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HYDROGEOLOGY

Comparative study of the vulnerability to groundwater pollution by the DRASTIC and SINTACS methods on the Amizour plain (Béjaia, North Algeria)

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ABSTRACT

The present study deals with the vulnerability and the risks of pollution on the Amizour plain aquifer (north Algeria), already threatened by several sources of pollution (e.g., industries, agriculture, illegal dumping, etc.) that collapsed this region, without any planned environmental protection measures. In the aim to study the sensitivity of the Amizour plain against pollution two methods (DRASTIC and SINTACS models) were used and the results were compared and evaluated. The maps showed a similarity in the degrees of vulnerability ranged from high to medium. Most of the plain is affected by a high degree of vulnerability of 76% and 67% as estimated by DRASTIC and SINTACS, respectively. In fact, such remarkable degree is justified by the shallow position of the groundwater and the type of aquifer. The degree of groundwater vulnerability was 18% and 33% in the northern and southern part of the studied zone as estimated by DRASTIC and SINTACS methods, respectively. According to the DRASTIC approach, an area with a very high vulnerability (6%) was observed amidst the Amizour plain. Superimposing both maps of vulnerability and the pollution source sites allowed us through the risk map to frame the areas at high risk of groundwater contamination. This investigation will facilitate to make decisions in implementing of an accurate and urgent management project for safeguarding the studied zone. The applicability of these findings has been discussed and suggestions for attenuating the risk of contamination have been given.

Keywords: Vulnerability; DRASTIC; SINTACS; Groundwater; Amizour; Soummam.

Estudio comparativo de la vulnerabilidad de polución de aguas subterráneas a través de los modelos DRASTIC y SINTACS en el valle de Azimour (Bugía, norte de Argelia)

RESUMEN

El presente estudio trata sobre la vulnerabilidad y los riesgos de contaminación del acuífero del valle de Amizour (norte de Argelia), el cual se encuentra amenazado por varias fuentes de polución (como las industrias, la agricultura, vertidos ilegales, entre otros) que colapsaron la región y donde no se evidencian medidas planeadas de protección ambiental. Con el objetivo de estudiar la respuesta del valle de Amizour ante la polución se usaron dos métodos (modelos DRASTIC y SINTACS) y los resultados se compararon y evaluaron. Los mapas mostraron una similitud en los grados de respuesta que van de alto a medio. La mayor parte del valle se encuentra afectada por un alto grado de vulnerabilidad de 76 % y 67 % de acuerdo con las estimaciones del modelo DRASTIC y el modelo SINTACS, respectivamente. De hecho, este grado notable se justifica en la posición poco profunda del agua subterránea y en el tipo de acuífero. El grado de vulnerabilidad de las aguas subterráneas es de 18 % y 33 % en las partes norte y sur de la zona de estudio, de acuerdo con las estimaciones de los modelos DRASTIC y SINTACS, respectivamente. De acuerdo con los calculos del modelo DRASTIC, se observó una área con una muy alta vulnerabilidad (6 %) en medio del valle de Amizour. El sobreponer los mapas de vulnerabilidad y de las fuentes de polución permitió a los autores construir un mapa donde se enmarcan las áreas de alto riesgo de contaminación de las aguas subterráneas. Esta investigación facilitará la toma de decisiones en la implementación de un proyecto de manejo exacto y urgente para la salvaguarda de la zona de estudio. La aplicabilidad de estos hallazgos fue discutida y se presentan sugerencias para la atenuación de los riesgos de contaminación.

Palabras clave: Vulnerabilidad; DRASTIC; SINTACS; aguas subterráneas; valle de Amizour; Soummam

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1. Introduction

Groundwater is the most important commodity for water resources in arid and semi-arid regions such as North Africa. Barbulescu (2020) emphasized that climate change, along with water pollution, has become a major issue all over the world, and if not urgent decisions will be taken for securing access to drinking water, the number of people lucked basic services linked to water availability would still rise (Reddy, 2023). If aquifer resource is affected, the cleaning up will be costly and time consuming; this, often, is recognized when the remediation is almost infeasible.

The Amizour aquifer (northeastern Algeria) is an active agricultural area and the exploitation of groundwater resources is extremely important due to the scarcity in water resources. The aquifer of the Amizour is threatened by several hazards such as the industrial wastes, the presence of wild dumps, domestic discharges, the intensification of agricultural activities through the use of pesticides and fungicides, and so on. Moreover, this region is currently experiencing a severe dreadful contamination due to untreated liquid discharges (urban and industrial) impounding in the Soummam River and hence percolating and harming the aquifer resources. The conduction of qualitative studies on groundwater resources is a basic and practical action permitting hence to obtain accurate information of the state of water resources. Water used for each purpose, for example irrigation and industry, has its own feature, and low quality of water is reportedly not desirable for any utilization (Eftekhari et al., 2021). Under such circumstances, the protection and preservation of groundwater quality in this region is increasingly important because this vital resource, once contaminated, it will become unsuitable for consumption and exploitation (Jourda et al., 2007).

The assumption of groundwater vulnerability first emerged in the 1960s in France to create an alertness of groundwater contamination (Vrba and Zaporozec, 1994). The notion of pollution vulnerability of an aquifer is defined as its intrinsic susceptibility to spaciotemporal modification in the quality and quantity of groundwater, due to natural processes and/or anthropogenic activity (Civita, 1994). According to Albinet and Margat (1970), establishing groundwater pollution vulnerability maps can allow us to well demonstrate what are the possibilities of penetration, uptake and propagation of pollutants in aquifers, taking into account the nature of the ground encountered at the surface and the hydrogeological situations. Such studies help decision makers by shedding light on pollution areas already or prone to harm groundwater aquifers.

In the aim to provide first information for an urgent management of the Amizour aquifer, two models were adopted during this study, these are the DRASTIC and SINTACS methods thanks to the large number of parameters they treated. The SINTACS method used in this investigation was developed by Civita (1990; 1993; 1994) and Civita and De Maio (1997) to estimate relative groundwater pollution vulnerability by using seven hydrogeological attributes (Kuisi et al., 2006). Further, introduced in 1985, DRASTIC is the most popular overlapping index approach used in groundwater vulnerability evaluation due to its reliability and easy-to-use (Rahman, 2008). The objective of this study was to assess the vulnerability against pollution on the groundwater resources of the Amizour aquifer by two methods (i.e., DRASTIC and SINTACS) for selecting the most suitable method, and hence establishing a risk map. The outcome of this investigation will contribute in the optimization of a protection project of the Amizour aquifer through proposing some recommendations.

2 Materials and methods

2.1 Presentation of the processing software

The process strategy adopted in this study for the development of a systematic analytical procedure is (SURFER 11). This method was implemented in a study area called plain of Amizour and also maps were used: topographic map 1/ 50000, geological map, land cover map, soil map GPS (Global Position System).

The SURFER 11 software designed by Golden Software, allows to drawn maps from a digital terrain model (DTM) in Lambert coordinates. The software enables to create grids that will interpolate irregular data from points x, y, and z, in aim to order them.

These grids can be imported from several sources to produce different types of maps, including contours, vectors, images as well as surface maps. SURFER 11 contains several map options that allowing producing a map with best represented data. The maps can be enhanced by displaying data points, combining multiple maps, or adding drawings or annotations.

The variety of interpolation methods facilitates different interpretations of the data and to screen for the most appropriate method needed to be used. The grid files themselves can be edited, combined, filtered, cut and transformed mathematically.

2.2 Study area

The plain of Amizour has an area of ca. 50 km^2, it is located on the right bank of the Soummam river, limited by the mountains of Barbacha and the massif of Oued Amizour in the North-West, and by the municipalities of 'Oued Ghir and Tala Hamza in the North-East, and by the municipalities of Boukhlifa and Semaoun in the East and the West, respectively. The studied zone's territory is split up into two parts: one is located on a plain and the other in a mountainous area. The latter occupies more than 75% of the territory of the municipality (Fig. 1).

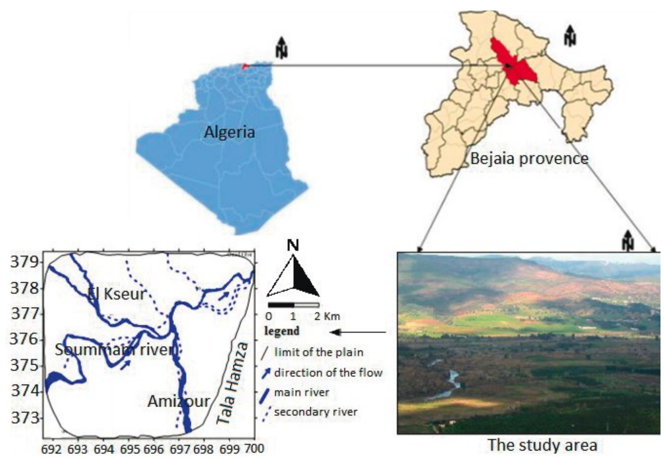

Figure 1. The geographic situation of the study area

2.3 Geology and pedology

The Soummam valley (Fig.2) contains alluvial deposits made up of pebbles and most often sandstone gravel and sand that is attributed to the Miocene. The coarse Miocene reaches 10 to 15 m of thickness at Ilmatten and 10 to 25 m in the region of El Kseur to where the study area belongs.

In the upstream zone at Sidi Aïch and Oued Amizour, the aquifer is free or semi-confined, in the downstream zone at the mouth of Oued Amizour, the aquifer is loaded by silt whose thickness increases from upstream to downstream. Table 1 shows the hydrogeological interest for each soil formation (Saadali et al., 2022).

Table 1. The hydrogeological interest of lithological formations in the studied area (Saadali et al., 2022).

Location	The study area	North and South of land
Formation	Sand, silt and gravel	Clay and sandstone medium
Thickness	+10m	+15m
Hydrogeological interest	Permeable (very important interest)	Semi permeable (important interest)

2.4 Piezometric map

According to the piezometric map, established based on data collected during the month of February 2020 (Fig.3) for the Amizour plain, taking into account the piezometric level of all the wells, showed that the flow of the water table is from South-West to North-East in accordance with the direction of surface water flow (Soummam river). All the streamlines tend towards the river and hence supply the water table. Accordingly, this explains the relationship between the Soummam river and the water table. The isopiezes are narrow in the northern part, representing a supply zone. The approximation of the isopiezes curves gives a potentially strong hydraulic gradient. In the western and southern part of the study area, the isopiezoid curves become spaced out, which generates a weak hydraulic gradient (Castany, 1965; 1982).

Overall, it has been noted that the flow of water table is from the edges towards the center of the aquifer. Therefore, the main flow of the aquifer is convergent from upstream to downstream.

2.5 Methodology

2.5.1 DRASTIC

The DRASTIC index is one of the vulnerability indices that could be applied in Algeria because of its applicability on all climatic conditions, aquifer distribution and aquifer settings. In addition, the DRASTIC index has been selected according to its wide variation of studied parameters that absolutely affect the groundwater system regardless of the environment. In this model the assessment benchmark of the vulnerability is: spatial datasets on depth to groundwater (D), recharge by rainfall (R), aquifer type (A), soil properties (S), topography (T), impact of the vadose zone (I) and hydraulic conductivity of the aquifer (C). These variables are combined to assess the vulnerability of the aquifers against surface activities (Table 3) (Engel et al., 1996). The following equation that governing DRASTIC index DI (equation 1) was defined by Knox et al. (1993), Fortin et al. (1997) and Fritch et al. (2000):

$$DI = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw \quad (1)$$

where DI is the DRASTIC Index, Dr is the rate of the D factor and Dw is the weight of the D factor, Rr is the rate for the recharge factor and Rw is the weight for the recharge factor, Ar is the rate for the aquifer media factor and Aw is the weight to the aquifer media factor, Sr is the rate to the soil media factor, Sw is the weight to this factor, Tr is the rate to the topography factor, Tw is the weight to that factor, Ir is the rate of the impact of the vadose zone rate, Iw is its weight, and finally Cr is the rate for the hydraulic conductivity rate and Cw is the weight to this factor; these DRASTIC index in the equation is considered as an indicator to estimate the pollution potential of an environment (Table 2). The effect of different parameters on groundwater vulnerability has been described by Piscopo (2001).

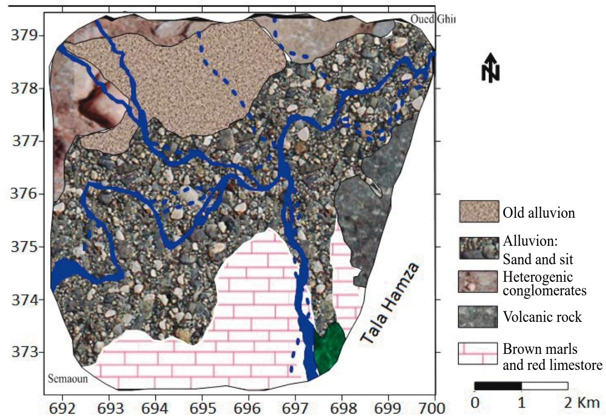

Figure 2. Geological map of the Amizour aquifer (Saadali et al., 2022)

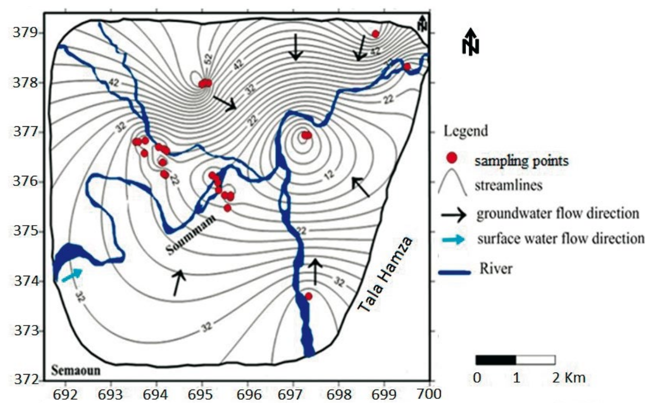

Figure 3. Piezometric map of the Amizour aquifer (February 2020) (Saadali et al., 2022)

Table 2. DRASTIC index method for assessing groundwater vulnerability (Aller et al., 1987).

Parameter	Range	Rating	Relative weighting
Depth to Water (D)	0-2 m	7	
	2-5 m	6	
	5-9 m	5	
	9-15 m	4	5
	15-23 m	3	
	23-30 m	2	
	> 30 m	1	
Recharge by rainfall (R)	3	1	
	4	2	
	5	3	
	6	4	4
	7	5	
	8	6	
	9	7	

Parameter	Range	Rating	Relative weighting
Aquifer media (A)	Massive shale	2	
	Metamorphic/igneous	3	
	Weathered met./igneous	4	
	Bedded sandstone, Limestone	6	
	Shale sequences	6	4
	Massive sandstone	6	
	Massive limestone	6	
	Sand and gravel	8	
	Basalt	9	
	Karst limestone	10	
Soil media (S)	Soil thin or absent	10	
	Gravel	9	
	Sand	8	
	Peat	7	
	Shrinking and/or aggregated clay	6	2
	Sandy loam	5	
	Loam Silty loam	4	
	Clay loam	3	
	Muck	2	
	non-aggregated clay	1	
Topography (T)	0-2%	7	
	2-6 %	6	
	6-10%	5	1
	10-16%	3	
	16-25%	2	
	>25%	1	
Impact of vadose zone	Confining layer	1	
	Silt/Clay or Shale	3	
	Sand, gravel, silt and clay	4	
	Limestone or Sandstone	6	5
	Sandstone shale	6	
	Metamorphic /Igneous	4	
	Sand and grave	8	
	Vesicular basalt	9	
	Karst limestone	10	
Hydraulic conductivity	0.50×10^{-6}-0.50×10^{-4}	1	
	0.50×10^{-4} - 0.15×10^{-3}	2	
	0.15×10^{-3} - 0.36×10^{-3}	4	3
	0.36×10^{-3} - 0.51×10^{-3}	6	
	0.51×10^{-3} - 0.10×10^{-2}	8	
	> 0.10×10^{-2}	10	

Table 3. The assessment benchmark of vulnerability in DRASTIC model (Aller et al., 1987).

Degree of vulnerability	Vulnerability index
Very Low	23-83
Low	84-113
Medium	114-144
High	145-174
Very High	175-226

2.5.2 SINTACS

The parametric models like SINTACS belong to the point count system model cluster in which every factor has not only its own score, but also an additional weight to decrease or amplify its importance during the analysis (Alsharifa, 2016). SINTACS is one of the most popular methods devoted to systematically assess groundwater pollution vulnerability. It was developed by the National Research Group for Protection against Hydrogeological Disasters of the Italian National Research Council(Civita, 1994; Civita and De Maio, 1997). This approach is the advanced form of the American DRASTIC model adapted to Mediterranean circumstances and areas with karstic features (Rahman, 2008). Thought both the models use the same settings, the data are interpreted differently. Indeed, SINTACS has been preferred over many other methods due to its suitability for Mediterranean conditions, low costs, availability of data and reliability of results when applied in different geological and hydrogeological contexts (Al-Amoushet al., 2010). The acronyms SINTACS stands for the seven parameters used in the model (Tables 4 and 5): Water table depth (S), Effective infiltration (I), Unsaturated zone (N), Soil media (T), Aquifer media (A), Hydraulic conductivity zone (C), and Topographic slope (S) (Eftekhari and Akbari, 2020). These parameters are further classified to represent various hydrogeological settings and each class is then assigned a rating value on a scale of 1 to 10 (Kuisi et al., 2006). This model has been used by Civita (1994) in order to evaluate the capability of groundwater relative contamination vulnerability, using seven hydrogeological parameters (equation 2).

$$\text{SINTACS-Index} = (Sr \times Sw) + (Ir \times Iw) + (Nr \times Nw) + (Tr \times Tw) + (Ar \times Aw) + (Cr \times Cw) + (Svr \times Svw) \quad (2)$$

R: Rank; W: Weight

Table 4. The weights and ranks related to the SINTACS model modified (Ahmadi Far et al. 2017).

Parameter	Rank	Parameter	Rank
Water table depth (S) (weight 5) m		Hydraulic conductivity (C) (weight 3)	
0-3	9	0.07-0.1	3
3-5	8	0.1-0.864	4
5-7	7	0.864-4.32	5
7-10	6	4.32-8.64	6
10-13	5	8.64-43.2	7
13-20	4	43.2-86.4	8
20-30	3	86.4-366.39	9
30-36	2		
36<	1	Topographic slope (S) (Weight 2)%	
		0-3	10
Aquifer media (A) (Weight 3)	9	3-5	9
Sand and gravel	7	5-7	8
Sand and gravel along and clay	3	7-10.5	7
Clay and silt		10.5-13.5	6
		13.5-16.5	5
Effective infiltration (I)(Weight 4)		16.5-19.5	4
0-50	1	19.5-23	3
50-100	3	23-27.5	2
100-175	6	27.5<	1
175-250	8		
250<	9	Soil media (T) (Weight 4)	
		Loam	6
Aquifer media (A)(Weight 5)		Sandy loam	5
Fine alluvial sediments,clay and silt	5	Fine sand	9
Sand	7	Sand	10
Coarse alluvial sediments and gravel	9		
Clay and silt	2		

Table 5. The assessment benchmark of vulnerability in SINTACS model (Hamza et al., 2008)

Degree of vulnerability	Vulnerability index
Low	<106
Medium	106 – 186
High	187 – 210
Verry High	>210

2.5.3 Contamination factor (Fc)

The contamination factor has been calculated to ascertain the vulnerability of groundwater and to check for the most accurate method that would be fitting with the studied area.

Contamination factor (Fc) is an index introduced by Hakanson (1980). It is a straightforward and effective element to monitor contamination of the environment by heavy metals (Shen et al., 2019). It allows highlighting the presence or absence of contamination in the medium (Table 6) by the metallic trace elements (ETMs) and gives the level of contamination. The Fc is expressed by the ratio of the concentration of the components measured in the groundwater sampled and the standard permissible values (WHO). Equation 3 shows the calculation method.

$$Fc = \frac{\text{Concentration of ETM in water}}{\text{Standard permissible values (WHO)P}} \quad (3)$$

Table 6. Contamination factor and classes (Hakanson, 1980)

Fc	Level of contamination
Fc<1	Low contamination
1<Fc<3	Moderate contamination
3<Fc<6	Considerable contamination
Fc>6	Very high contamination

3 Results and discussion

3.1 DRASTIC versus SINTACS method

To interpret the DRASTIC vulnerability map the seven parameters should be taken and analyzed each one individually.

The evaluation of the parameter (D) was made from the values recorded directly at the level of the well sections. These values were ranked according to the ranges established in Table 2. The data are represented on the whole region as shown in the map in Figure 4. The evaluation of the parameter (R) was established from the results of water balances carried out by several authors (e.g., Thornthwaite, 1948; Turc, 1961).

The partial index of parameter (A) brought out two important areas; sands and gravels with massive sandstone, and the soil study of the region (S) gives us two areas; sand and gravel with clay loam soil (Fig. 4); and for this reason sand and gravel do not prevent contamination of groundwater by pollutants of anthropogenic activities, especially in agriculture. Our results corroborate the study of Amadi et al. (2014) who emphasized that groundwater vulnerability in the Niger Delta was consistently impacted by anthropic activity (incorporated in the A factor).

Regarding (T) parameter and from the topographic map, we were able to highlight a single slope range (0 – 2%) and for the parameter (I) the unsaturated zone in the plain is shown; the gravel, sands and sandstones (Fig. 4). The variation of the hydraulic conductivity (C) of the aquifer displayed two classes (Fig. 4).

Overlapping the seven previous thematic maps enables to draw the final vulnerability map (Fig. 5); the latter allowed us to determine the different zones vulnerable to pollution in the plain of Amizour which are: zone of medium vulnerability (in green); zone of high vulnerability (in yellow) and very high vulnerability zone (in red).

The medium vulnerability zone occupies almost 18% of the area of the plain. This class reflects a moderate vulnerability to pollution which can be explained by the high altitude and the influence of soil manifested by the presence of clays and sandstones. These soil components are known to be semi-permeable formations preventing thus the penetration of pollutants. The high vulnerability zone covers 76% of the total surface and is located in the center of the plain. The situation of this zone match with the most permeable lithological formations made up mainly with sand, gravel and pebbles. These lands are exposed to an outstandingpollution due to urban and industrial wastewater discharged and transported by the Soummam river and its tributaries (Amizour, El Kseur).

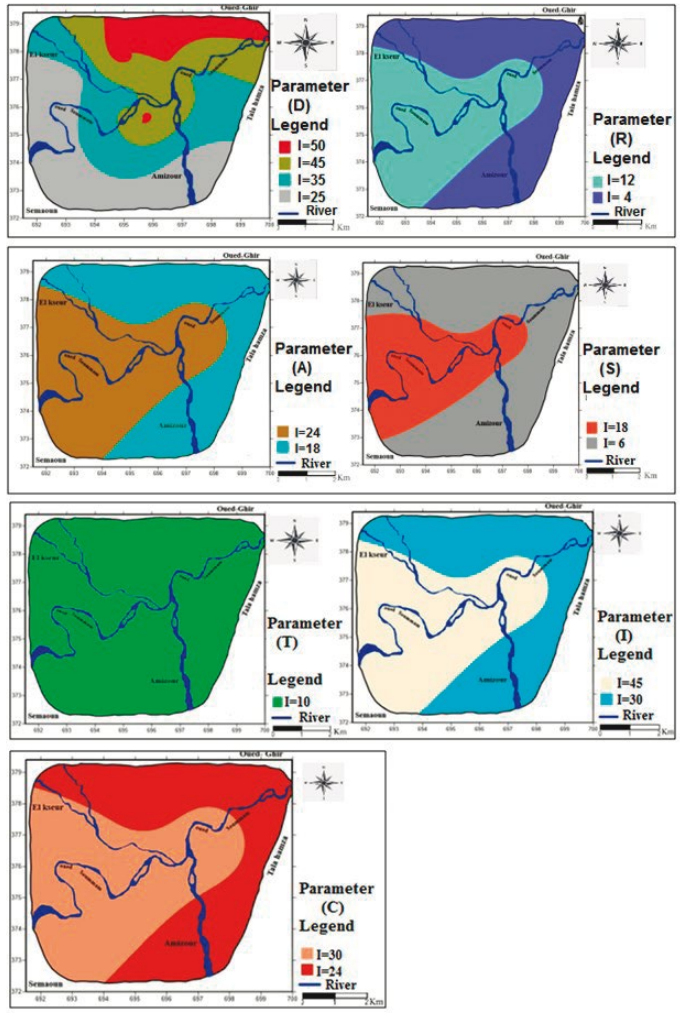

Figure 4. Maps showing the depth to groundwater (D), recharge by rainfall (R), aquifer type (A), soil properties (S), topography (T), impact of the vadose zone (I) and hydraulic conductivity (C) of the Amizour aquifer.

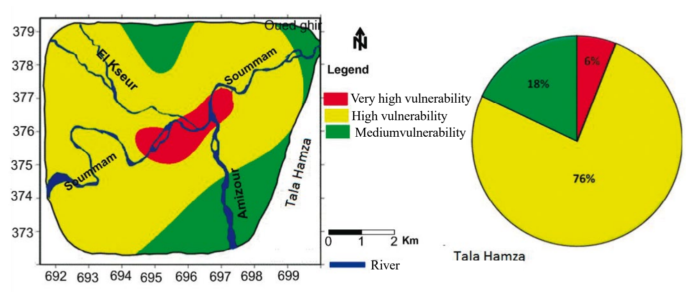

Figure 5. Vulnerability map showing the groundwater pollution of Amizour aquifer according to the DRASTIC method.

The very high vulnerability zone is found amidst the studied zone, representing 6% of the total surface. This degree of vulnerability can be explained likely by the type of soil and the shallow position of aquifer, impelling hence the groundwater pollution process. This area is known for the intensive application of fertilizers and pesticides in agricultural fields (Fig. 6). The pesticides are assumed to be the main unsustainable land-use product affecting groundwater quality (Jawarneh and Biradar, 2017).

Prior interpreting the SINTACS vulnerability map we should evaluate the seven parameters and interpret them each one apart.

The evaluation of the parameter (S) was made from the values recorded at the level of the well sections (high water period, February 2020). These values have been classified according to the SINTACS rating system. In order to develop a vulnerability map, natural fluctuations and anthropogenic pressure on the aquifer should be taken into account. Figure 9 displays the depth of the water table (S); and for the parameter (I), the two partial indices exhibit 2 zones where their impact is normal since it have a partial vulnerability index of 8 and 12 (Fig. 6).

The impact of the unsaturated zone (N) is considered to be a very important parameter by the SINTACS method this is because both the nature and the thickness of the zone between the ground surface and the aquifer govern water pollution. Formed with two zones (Figure 10), parameter (T) evaluation shows that soil has an impact on the water that penetrate through the soil to reach the groundwater and therefore accelerate vertical leaching of the pollutants through the unsaturated zone. According to the analysis of the pedological map of the soil, two kinds of soil were noted: alluvial soil with a vulnerability index of 38.8 and loamy clay soil marked by the index of 28 (Fig. 6).

The calculation of the partial index for the parameter (A) revealed two zones, the coarse Alluvium with an index of 24 and the Sandstone-conglomerates with an index of 21 (Fig. 6). The evaluation of the partial index of parameter (C) output two zones: (1) alluvium (gravel) with an index of 30 and (2) the sandstone zone with an index of 21 (Fig. 6).

The degree of the slope (S) determines the infiltration capacity of the runoff water. The slope indicates whether the water will run off on the surface, or if it will infiltrate into the ground. Examination of the topographic map of the study area shows a single slope range (0–5%) (Fig. 6).

The superposition of the seven established thematic maps and the application of the general SINTACS index equation allowed us to draw the final vulnerability map (Fig. 7)

The analysis of the final map is classified into two categories according to the degree of vulnerability (medium and high). Most of the plain is characterized by a high degree of vulnerability which covers 67% of the total surface. It is situated in sectors where the type of aquifer consists of sand, gravel and pebbles, these formations are permeable. The northern and southern part of the plain is affected with an intermediate degree of vulnerability, and which represents 33% of the total surface of the plain. This zone is consistent with the sectors where the soil is composed by clay and sandstone, which present semi-permeable formations.

When comparing the two vulnerability maps (Table 7), only a small heterogeneity in the vulnerability index can be noticed. For example DRASTIC method represents 6% of the total area of the plain with very high vulnerability, while in SINTACS, there exists no area with a very high vulnerability. Regarding high to medium vulnerability, the heterogeneity between the two approaches never exceeds 15 %.

Table 7. Comparison of the vulnerability between the two methods

Type of vulnerability	DRASTIC (%)	SINTACS (%)
Very high vulnerability	6	no area
High vulnerability	76	67
Medium vulnerability	18	33

3.2. Validation of vulnerability maps

We have chosen the zinc (Zn) as a pollution factor to select for the most suitable method between DRASTIC and SINTACS, because of the occurrence of a Zn exploitation deposit at the level of the Amizour region (Saadali et al., 2022).

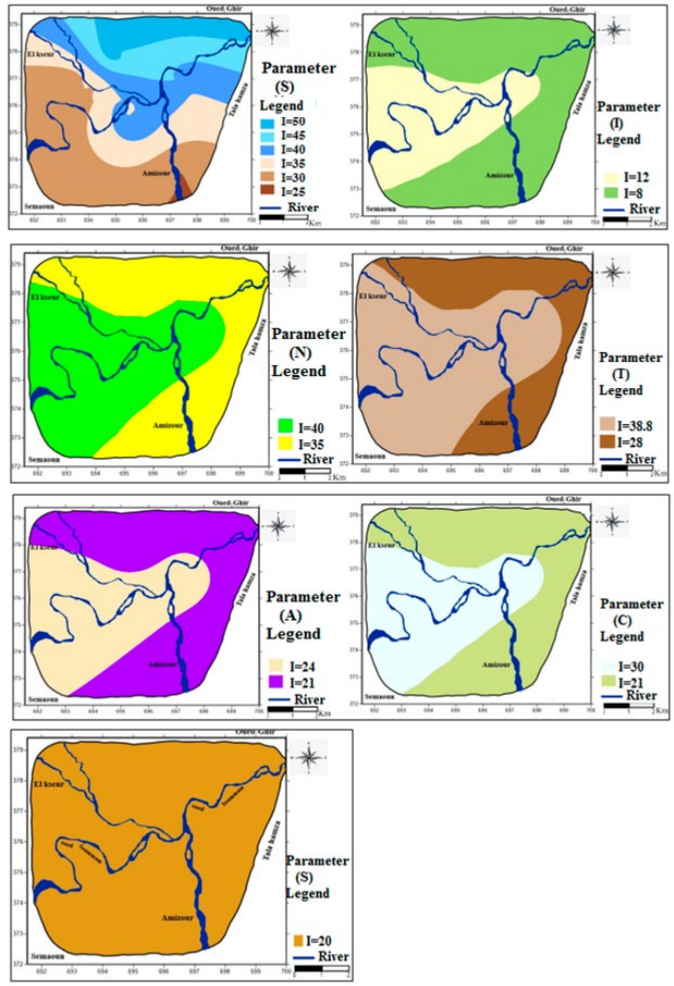

Figure 6. Maps of the water table depth (S), effective infiltration (I), unsaturated zone (N), soil media (T), aquifer media (A), hydraulic conductivity zone (C) and topographic slope (S) of the Amizour aquifer.

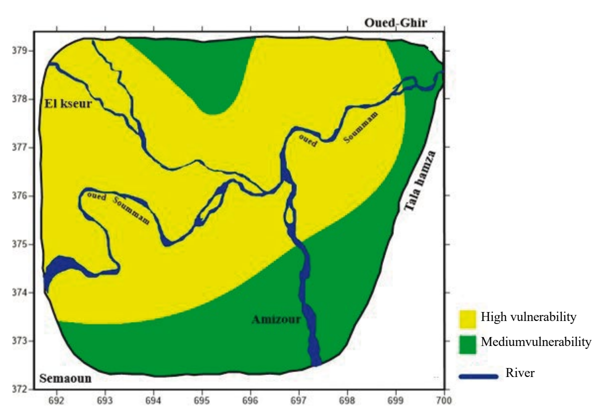

Figure 7. Vulnerability map showing the groundwater pollution the Amizour aquifer according to the SINTACS method.

The relationship between the DRASTIC index and Factor concentration (Fc) of Zn in groundwater (Fig. 8) was investigated to verify the effectiveness of the DRASTIC method. Therefore, 23 groundwater samples were collected around the wells located in the study area (Fig. 3) in February 2020.

This relationship between Fc and DRASTIC index reveals a great homogeneity (Fig.08) (6% very high for the DRASTIC and 13% very high contamination for FC) mainly in the central part of the study area which exceeds the Fc for Zn (WHO) standards (15ppb) and argues that the most adequate method of our study area is DRASTIC model. However, figure 9 shows a weak relationship between Fc and SINTACS mainly with the very high contamination zone which is not indicated in the SINTACS map.

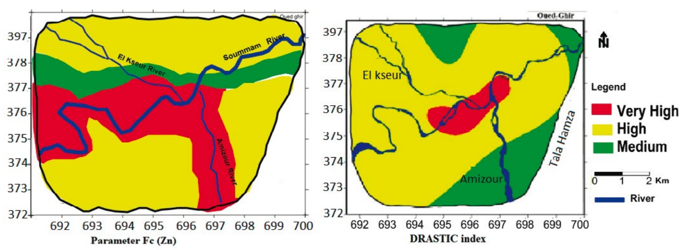

Figure 8. The spatial comparison between the DRASTIC index and the contamination factor Fc (Zn).

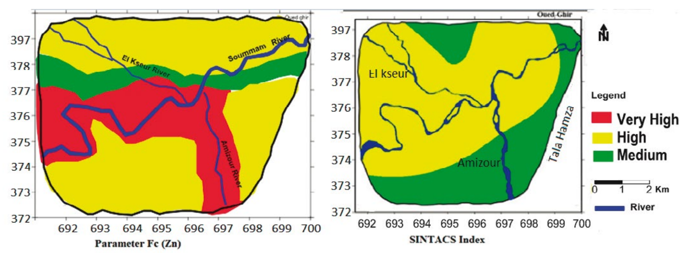

Figure 9. The spatial comparison between the SINTACS index and the contamination factor Fc (Zn).

3.3 Risk Map

The presence of pollution sources in the study area (uncontrolled dumping; the industrial zone and agricultural pollution) has a significant vulnerability and a severe impact on biodiversity, the environment and public health. The projection of pollution sources upon the vulnerability map gives us a risk map according to the following formula (Fig. 10).

Risk map = Vulnerability map × Hazard.

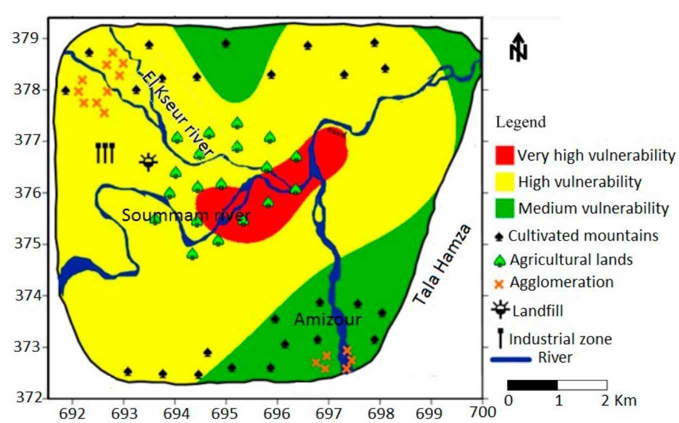

Figure 10. Risk map of the Amizour aquifer (February 2020).

4 Conclusion

The two methods give relatively similar results. The classes at the level of the DRASTIC method are substantially identical to those observed at the level of the SINTACS method (the difference between the three contamination levels did not exceed 15%), the small difference obtained between the two zones is just that of the level of very high vulnerability class. Our study zone is prevailed by the high vulnerability class followed by the medium vulnerability one. In both approaches, the high vulnerability zone occupies a huge part of the study area (ranged from 67 % to 76%) and the medium vulnerability zone occupies the northern and southern part of the study area where the soil type is generally sandstone. The very high vulnerability class highlights the zone with greatest pollution risks. This zone, in our study, occupies only a limited area (6%) encounteredin the center of the plain of Amizour as exhibited by the DRASTIC method. The presence of very high vulnerabilities could be justified by the presence of shallow groundwater.

To protect the Amizour aquifer against pollution and to make a sustainable ecological development in the region, several recommendations are suggested:

- Prohibiting direct discharges of wastewater (domestic, agricultural, industrial) in the Soummam river;
- Realization of a micro piezometer intended for hydrogeological studies (quantitative and qualitative monitoring of groundwater);
- Making farmers aware of the consequences of the use of fertilizers which constitute presumably the most important risk of contamination in the studied region;
- Establishing a hydrochemical monitoring of groundwater and surfaces;
- Updating of periodic risk maps to highlight the possible contamination of aquifers.

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