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APPLICATION OF THE DRASTIC GROUNDWATER VULNERABILITY MAPPING TO THE AQUIFER OF MAGHNIA (NORTH-WEST OF ALGERIA)

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ABSTRACT

Mapping the vulnerability of ground waters in regions of high anthropogenic actions is a crucial step in any realisation in order to ensure rational management of water resources as well as a harmonious urban and socio-economical development.
The present work aims at the determination of vulnerable areas of one of the most important aquifer in the north western region of the "wilaya" (department) of Tlemcen. Indeed, this important aquifer of Maghnia which encroaches on the Moroccan territory is increasingly used by farm operators. It is formed by alluvial and clayey sand formations of Plio-Quaternary. Water pumping in this region is realised by means of classical wells (the most widely used method) as well as by drillings. Unlike wells, the drillings can capture all the water, which may results in an intensive exploitation of the aquifer. In this paper, we used the DRASTIC method to obtain the mapping of the intrinsic vulnerability of this aquifer. The results clearly indicate two vulnerable areas. This map constitutes an important basis for the integrated groundwater management studies and the long-term planning of protective measures.

Keywords: Map of vulnerability, pollution, groundwater protection, Drastic, aquifer of Maghnia.

RESUME

L'établissement des cartes de vulnérabilité à la pollution des eaux souterraines dans les régions à forte action anthropique est une étape décisive dans toute mise en œuvre (entreprise) autant pour une gestion rationnelle des ressources en eau que pour un développement socio économique et urbain harmonieux.
La présente contribution a pour but de mettre en évidence les zones les plus sensibles à la pollution d'un des plus importants aquifères de la région nord ouest de la wilaya de Tlemcen. En effet, la nappe de Maghnia se prolongeant en partie en territoire marocain, est de plus en plus sollicitée par les agriculteurs. C'est une nappe contenue dans les formations alluvionnaires argilo sableuses du Plio-Quaternaire. La mobilisation des eaux se fait par puits (la méthode la plus répandue) mais aussi par forages. Ces derniers permettent de capter la totalité de la nappe contrairement aux puits induisant ainsi une exploitation intensive. L'élaboration de la carte de vulnérabilité de cette nappe a été possible par l'application de la méthode DRASTIC. La carte obtenue montre deux zones de vulnérabilité. Cette carte constitue une base importante pour les études de la gestion intégrée des eaux souterraines et la planification à long terme de mesures de protection.

Mots clés : Carte de vulnérabilité, pollution, protection des eaux souterraines, Drastic, nappe de Maghnia.

INTRODUCTION

The aquifer of Maghnia is a fairly large and economically important hydro geological system in the area since it is the main water resource of the region. This water resource is used for both drinking water and agricultural activities. In fact, Maghnia irrigation scheme is ranked at a national level. Maghnia aquifer has been extensively studied (Bonnet, 1965; ANRH 1995; Baba Hamed, 2007) and piezometric campaigns are regularly conducted by the ANRH (Agence Nationale des Ressource Hydriques / National Agency for Water Resources) services. The high demand of these water resources exposes them to an overexploitation and degradation of quality. Hence, the protection of the groundwater of this region is of a significant concern. The goal of this work is to realize a map of the intrinsic vulnerability of this aquifer. This map will probably help local managers to make wiser decisions in order to protect this vital resource. The DRASTIC method used herein to realize this map is probably the most widely used groundwater vulnerability mapping technique.

DESCRIPTION OF STUDY AREA

The plain of Maghnia lies in the extreme North-West of Algeria in the wilaya of Tlemcen (Figure 1). It extends over approximately 351 km^2 which represent 80% of the communal space and where the prevailing climate is semi-arid. This plain is surrounded by the mountains of Tlemcen to the south (Rhar-Roubane) and by the Traras to the north (Jebel fillaoucene). It is bordered to the east by the Tafna valley and to the west it is prolonged by the Angads plains in Morocco. Elevations oscillate around 400m. The whole plain is drained by two main water courses, namely:

• Oued Mouillah: a major inflowing of the left bank of the Tafna which originates in the area of El Abed. It follows its course into the Moroccan territory as Oued Isly, then Oued Bou Naim, and finally, returns to the north of the city of Maghnia in the Algerian territory.

• Oued Ouerdefou collects the waters of oued Mehaguene and oued El Abbes which drains the southern part of the plain.

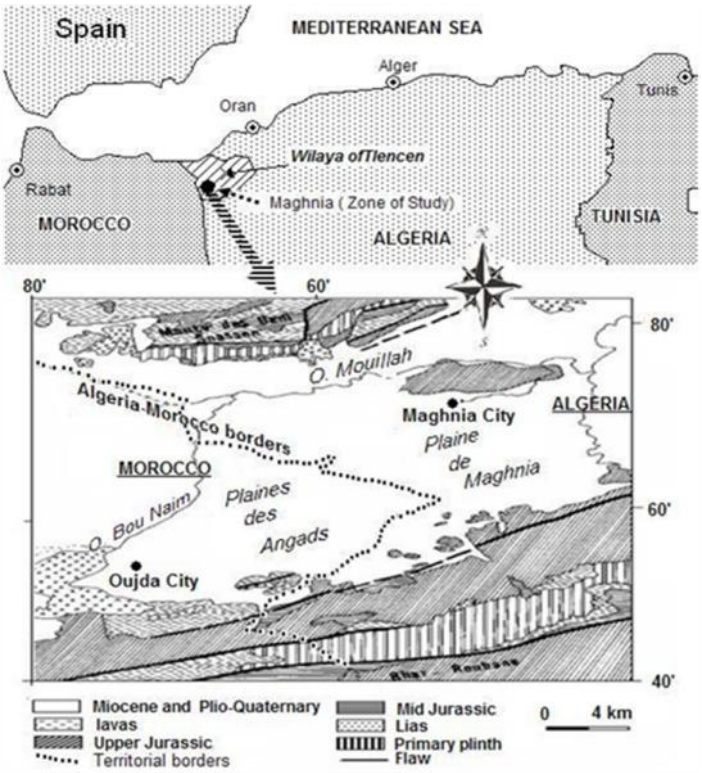

Figure 1 : Location of the study area and its geological map (geological map in Baba Hamed, 2007)

The geology and hydrogeology of this region have been researched extensively by Lucas (1942), Bonnet (1965) and Baba Hamed (2007). The plain of Maghnia is a basin elongated in a direction ENE-WSW and filled with deposits produced by the erosion of coastal mountains (Rhar Roubane, Fillaoucene). These are alluvial and lacustrine sediments of the Plio-Quaternary which lie on a marly impermeable substrat of the Miocene.
As assessed by the study of lithological logs of drillings and trial holes realised in the plain of Maghnia, the Plio-Quaternary cover varies greatly from one location to another. It is much thicker at the center of the plain where it reaches its maximum thickness and is generally composed of gravel.
Maghnia groundwater is mainly used for irrigation and supply of drinking water to the local population. The water pumping is generally realised either through shallow wells or through medium depth drillings.

METHODOLOGY

Approach and mapping procedure

Various methods aiming at the evaluation of vulnerability have been developed and applied with satisfaction in different regions of the world. Among these techniques, we can mention AVI (van Stempvoort et al., 1992), DRASTIC (Aller et al., 1987), EPIK (Doerfliger et al., 1999) and ISIS (Civita and De Regibus, 1995). Such vulnerability methodologies take into account that the natural environment protects itself when a contaminant is introduced. The purpose of groundwater vulnerability assessments is to characterize the potential of contamination within a geologic setting and define areas that are more vulnerable than others.
The DRASTIC method applied in this work to evaluate the pollution potential of the aquifer of Maghnia is probably the most widely used mapping method to assess the vulnerability to pollution of groundwaters. Developed by the US Environmental Protection Agency (EPA), DRASTIC is an aquifer vulnerability methodology which incorporates the major hydrologic factors which affect and control groundwater movement. These factors are depth to water, net recharge, aquifer media, soil media, topography (slope), impact of vadose zone media, and hydraulic conductivity of the aquifer. These seven factors, which form the acronym DRASTIC, are incorporated into a relative ranking scheme that uses a combination of weights and ratings to produce a numerical value called the DRASTIC Index. The equation for determining the DRASTIC Index is:

$$I = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \quad (1)$$

The indices *r* and *w* in equation (1) refer respectively to rating and weight parameters. The index number, *I*, evaluated by equation (1) represents a relative measure of the groundwater pollution potential. Each parameter is assigned a

relative weight ranging from 1 to 5 (Table 1) and a rating which varies from 1 to 10 for different ranges of values (Table 2). Once a DRASTIC Index is computed, it is possible to identify areas which are more likely to be susceptible to groundwater contamination relative to others. The higher the DRASTIC Index is, the greater the groundwater potential of pollution. The DRASTIC numerical Index can be further divided into five categories: very low, low, moderate, high and very high potential of contamination according to table 2 as adopted by HAMZA et al. (2008).

Table 1 : Assigned weights for DRASTIC features (Aller et al., 1987)

Features	Weight
Depth to Water	5
Net Recharge	4
Aquifer Media	3
Soil Media	2
Topography	1
Impact of the Vadose Zone Media	5
Hydraulic Conductivity of the Aquifer	3

Table 2. Ranges and ratings for Drastic features (Aller et al., 1987)

Depth to Water (feet)		Net Recharge (in.)		Aquifer Media			Soil Media		Topography (Percent Slope)		Impact of the Vadose Zone Media			Hydraulic Conductivity of the Aquifer	
Range	Rating	Range	Rating	Range	Range	Typical Rating	Range	Rating	Range	Rating	Range	Rating	Typical Rating	Range (gpd/ft²)	Rating
0-5	10	0-2	1	Massive Shale	1-3	2	Thin or absent	10	0-2	10	Confining Layer	1	1	1-100	1
5-15	9	2-4	3	Metamorphic /Igneous	2-5	3	Gravel	10	2-6	9	Silt/Clay	2-6	3	100-300	2
15-30	7	4-7	6	Weathered Metamorphic/ Igneous	3-5	4	Sand	9	6-12	5	Shale	2-5	3	300-700	4
30-50	5	7-10	8	Glacial Till	4-6	5	Peat	8	12-18	3	Limestone	2-7	6	700-1000	6
50-75	3	>10	9	Bedded Sandstone, Limestone and shale sequences	5-9	6	Shrinking and/or aggregated Clay	7	>18	1	Sandstone	4-8	6	1000-2000	8
75-100	2			Massive Sandstone	4-9	6	Sandy Loam	6			Bedded Limestone, Sandstone, Shale	4-8	6	>2000	10
>100	1			Massive Limestone	4-9	6	Loam	5			Sand and Gravel with significant Silt and Clay	4-8	6		
				Sand & Gravel	4-9	8	Silty Loam	4			Metamorphic /Igneous	2-8	4		
				Basalt	2-10	9	Clay Loam	3			Sand and Gravel	6-9	8		
				Karst limestone	8-10	10	Muck	2			Basalt	2-10	9		
							Nonshrinking and nonaggregated Clay	1			Karst Limestone	8-10	10		

Table 3. The vulnerability classes adopted in this work

DRASTIC Index	Vulnerability
<80	Very low vulnerability
80-120	Low vulnerability
121-160	Moderate vulnerability
161-200	High vulnerability
>200	Very high vulnerability

Implementation of DRASTIC to the aquifer of Maghnia

The DRASTIC method is applied in this work to the aquifer of Maghnia to assess the degree of vulnerability to pollution by studying each of the seven parameters separately. Each DRASTIC parameter has been weighted with respect to each other and assigned a number from 1 to 5 according to table 1.

These parameters have been afterwards divided into ranges or descriptive terms and assigned associated ratings according to table 2. The DRASTIC index for each parameter is obtained by multiplying the weight and the rating and the corresponding maps are drawn for each individual DRASTIC feature. The resulting vulnerability DRASTIC map is finally drawn in figure 2 by adding individual DRASTIC indices as stated by equation (1). The details of the mapping procedure are explained below.

The ranges of depths to water are evaluated using piezometric depths recorded by ANRH during 2002 (Benabdelkim, 2008). About 13 water points distributed over the plain of Maghnia were recorded during this period. In our work we have considered only values corresponding to the wettest period (values recorded during April). Three depth ranges were obtained over the whole area of study. These ranges correspond to the depth ratings of 5, 3, 2 and 1 according to table 2.

The evaluation of the net recharge ratings were performed on the basis of an annual precipitation value equal to 368.8 mm recorded by the weather forecast station of Maghnia during 2002 (Benabdelkim, 2008). The aquifer net recharge was calculated according to the Williams and Kissel method (1991), which is the most suitable method for the area under study. With this method we found a recharge value of about 54.92 mm all over the aquifer. This value corresponds to a rating equal to 3 taken from table 2.

Based on findings from lithostratigraphic logs of 17 boreholes and wells spread over the plain we concluded that the aquifer media is constituted by sand and gravel. Hence, a rating value equal to 8 was assigned to the whole aquifer.

Soil Media ranges were estimated based on the pedological map of the land use of the region under study. Three soil ranges were recognized which correspond to the ratings of 6, 3 and 1 according to table 2.

The main level curves given by the topographic map of Maghnia at a scale 1:50,000 were used to estimate the slope distribution in the study area. Two classes of slopes were identified. The major part of the study area was found to correspond to a rating equal to 10 and only a negligible portion of the region has slopes which correspond to a rating value equal to 5.

The litho-stratigraphic log of boreholes and wells of the region shows that this zone is constituted of sand and gravel with significant silt and clay. Hence, a unique rating value equal to 6 was assigned to the impact of the vadoze zone media.

The conductivity values used in this work are those given by the ANRH. The region under study is constituted by four ranges of hydraulic conductivity corresponding to rating values of 2, 4, 8 and 10 according to table 2.

The individual indices for each of the seven parameters were evaluated by multiplying the ratings given above by the corresponding weights taken from table 1. As mentioned earlier, the final vulnerability map was obtained by adding individual indices according to the global DRASTIC index given by equation (1). The study region was discretized by square cells. The resulting

map (figure 2) shows that DRASTIC index for the plain of Maghnia varies from 95 to 128 which can be divided into two classes according to table 3 (i.e. 95-120: Low vulnerability and 121 – 128: Moderate vulnerability):

1) The low vulnerability class is observed in the majority of the aquifer surface (68% of the total mapped area). This can be explained by the weak influence of some parameters such as net recharge and soil media.

2) The moderate vulnerability class represents 32% of the mapped area and is distributed in five small areas (fig 2). In area 1 which lies in a north-south extension located in the extreme west of the plain near the Moroccan border, the degree of vulnerability is moderate. This is mainly due to a relatively high permeability. In area 2, which is elongated in a northeast- southwest direction and situated nearly in the middle of the study area, the moderate vulnerability is due to a relatively high permeability and the presence of a sandy loam soil. Areas 3 and 4 have moderate vulnerabilities due essentially to a very high hydraulic permeability. Finally in area 5, which is located in the middle southern part of the plain, the moderate vulnerability is due to the existence of a low water depth and a sandy loam soil.

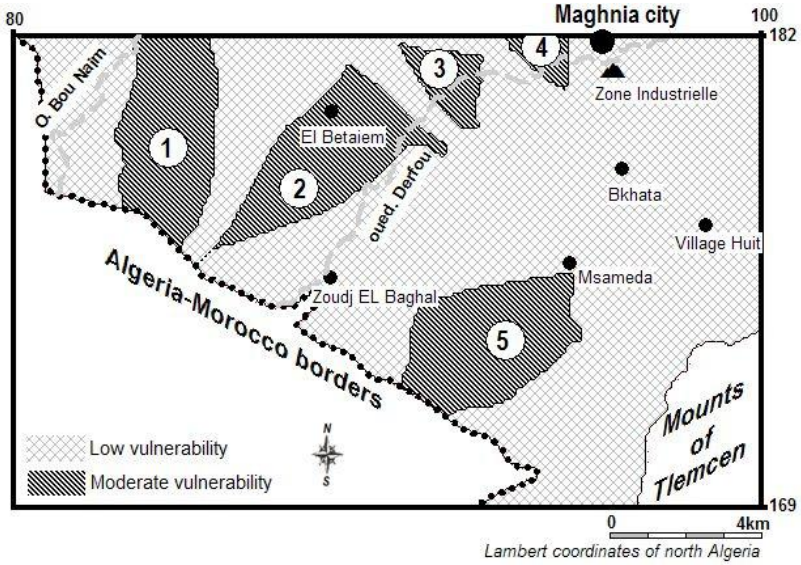

Figure 2 : The DRASTIC vulnerability map of Maghnia groundwater

CONCLUSION

The plain of Maghnia has an agricultural vocation; therefore, it is crucial to protect the quality of its underground water resources from the danger represented by environmental risk factors such as the use of pesticides, chemical

and organic fertilizers and the irrigation of the land with unconventional methods by land farmers, as well as the contamination by animal dejections.
To be able to detect zones of vulnerability is instrumental in the design of a more effective way to fight underground water pollution. In this paper, we have used the DRASTIC method to establish a vulnerability map to pollution of the underground waters of the plain of Maghnia. Our results point to the presence of two degrees of vulnerability: a low level extending over 68% of the total mapped area and a moderate level extending over 32% of the mapped area due likely to a relatively high hydraulic conductivity of these zones.
We strongly believe that using the mapping technique in order to identify and evaluate the severity of the vulnerability represents a very useful tool to help all decision makers in the management of water resources take adequate measures to further improve the protection and preservation of the underground water resources.

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