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GROUNDWATER VULNERABILITY ASSESSMENT IN THE M'ZAB VALLEY - SOUTHERN ALGERIA

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ABSTRACT

The water pollution risk is considering a topical subject in Algeria and throughout the world, especially in view of the problems of water scarcity and the climate change phenomena. The infiltration of untreated urban waste into the subsoil presents a major risk of pollution for groundwater close to the surface and which constitutes an important source of water in arid areas.

In the Algerian Sahara, the M'Zab valley has recently experienced a critical health and environmental situation, the latter is due to major urban discharges into nature without any means of protection and preservation and especially at El-Atteuf oasis in the downstream of the M'Zab wadi. In this regard, the main objective of this work is to assess the intrinsic vulnerability to pollution of the phreatic aquifer in the M'Zab valley. In this work and through several parameters, the vulnerability study was carried out by applying three methods (GOD, DRASTIC and SINTACS) using piezometric observations for 62 wells. The results are presented in the form of several maps developed by GIS. These maps can be considered as a helper tool for planners and managers to improve the environmental situation of the M'Zab valley.

Keywords: Urban discharge, Groundwater pollution, Vulnerability methods, Mapping.

INTRODUCTION

Groundwater is the main resource in arid areas and are often threatened by human activities (Baali et al., 2007). The increasing use of domestic and industrial discharges make them even more vulnerable (Mohammadi et al., 2009). Preserving groundwater against pollution is an important step in the management of aquifers, to which scientists are increasingly making efforts, especially studying the groundwater vulnerability to pollution. The concept of groundwater vulnerability was developed over forty years ago and does not have a single definition, but differs according to the sensitivity of the approaches and the authors (Atiqur, 2008). Some of them have defined it as an intrinsic property of the aquifers; others suggest it is related to the specific properties of the contaminant whilst others associate it with human activities soil properties. Nevertheless, it admitted that the vulnerability is assessed qualitatively based on the study of transfer mechanisms of a pollutant introduced at the surface throughout the subsurface layers (Margat, 1968; Foster, 1987).

Admittedly, this type of study improve water management and guide protection measures to be undertaken (Graillat et al, 1994). Additionally, geographic Information Systems (GIS) meet management, planning and development requirements thanks to their enormous potential for cross-processing spatial databases that facilitate the synthesis and guidance of decision-making (Eastman, 1995; Duchaine, 1998).

In this regard, the main objective of this modest work is the assessment of the intrinsic vulnerability of the phreatic aquifer in the M'Zab valley to pollution using parametric methods in order to map it, which will be useful for emergency planners and managers to improve the environmental situation.

PROBLEMATIC

In the Algerian Sahara and more precisely in the M'Zab valley, for centuries peoples have thought of a rigorous control of the management of water resources (Remini; 2020). This management changed after drilling the first deep well through an anarchic exploitation of the groundwater, which led to the release of large quantities of urban and industrial discharges in the main wadi (Fig 1). This situation has led to the appearance of polluted lakes and more particularly in the part of El Atteuf, where several wells have been abandoned because of the contamination of the water (Zegait; 2020).

Figure 1**: Pollution caused by urban waste in M'Zab valley**

STUDY AREA

The M'Zab valley is located 600 km south of Algiers (Fig 2) and considered one of the great oases of the Algerian Sahara with a climate that characterized by low rainfall and sudden floods (Dubief, J., 1953), high temperatures can exceed 45 °C in summer. The relative humidity of the air is very low and winds are relatively frequent with strong evaporation that approximates yearly 2500 mm (ONM, 2015).

Figure 2: Situation of the study area (Visible Earth, NASA; 2002)

HYDROLOGICAL SITUATION

The main water resources in the valley are of underground origin. They are contained in two types of aquifers; the phreatic aquifer and the continental intercalary known as Albian aquifer (ANRH, 2011).

This phreatic aquifer is captured by thousands of traditional wells (more than 5700), which are sheltered in the alluvium of M'Zab wadi. Feeding and hydrogeological behavior are closely related to rainfall. The depth of these wells varies between 10 and 30 m including a 6 m of their static level. Their recharge improved by ingenious devices as dams delaying the flow of floods (on the M'Zab Wadi in particular) or low walls concentrating and directing the runoff on the limestone of the valley sides. These wells intended mainly to irrigate the palm groves of the valleys with a flow ranged from 1 to 3l/s.

While the Continental Intercalary (CI) aquifer covers an area around 1100,000 km² approximately (Dubost, 1991). It represents the main water resource in all of the Sahara (Fig 3). The aquifer is composed of sands, sandstone and sandy clays of Albian age. It is captured approximately at (400-1000m) of depth (Côte, 1996).

The continental intercalary aquifer is exploited by drilling with average unit flows ranged from 40 to 80 l/s, which can reach up to 100 l / s. The Albian aquifer is Artesian, but the backflow level only reaches the top of the well in a few places.

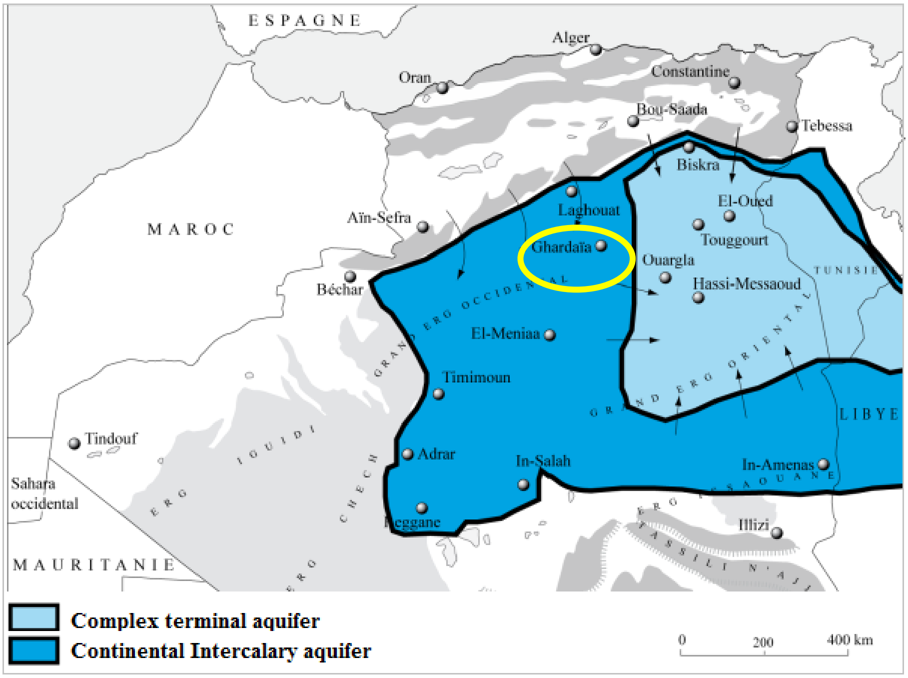

Figure 3**: Area of the Aquifer System of the Northern Sahara**

MEASUREMENT CAMPAIGNS

During this study, we selected 62 wells distributed uniformly across the downstream bed of the M'Zab wadi from the Oasis of Bounoura to the El-Atteuf dam (Fig. 4) in order to record the various hydraulic parameters of the wells such as water levels, and depth using an electric probe (Fig 5).

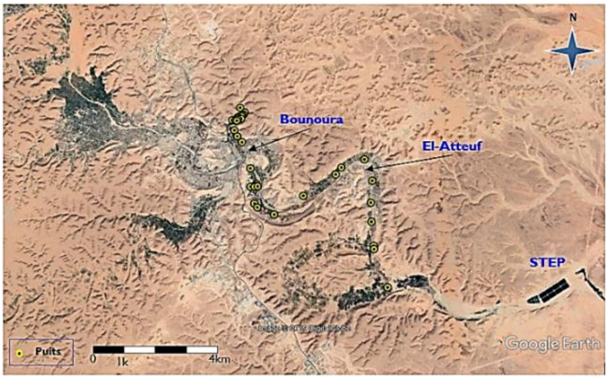

Figure 4: Location of water points

Figure 5: Measuring equipment (Taken by Zegait; 2015)

METHODOLOGY

The protection of water resources requires measures and works appropriate to the challenges. To achieve this objective, it is necessary to qualify and rank the vulnerability of underground aquatic environments, but one of the essential difficulties lies in estimating the vulnerability of these environments. For this, many methods have been developed around the world depending on the case studied, ranging from the most complex with models taking into account the physical, chemical and biological processes in the flooded area, to weighting methods between different criteria affecting vulnerability. The application of these methods cannot be possible without the use of Geographic Information Systems (GIS), due to the very large amount of data required (Vaillant et al; 1995). In this study we referred to the three the most widely used method, DRASTIC (Aller et al., 1987), GOD (Foster, 1987) and SINTACS (Civita, 1994).

GOD Method

The GOD method was developed by Foster in 1987, and presents the vulnerability of the aquifer to vertical percolation of pollutants through the unsaturated zone and does not address lateral migration of pollutants into the saturated zone (Mardhel et al., 2005). According to Foster (1987), the GOD method is a parametric method using the product of the three parameters:

$$I_{GOD} = C_i \times C_p \times C_a$$

Where:
I_{GOD}: Potential pollution index (GOD index) or vulnerability degree;
C_i: Aquifer type coefficient;
C_p: Groundwater depth coefficient;
C_a: Coefficient of lithology of the aquifer.

The coefficients are assigned to the parameters according to their importance for the vulnerability of the aquifer. They correspond to the punctuation attributed to the hydrogeological characteristic of the aquifer. These coefficients take values in an interval of given numerical classes. The classes defined taking into account the transfer time of the pollutant to the aquifer and starting from the most favorable condition, or low vulnerability (the value of the score is equal to 0), up to the most critical condition (the coefficient value is equal to 1). Each critical factor was analyzed and evaluated against the other parameters to define its relative importance in the vulnerability estimate. The high coefficients are attributed to factors facilitating the infiltration of pollutants, from the soil surface, to the phreatic aquifer (Smida H, et al 2012).

DRASTIC Method

The DRASTIC method is one of the methods of the PCSM (Point Count System Model) subgroup that was developed by Aller et al. (1987) with the objective of evaluating the risks of groundwater pollution (Verba and Zaporozec, 1994; Knox et al .; 1993).The proposed method is based on the following basic assumptions: the potential sources of contamination are on the surface of the soil; potential contaminants reach the aquifer through the efficient infiltration mechanism; the contaminant has the same mobility as groundwater; the hydrogeological unit in question is greater than 0.4 km^2 (Murat et al., 2003). The DRASTIC method is the most widely used method for evaluating the vulnerability to potential pollution of aquifers by parametric systems in the world; the common principle of these systems is to first select the parameters on which the vulnerability assessment is based. Each parameter is subdivided into intervals of significant values and assigned an increasing numerical rating according to its importance in vulnerability (Evans and Mayers, 1990; Khemiri S et al, 2013). The precision with which the DRASTIC method makes it possible to distinguish vulnerable regions has been verified by physico-chemical analyzes in different climatic regions: United States, Quebec, Mexico, and other countries (Knox et al.; 1993).

A numerical value called the **DRASTIC vulnerability index** and noted $I_{DRASTIC}$ is determined, it describes the degree of vulnerability of each hydrogeological unit. The vulnerability index is calculated by adding the products of the ratings to the weights of the corresponding parameters:

$$I_{DRASTIC} = D_p \times D_c + R_p \times R_c + A_p \times A_c + S_p \times S_c + T_p \times T_c + I_p \times I_c + C_p \times C_c$$

Where D, R, A, S, T, I, and C are the seven parameters of the DRASTIC method, ″P″ being the weight of the parameter and c, the associated rating (Knox et al. 1993 Fortin et al, 1997). The values of the DRASTIC index obtained represent the measure of the hydrogeological vulnerability of the aquifer. These values vary from 23 to 226 (Engel et al., 1996). They are subdivided into eight intervals (Murat et al., 2003). These values represent the measure of the hydrogeological vulnerability of the aquifer and are within the range of theoretical values according to the classification of Engel et al. (1996) which made it possible to set the limits of the intervals of the calculated indices and to match vulnerability classes to these indices.

SINTACS Method

The SINTACS method, developed by Civita in 1994, is the Italian version of the DRASTIC method: it is an adaptation of this method to Mediterranean conditions and large-scale mapping (Pételet-Giraud, 2000). The specificity of the SINTACS method compared to the DRASTIC method is that it offers five different vulnerability scenarios (Khemiri S et al, 2013), (Normal impact, severe impact, significant drainage, very karstified land, cracked land)

A weight ranged from 1 to 5 is assigned to each parameter, and each parameter is classified into several classes, each of which is associated with a variant rating from 1 to 10 (Khemiri S et al, 2013) (Tab.1). Unlike the DRASTIC method, the SINTACS method makes it possible to use, at the same time and in different cells, weights which vary according to the situation (Schnebelen et al., 2002). The SINTACS vulnerability index is calculated in the same way as the DRASTIC method. According to the values of this index four vulnerability classes can be extracted.

Table 1: Weights attributed to SINTACS parameters (Civita, 1994)

Scenario	Normal impact	Severe impact	Significant drainage	Karst	Cracked land
S	5	5	4	2	3
I	4	5	4	5	3
N	5	4	4	1	3
T	4	5	2	3	4
A	3	3	5	5	4
C	3	2	5	5	5
S	2	2	2	5	4

Vulnerability mapping

The use of the GIS methodology under ESRI's ArcGIS 10.4 software for spatial analysis allowed us to draw up thematic maps for the various parameters studied, such as piezometric maps of the phreatic aquifer of the M'Zab valley, as well as maps of the vulnerability index to pollution. The process of the applied method is summed up like this;

1. Creation of a database (Geodatabase) for the piezometric data studied
2. Spatial exploration of the studied data (ESDA) and transformation of the data if they are abnormally distributed around their mean using the Quantile-Quantile (QQ) Plot module.
3. Spatial interpolation of piezometric data and indices of vulnerability mapping by simple and universal kriging method.
    - Calculation of the semi-variogram
    - Choice of the adjustment model
    - Calculation and adjustment of the model parameters (size of the lags, Number of bins)
    - Treatment of anisotropia
4. Cross-validation of the fitted model
5. Generation of thematic surfaces (maps) of the study area.

RESULTS

The results of the various observations at the level of the wells have been shown in the following tables:

Table 2: Coordinates and depths of wells

Well	UTM coordinates		depth (m)	Well	UTM coordinates		depth (m)
	X	Y			X	Y	
1	565822	3596095	14.9	32	565673	3595595	11.55
2	565712	3595615	12.83	33	565551	3595633	11.7
3	565772	3595638	13.5	34	565539	3595621	13.2
4	566353	3593226	2.3	35	565659	3595622	13.45
5	566411	3593242	2.7	36	567161	3592181	5.3
6	566397	3593267	3.76	37	567155	3592230	2.4
7	566422	3593291	3.55	38	567013	3592248	1.6
8	566451	3593238	2.73	39	566954	3592184	10.7
9	566214	3593228	7.9	40	566448	3592500	6
10	565959	3595897	17.25	41	566348	3592634	8.9

11	565952	3595999	18.1	42	566380	3593267	3
12	566030	3595981	18.8	43	566401	3593328	2.8
13	565992	3595922	17.5	44	566379	3593325	2.9
14	565948	3595845	16	45	566398	3593417	3.6
15	565885	3595822	14.7	46	566425	3593413	3.7
16	565900	3595812	16	47	566372	3593844	2.6
17	565870	3595774	16	48	566610	3593137	3.5
18	565858	3595688	15	49	566199	3593878	2.3
19	565818	3595786	13.8	50	568048	3592912	4.3
20	565752	3595748	13.9	51	568002	3592889	5.1
21	565901	3594827	9.2	52	569116	3593633	4.6
22	565735	3595041	15.4	53	569316	3593878	2.8
23	565750	3595018	9.45	54	569388	3593918	2.1
24	565671	3595231	11.55	55	570114	3594158	1.8
25	565631	3595261	10.7	56	570357	3593399	2.6
26	565650	3595288	12.1	57	570282	3592707	2.2
27	565750	3595665	13.2	58	570281	3592627	2.7
28	565736	3595656	13	59	570279	3591967	2.3
29	565750	3595619	13.2	61	570325	3591146	8.2
30	565703	3595686	13.5	62	570331	3591037	5.3
31	565728	3595707	14.3				

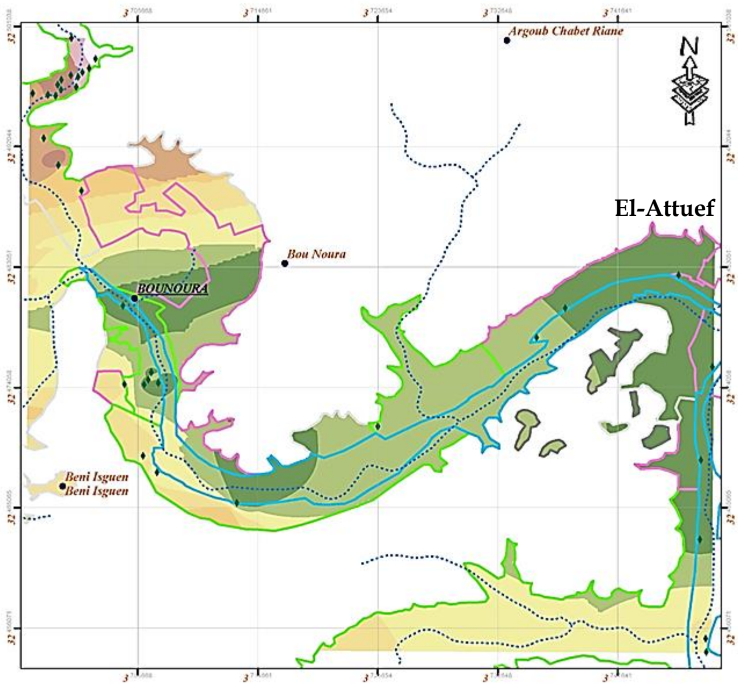

Figure 6: Isobath map of phreatic aquifer (2015)

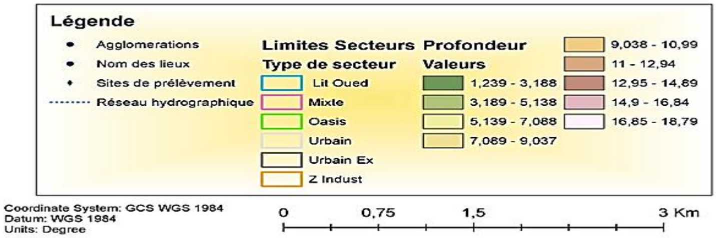

Table 3: Parameters and GOD index method

Well	Ci	C_p	C_a	I_{GOD}	Well	Ci	C_p	C_a	I_{GOD}
1	0.8	0.7	0.7	0.39	32	0.8	0.7	0.7	0.39
2	0.8	0.7	0.7	0.39	33	0.8	0.7	0.7	0.39
3	0.8	0.7	0.7	0.39	34	0.8	0.7	0.7	0.39
4	0.8	0.7	0.9	0.5	35	0.8	0.7	0.7	0.39
5	0.8	0.7	0.9	0.5	36	0.8	0.7	0.8	0.45
6	0.8	0.7	0.9	0.5	37	0.8	0.7	0.9	0.5
7	0.8	0.7	0.9	0.5	38	0.8	0.7	1	0.56
8	0.8	0.7	0.9	0.5	39	0.8	0.7	0.7	0.39
9	0.8	0.7	0.8	0.45	40	0.8	0.7	0.8	0.45
10	0.8	0.7	0.7	0.39	41	0.8	0.7	0.8	0.45
11	0.8	0.7	0.7	0.39	42	0.8	0.7	0.9	0.5
12	0.8	0.7	0.7	0.39	43	0.8	0.7	0.9	0.5
13	0.8	0.7	0.7	0.39	44	0.8	0.7	0.9	0.5
14	0.8	0.7	0.7	0.39	45	0.8	0.7	0.9	0.5
15	0.8	0.7	0.7	0.39	46	0.8	0.7	0.9	0.5
16	0.8	0.7	0.7	0.39	47	0.8	0.7	0.9	0.5
17	0.8	0.7	0.7	0.39	48	0.8	0.7	0.9	0.5
18	0.8	0.7	0.7	0.39	49	0.8	0.7	0.9	0.5
19	0.8	0.7	0.7	0.39	50	0.8	0.7	0.9	0.5
20	0.8	0.7	0.7	0.39	51	0.8	0.7	0.8	0.45
21	0.8	0.7	0.8	0.45	52	0.8	0.7	0.9	0.5
22	0.8	0.7	0.7	0.39	53	0.8	0.7	0.9	0.5
23	0.8	0.7	0.8	0.45	54	0.8	0.7	0.9	0.5
24	0.8	0.7	0.7	0.39	55	0.8	0.7	1	0.56
25	0.8	0.7	0.7	0.39	56	0.8	0.7	0.9	0.5
26	0.8	0.7	0.7	0.39	57	0.8	0.7	0.9	0.5
27	0.8	0.7	0.7	0.39	58	0.8	0.7	0.9	0.5
28	0.8	0.7	0.7	0.39	59	0.8	0.7	0.9	0.5
29	0.8	0.7	0.7	0.39	61	0.8	0.7	0.8	0.45
30	0.8	0.7	0.7	0.39	62	0.8	0.7	0.8	0.45
31	0.8	0.7	0.7	0.39					

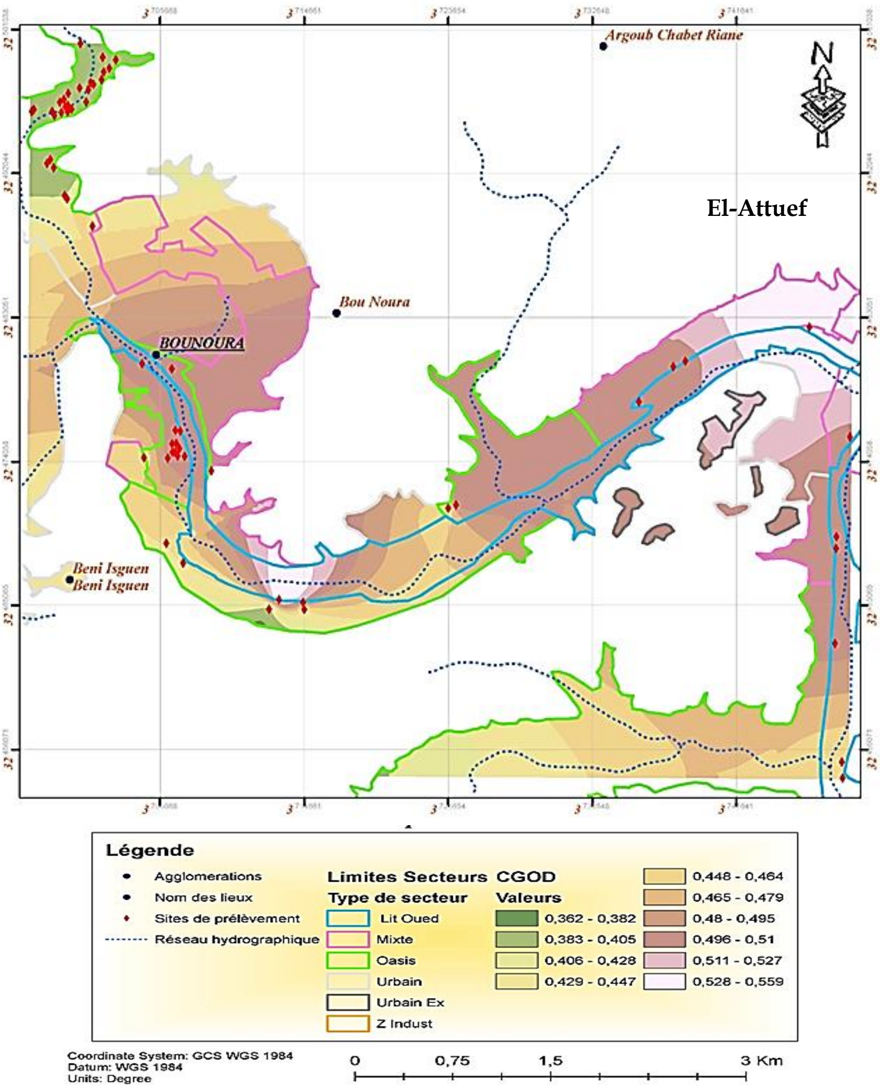

Figure 7: Spatial distribution map of the GOD index

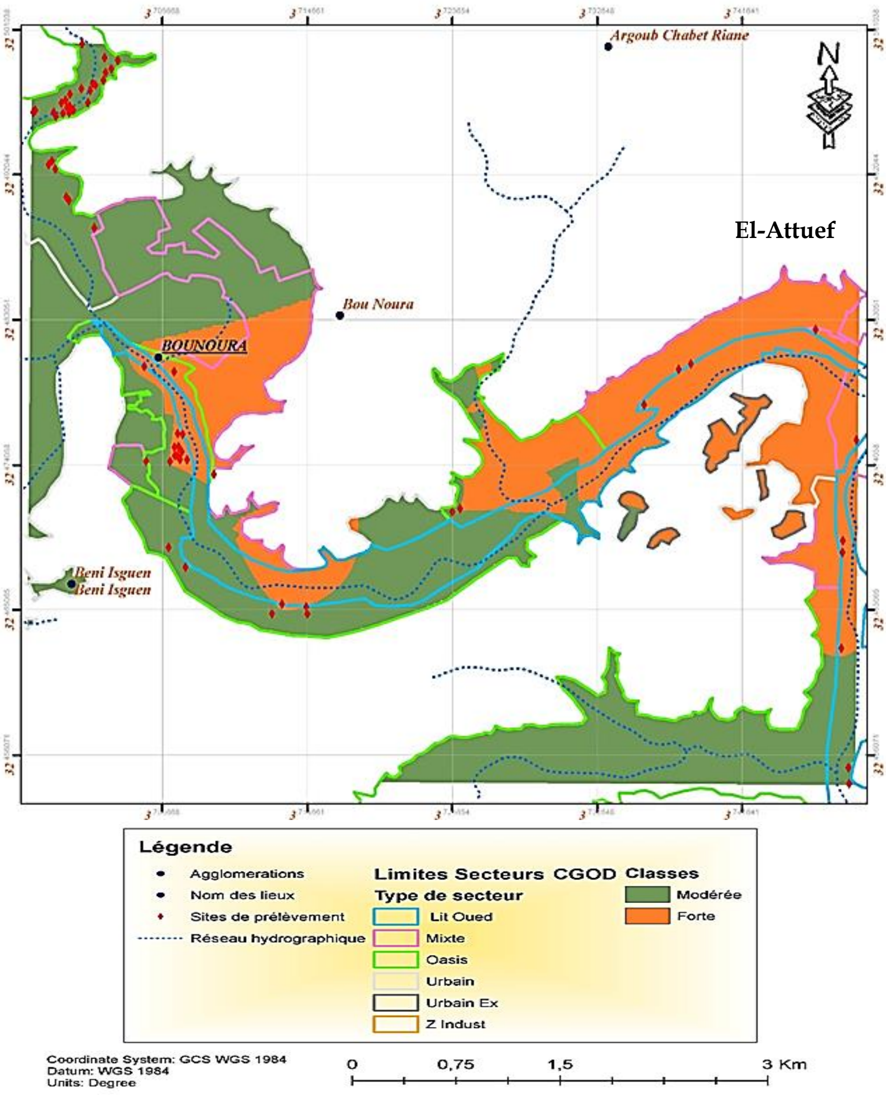

Figure 8: Vulnerability map of the phreatic aquifer using the GOD method

Table 4: Parameters and DRASTIC index method

Well	D	R	A	S	T	I	C	$I_{DRASTIC}$	Well	D	R	A	S	T	I	C	$I_{DRASTIC}$
1	5	3	8	6	10	8	1	126	**32**	5	3	8	6	10	8	1	126
2	5	3	8	6	10	8	1	126	**33**	5	3	8	6	10	8	1	126
3	5	3	8	6	10	8	1	126	**34**	5	3	8	6	10	8	1	126
4	9	3	8	6	10	8	1	146	**35**	5	3	8	6	10	8	1	126
5	9	3	8	6	10	8	1	146	**36**	7	3	8	6	10	8	1	136
6	9	3	8	6	10	8	1	146	**37**	9	3	8	6	10	8	1	146
7	9	3	8	6	10	8	1	146	**38**	9	3	8	6	10	8	1	146
8	9	3	8	6	10	8	1	146	**39**	5	3	8	6	10	8	1	126
9	7	3	8	6	10	8	1	136	**40**	7	3	8	6	10	8	1	136
10	3	3	8	6	10	8	1	116	**41**	7	3	8	6	10	8	1	136
11	3	3	8	6	10	8	1	116	**42**	9	3	8	6	10	8	1	146
12	3	3	8	6	10	8	1	116	**43**	9	3	8	6	10	8	1	146
13	3	3	8	6	10	8	1	116	**44**	9	3	8	6	10	8	1	146
14	3	3	8	6	10	8	1	116	**45**	9	3	8	6	10	8	1	146
15	5	3	8	6	10	8	1	126	**46**	9	3	8	6	10	8	1	146
16	3	3	8	6	10	8	1	116	**47**	9	3	8	6	10	8	1	146
17	3	3	8	6	10	8	1	116	**48**	9	3	8	6	10	8	1	146
18	3	3	8	6	10	8	1	116	**49**	9	3	8	6	10	8	1	146
19	5	3	8	6	10	8	1	126	**50**	9	3	8	6	10	8	1	146
20	5	3	8	6	10	8	1	126	**51**	7	3	8	6	10	8	1	136
21	5	3	8	6	10	8	1	126	**52**	7	3	8	6	10	8	1	136
22	3	3	8	6	10	8	1	116	**53**	9	3	8	6	10	8	1	146
23	5	3	8	6	10	8	1	126	**54**	9	3	8	6	10	8	1	146
24	5	3	8	6	10	8	1	126	**55**	9	3	8	6	10	8	1	146
25	5	3	8	6	10	8	1	126	**56**	9	3	8	6	10	8	1	146
26	5	3	8	6	10	8	1	126	**57**	9	3	8	6	10	8	1	146
27	5	3	8	6	10	8	1	126	**58**	9	3	8	6	10	8	1	146
28	5	3	8	6	10	8	1	126	**59**	9	3	8	6	10	8	1	146
29	5	3	8	6	10	8	1	126	**61**	7	3	8	6	10	8	1	136
30	5	3	8	6	10	8	1	126	**62**	7	3	8	6	10	8	1	136
31	5	3	8	6	10	8	1	126									

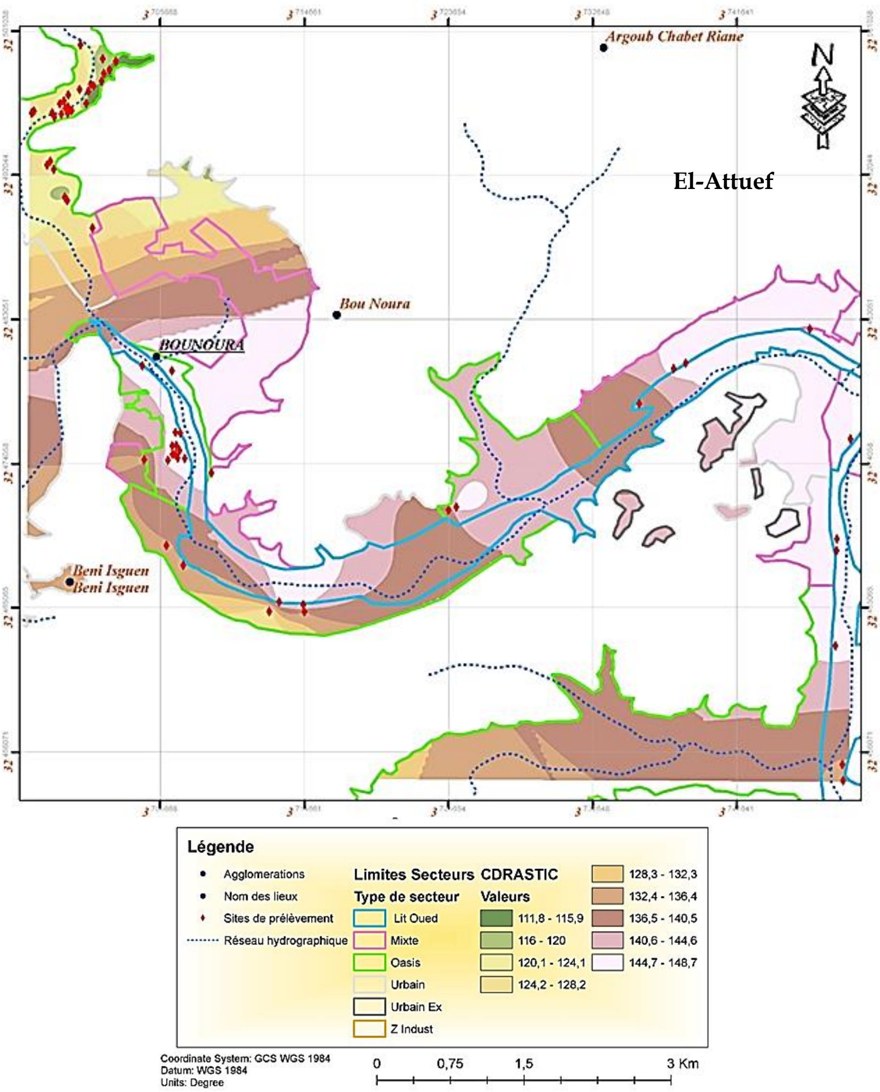

Figure 9: Spatial distribution map of the DRASTIC index

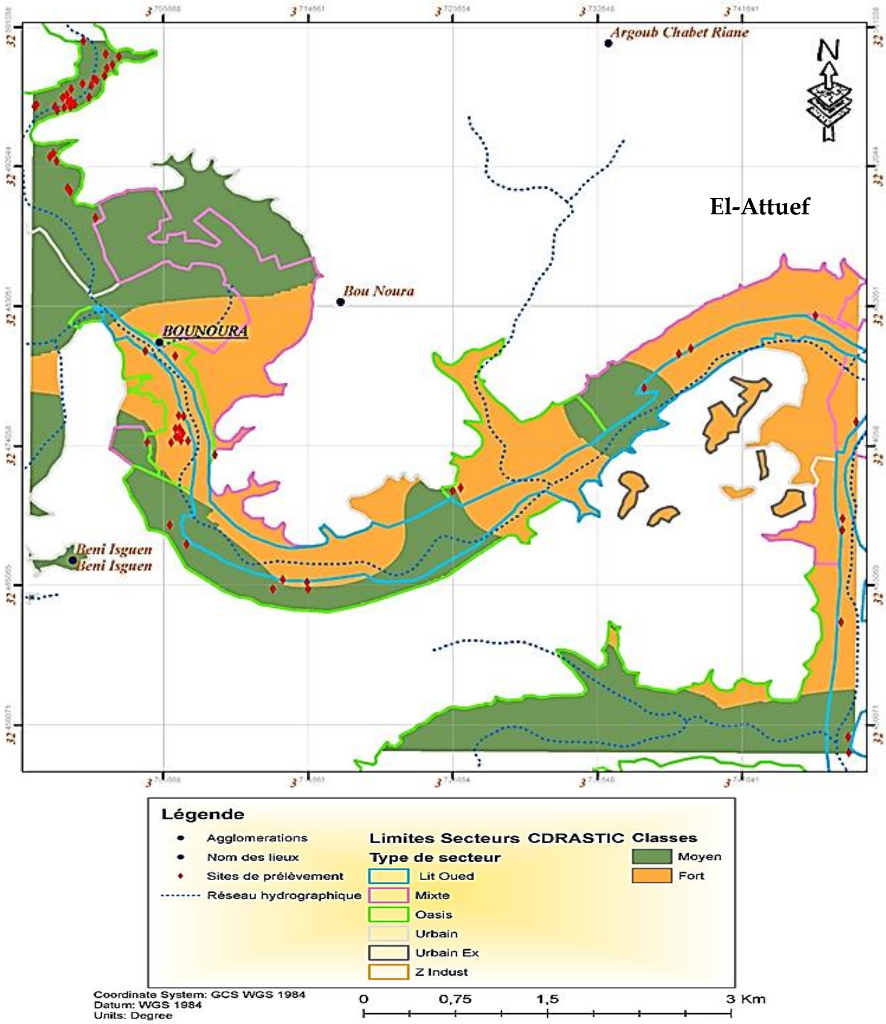

Figure 10: Vulnerability map of the phreatic aquifer using the DRASTIC method

Table 5: Parameters and SINTACS index method

Well	S	I	N	T	A	C	S	S	I_{SIN}	Well	S	I	N	T	A	C	S	S	I_{SIN}
1	5	3	8	6	8	1	10	2	141	32	5	3	8	6	8	1	10	2	141
2	5	3	8	6	8	1	10	2	141	33	5	3	8	6	8	1	10	2	141
3	5	3	8	6	8	1	10	2	141	34	5	3	8	6	8	1	10	2	141
4	9	3	8	6	8	1	10	2	161	35	5	3	8	6	8	1	10	2	141
5	9	3	8	6	8	1	10	2	161	36	7	3	8	6	8	1	10	3	149
6	9	3	8	6	8	1	10	2	161	37	9	3	8	6	8	1	10	3	157
7	9	3	8	6	8	1	10	2	161	38	9	3	8	6	8	1	10	3	157
8	9	3	8	6	8	1	10	2	161	39	5	3	8	6	8	1	10	2	141
9	7	3	8	6	8	1	10	1	158	40	7	3	8	6	8	1	10	2	151
10	3	3	8	6	8	1	10	2	131	41	7	3	8	6	8	1	10	2	151
11	3	3	8	6	8	1	10	2	131	42	9	3	8	6	8	1	10	2	161
12	3	3	8	6	8	1	10	2	131	43	9	3	8	6	8	1	10	2	161
13	3	3	8	6	8	1	10	2	131	44	9	3	8	6	8	1	10	2	161
14	3	3	8	6	8	1	10	2	131	45	9	3	8	6	8	1	10	2	161
15	5	3	8	6	8	1	10	2	141	46	9	3	8	6	8	1	10	3	157
16	3	3	8	6	8	1	10	2	131	47	9	3	8	6	8	1	10	1	168
17	3	3	8	6	8	1	10	2	131	48	9	3	8	6	8	1	10	3	157
18	3	3	8	6	8	1	10	2	131	49	9	3	8	6	8	1	10	2	161
19	5	3	8	6	8	1	10	2	141	50	9	3	8	6	8	1	10	1	168
20	5	3	8	6	8	1	10	2	141	51	7	3	8	6	8	1	10	1	158
21	5	3	8	6	8	1	10	1	148	52	7	3	8	6	8	1	10	1	158
22	3	3	8	6	8	1	10	2	131	53	9	3	8	6	8	1	10	1	168
23	5	3	8	6	8	1	10	2	141	54	9	3	8	6	8	1	10	1	168
24	5	3	8	6	8	1	10	2	141	55	9	3	8	6	8	1	10	1	168
25	5	3	8	6	8	1	10	2	141	56	9	3	8	6	8	1	10	1	168
26	5	3	8	6	8	1	10	2	141	57	9	3	8	6	8	1	10	1	168
27	5	3	8	6	8	1	10	2	141	58	9	3	8	6	8	1	10	1	168
28	5	3	8	6	8	1	10	2	141	59	9	3	8	6	8	1	10	2	161
29	5	3	8	6	8	1	10	2	141	61	7	3	8	6	8	1	10	3	149
30	5	3	8	6	8	1	10	2	141	62	7	3	8	6	8	1	10	3	149
31	5	3	8	6	8	1	10	2	141										

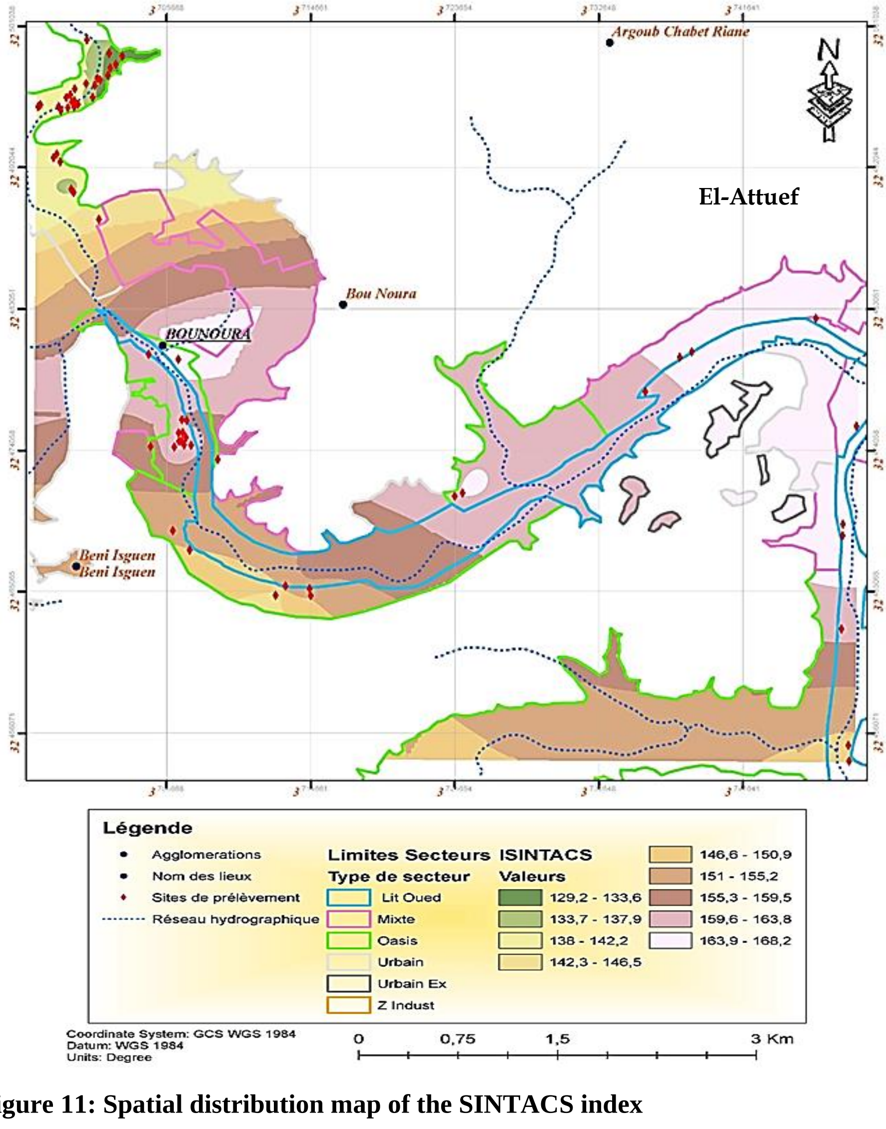

Figure 11: Spatial distribution map of the SINTACS index

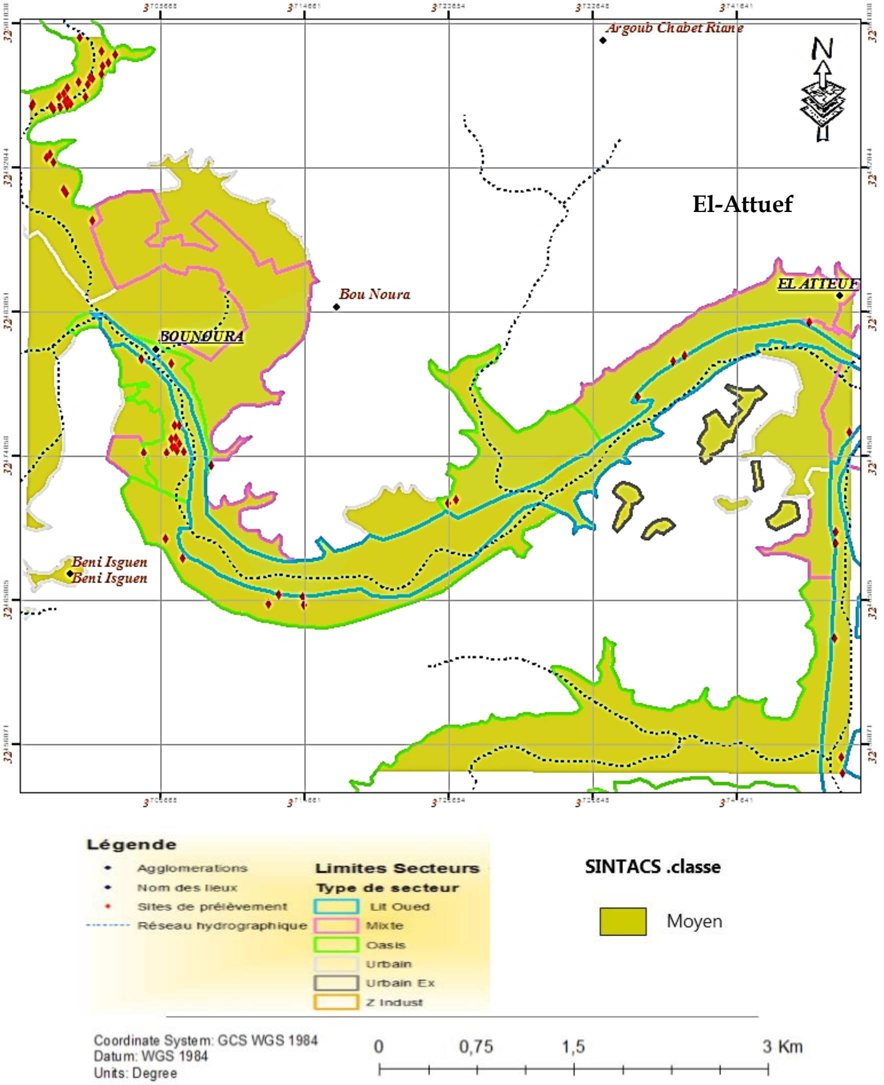

Figure 12: Vulnerability map of the phreatic aquifer using the SINTACS method

DISCUSSION

The examination of the different maps produced by applying three models, GOD, DRASTIC and SINTACS coupled to GIS using several parameters such as the depth of the phreatic aquifer, recharge, type of soil, topography and the impact of the unsaturated zone in view to assess the intrinsic vulnerability of the groundwater in the M'Zab valley to pollution allows us to show that the groundwater level data (Fig. 6) show that the water level does not exceed 20 m throughout the region. Four depth class intervals of the water are recorded, namely:

- D < 2m covers 3.2% of the groundwater surface studied;
- 2m < D < 5m presents 35.5 of the phreatic aquifer;
- 5m < D < 10m with 14.5% of the phreatic aquifer;
- 0m < D < 20m with 45.2% of the phreatic aquifer located in the palm groves of Bounoura

The shallow depth of this phreatic aquifer will expose it to almost certain pollution since the potential protection of the aquifer increases with the depth of the upper surface of the water.

The values of the GOD index ranged from 0.39 to 0.56 (Fig.7), where the low values (0.39) of the index were recorded in the palm groves of Bounoura, while the strongest values (> 0.50) were recorded at the level of El-Atteuf.

The GOD vulnerability map (Fig. 8) clearly shows that the study area is divided into two classes, moderate and strong:

- Moderate vulnerability class: occupies an area of 1750 ha, ie 70% of the surface area of the phreatic aquifer studied. It is located near Bounoura and at the entrance to El-Atteuf. The depth of the phreatic aquifer explains this degree of vulnerability, which is greater than 5 m.
- High vulnerability class covers 750 ha, ie 30% of the surface area of the phreatic aquifer studied, which is equal to 2,500 ha. The zones relating to this class are located at El-Atteuf towards the treatment plant in the direction of the flow of M'Zab Wadi where the phreatic aquifer is shallow (D <5m) which favors the displacement of pollutants towards this phreatic aquifer and increases their risk of pollution.

On the other hand, the DRASTIC index (ID) of our study region ranges from 116 to 146. (Fig. 9) shows that the low values of this index are recorded at the level of the palm grove areas of Bounoura and El-Attuef and they increase as they move towards urban areas.

From the vulnerability map of the phreatic aquifer studied (Fig.10), we can see that this phreatic aquifer is characterized by the spatial extent of land with high and medium vulnerability.

- Medium vulnerability; lands which extend over 58% of the phreatic aquifer are found in two regions of Bounoura which is characterized by a moderately deep-phreatic aquifer (5 m to 20 m).
- Highly vulnerable; lands cover 42% of the phreatic aquifer and are found in the regions of El Atteuf downstream. These lands are highly vulnerable areas characterized at the same time by a permeable unsaturated zone, a shallow phreatic aquifer (<4.5 m) and gravelly soils which can increase their risk of pollution.

The development of the SINTACS vulnerability map which was done in the same way as the DRASTIC method plus three distinct scenarios namely:

- The "normal impact" scenario that concerns areas where transformations are rare, with or without the existence of cultivated land and much dispersed urban perimeters, which is located on the outskirts of the region studied.
- The severe impact scenario, which corresponds to regions where land use is intensive, occupies the center of the study region.
- The significant drainage scenario from a surface network at the level of the Sebkhas and the drains.

The values of the SINTACS index in the study region range from 131 to 168 (Fig.11), which highlights a single vulnerability class; which concerns areas with a medium degree of vulnerability (Fig. 12), which occupy the entire surface area of the region, studied (100%).

CONCLUSION

Through this work a vulnerability study of the phreatic aquifer in the M'Zab valley was established by three methods GOD, DRASTIC and SINTACS using several parameters relating to the aquifer and the soil in order to assess the intrinsic vulnerability to pollution allows us to show that the spatial distribution of the degrees of vulnerability to pollution of the groundwater in the M'Zab valley ranging from medium to high. It is noted that the areas with medium vulnerability occupy 58 to 70% of the surface of the study area which is located in the palm groves of Bounoura and El-Atteuf, while the highest indices are located around urban areas which represent 30 to 42% of the studied area. This analysis reveals that the depth of the phreatic aquifer is the determining parameter on these two vulnerability models as long as the other parameters are homogeneous throughout the region studied, however, the SINTACS method shows that the entire phreatic aquifer of the valley at a medium vulnerability which does not reflect the variability of the polluted areas in the valley.

From our surveys at the valley level and the examination of the three maps produced allows us to deduce that the DRASTIC method is the most appropriate method for regional conditions, and which reflects the environmental situation of the study area. This spatialized approach to vulnerability allows better management of groundwater resources and appropriate interventions in the event of contamination. It also makes it possible to identify areas likely to be contaminated because of human activities. It constitutes a support for decision-making in planning and regional development.

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