the correlation coefficient of each model with the nitrate concentration in the groundwater. A relative coincidence of a high nitrate concentration and risk mapping was observed, this correlation was significant using the GOD method (Pisciotta et al. 2015).

The vulnerability approach is easy to apply and provides a good assessment of groundwater vulnerability to contamination. A great similarity can be observed in the distribution of the vulnerable zones recognized by map of nitrate (fig. 6).

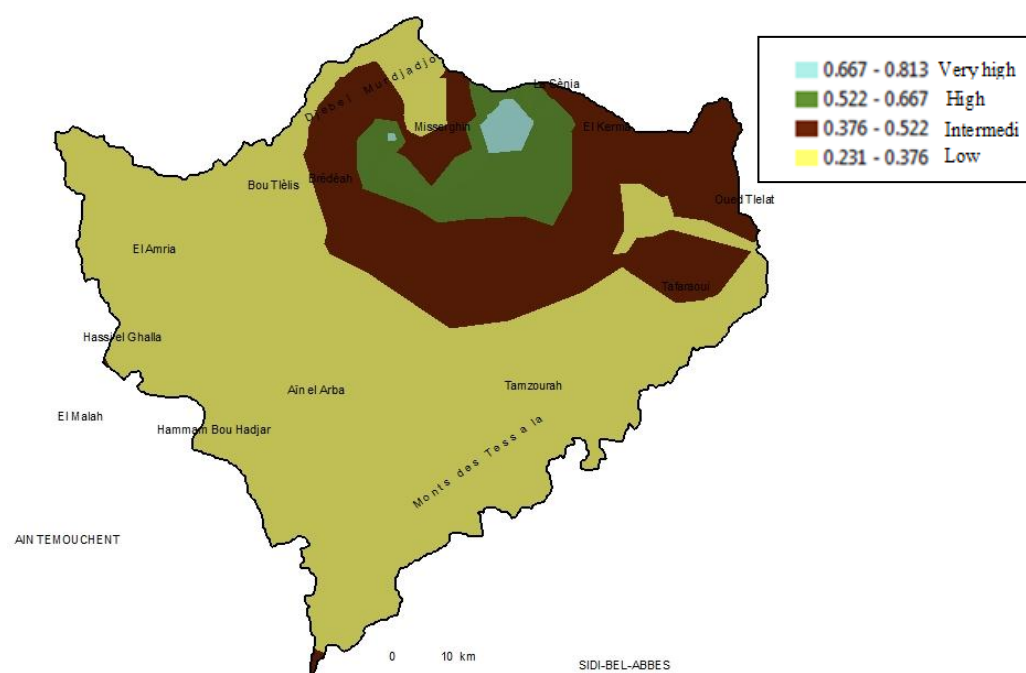


Figure 5: Vulnerability map of Oran Sebkhia basin.

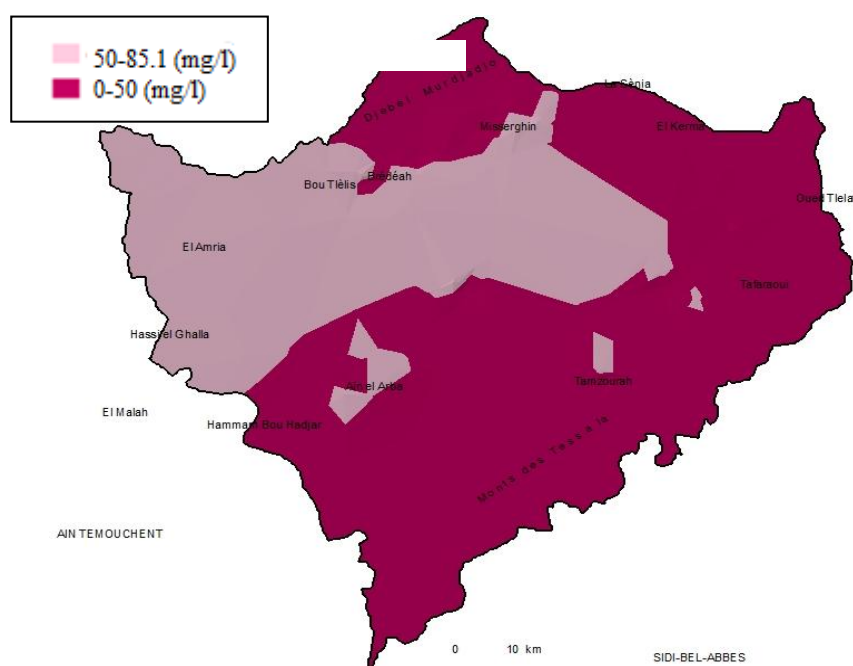


Figure 6: Nitrate pollution map.

Over fifty five water samples collected, eleven exceed the guideline value for nitrate in drinking water of 50 mg/l (WHO 2004), up to levels of about 85.1 mg/l by spectrometry method (Spectrometer Optizen 2120 UV). Highest concentration of nitrate was recorded at Boulélis,

Al Amria and Hassi El Ghalla. The calcareous/gypsum and sandy/marl aquifers are the system with the highest intrinsic vulnerability values. The main groundwater reservoirs are shallow aquifers with the water table being only a few tens of meters deep with overburden permeability on average quite high therefore short travel times for infiltration, this can indicate that the main source of nitrate pollution in the groundwater is due directly to

farming. May be increases in nitrate contents can be also attributed to the recharging pollution of sanitary drainage according to local movement of groundwater. The nitrate pollution map was based on average values for all of the measurements of nitrate concentration recorded for each sampling point (as there were no significant intra-annual variations). ArcGIS 10 was used to interpolate the nitrate concentrations used to generate the nitrate pollution map.

These observations lead to the conclusion that the vulnerability methods underestimate the real distribution of vulnerability to anthropogenic sources and do not take into account the specific properties of particular contaminants and they are inflexible in the assignment of ratings and weights to the model parameters (Sener and Davraz 2013). The methods applied only emphasize the special importance of the lithological nature of the unsaturated zone and of the soil texture for the purposes of vulnerability mapping.

This consideration explains the similarities of the distribution of vulnerability shown by the maps of the GOD method and nitrate. The intrinsic nitrate contamination risk from agricultural sources reflects the probability of groundwater to be actually contaminated by human activities. The potential risk maps show the highest risk of nitrate pollution of groundwater.

The intensive agricultural activities, inappropriate placement of commercial and industrial regions and high intensity residential areas can potentially cause pollution of the groundwater. The main aim of this study was to evaluate two prevalent vulnerability parametric methods.

GOD method developed from the probability estimation of the groundwater contaminant concentrations, hydrogeological approaches, and evaluation of the pollution risk from anthropogenic activities to assess the groundwater quality monitoring network and evaluate the risky zones of the aquifers (Pisciotta et al. 2015). The vulnerability mapping identifies locations which must have a high priority in terms of protection and pollution prevention.

5. Conclusion

The GIS techniques use, to identify contamination risk by mapping, is primarily due to the automatization of certain operations. The database, which is "behind" each layer can any time be updated. In addition, the use of GIS facilitates the rapid visualization of some elements in the map by selecting them from the attribute table. Vulnerability and the land use maps, contamination data and groundwater quality can be used in view of a rapid and correct evaluation of pollution risk. We are assured by using this technology that the information will be used in an efficient manner.

The GIS developed is a good decision tool. It is an efficient method for water resources management to

evaluate vulnerability. The results are a way to avoid possible contamination water.

The vulnerability of groundwater to contamination in the study area was quantified by using the GOD model combined with GIS. The models application showed that Oran Sebkhah basin was characterized by low to very high vulnerability degrees. The most vulnerable areas to pollution are located in the northwest part.

This disparity may be related to notes assigned to various parameters (Murat et al. 2003), the groundwater over-exploitation, the high permeability, the lithologic variability that are marked mainly by quaternary alluvium, facilitates the rainwater infiltration and accumulation. Waters are easily accompanied by various geochemical elements coming from toxic pesticides and their extensive use in farmland, and wastewater. In high vulnerability areas, we shouldn't allow additional high risk activities in order to obtain economic advantage and to reduce environmental pollution hazard and temporal scales. The vulnerability methods have to be used as screening tools. The aquifer protection issues are discussed using the groundwater vulnerability concept. Groundwater vulnerability to the pollution is a dimensionless parameter, which is not directly measurable. It cannot replace the professional expertise. In all cases, the limitations of different classes found, are not absolute values, but relative values (Khemiri et al. 2013). These limits can then vary from one study to another.

GOD method can be a good idea to sensitive zone in order to be forecast necessary protection for vulnerable area.

This paper represents a contribution to the problem of groundwater contamination risk assessment, and it shows the need to continue the research in this direction in order to improve and to standardize methods for the construction of the basic thematic maps and the final map.

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