Aquifer Vulnerability Assessment by DRASTIC and SI methods: The case study of Guelma Plain, Northeast Algeria

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ABSTRACT

Guelma plain, located in northern Algeria, contains an alluvial nappe that provides economic opportunities such as industrial and agricultural employment. In Guelma, the pressure of anthropogenic origin is combined with unfavorable climatological conditions that expose it to environmental and social risks. The current study aims to assess the level of groundwater vulnerability to pollution using two methods, DRASTIC and SI. These are coupled with the Arc Gis software in order to carry out the mapping. From south to north, several levels of vulnerability have been identified, from low to high. The result comparison allows us to conclude that the SI method is the most appropriate for assessing the vulnerability to pollution of the study region's wetlands. The result of this study can be used as a decision-support tool for the management and protection of the quality of water resources in the Guelma plain.

Keywords-Guelma; groundwater; nappe; vulnerability; pollution; DRASTIC; SI

I. INTRODUCTION

Water is one of the most important ecosystem, climate, and social components [1, 2]. Water in sufficient quantity and of acceptable quality is a fundamental necessity, but maintaining its quality is challenging [3]. Groundwater is severely overexploited because it is the main source of water for drinking, domestic, industrial purposes, and livestock operations, and it is in a critical state based on quantitative and qualitative evaluations [4-6]. Surface and ground water are the main resources of drinkable water, since the 97.5% of the total water on the globe is saline. Civilizations have long promoted an understanding of the need of protecting water resources. Technical methods are crucial for conserving these resources. These tools are based on evaluations of the sensitivity and susceptibility of water to pollution, as well as a compilation of maps that clearly delineate zones of sensitivity and vulnerability at various levels. The drop in groundwater level and ensuing rise in susceptibility are caused by human and agricultural activities. This study sought to ascertain Guelma alluvial plain's sensitivity to groundwater pollution using the following vulnerability methods: the general DRASTIC [7] approach and the SI [8] method combined with GIS. In order to establish measures to conserve these resources and prevent the loss of this wealth, the created maps of groundwater pollution sensitivity using various methodologies help us better pinpoint the location of polluted areas.

II. STUDY AREA

The wilaya of Guelma is located in the North-East of the country. It is limited by the wilaya of Annaba in the North, El Tarf in the North East, Skikda in the North-West, Souk Ahras and Oum El-Bouaghi in the South East, and finally Constantine in the West. It is a part of the Maghreb chain of eastern Algeria [9] and extends between 7° and 7°30' East and between 36° and 36°30' North, having between 180 and 250m altitude [10].

This area is characterized by subtropical climate. The rainy season lasts from October until May, with an annual precipitation that doesn't surpass 550mm and with sparse vegetation. In addition, the annual average value of temperature is 17.75°C, and the monthly temperatures variate between a minimum of 9.72°C and a maximum 26.76°C. It is surrounded by various thrust sheets, giving rise to the current mountains [9, 11-13]: Mahouna (1411m) to the south, Haouara (1292m) to the north, and Débar (1060m) to the North-West [10]. The reliefs are made up of allochthonous lands belonging mainly to the Tellian domain made up of Meso-Cenozoic marls and carbonates [14].

III. GEOLOGICAL AND HYDROGEOLOGICAL SETTINGS

The geology of Guelma region consists of three major sets: pre-aquifer, a Mio-Pliocene set (continental, from Guelma basin), and a recent set (Pliocene and Quaternary). Guelma region includes Djebel Debagh Neritic domain, Heliopolis, and Guelma South. This Jurassic-Cretaceous carbonate facies unit, which is more or less karstified, is overlain by several thrust layers and subjected to significant tectonic events. Along its course between Nador and Medjez Amar, the Seybouse wadi has deposited alluvium [9]. The center of the plain represents a zone of collapse filled with Miocene (clay and gypsum marl) and Quaternary (terraces of heterogeneous alluvium) deposits (Figure 2) [10]. These permeable alluviums are nourished by the infiltration waters of the rains and the lateral contributions of the Seybouse wadi's watershed. There are three distinct terrace levels (low, medium, and high) [10].

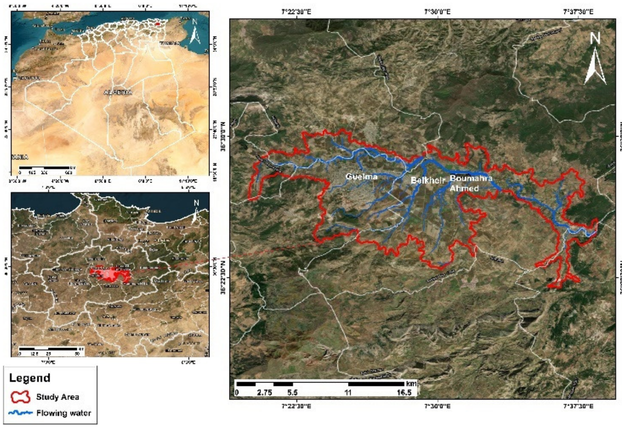

Fig. 1. Study area.

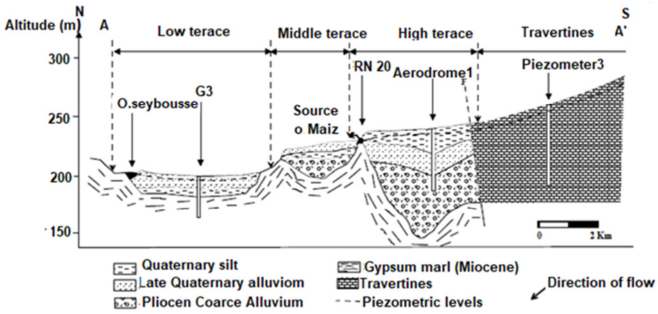

Fig. 2. Hydrogeological section in the Guelma north-south plain.

IV. MATERIALS AND METHODS

A. Application of the DRASTIC and SI Methods

The DRASTIC index was developed by the US Environmental Protection Agency as a standardized approach for measuring how sensitive groundwater is to pollution [6]. DRASTIC can be utilized by people with a wide range of backgrounds and degrees of competence due to its simplicity [6]. DRASTIC evaluates groundwater vulnerability by incorporating 7 physical and hydrogeological parameters: Depth of water (D), net recharge (R), aquifer media (A), soil media (S), topography (T), vadose zone impact (I), and hydraulic conductivity are the (C) parameters. For convenience of use, they have been organized to form the Abbreviation DRASTIC. The DRASTIC factors are measurable parameters for which data is generally available from a number of sources without extensive investigation. The Susceptibility Index (SI) is a modification of the DRASTIC approach for determining aquifer sensitivity to disperse agricultural pollution. Depth to water, net recharge, aquifer medium, topography, and land use are the 5 parameters involved. It differs from DRASTIC in that it includes the land-use factor while excluding the soil media, vadose zone, and aquifer. Land use is a critical and influential factor in groundwater contamination caused by anthropogenic activities such as agricultural land use which can negatively impact groundwater through the application of fertilizers, pesticides, and industrial land use, which can negatively impact groundwater through the disposal of chemical compounds into water bodies and landfills [11].

TABLE I. RATINGS AND WEIGHTS OF THE DRASTIC METHOD PARAMETERS [7]

D (m)	**Weight**	**Evaluation**
0-1.5		10
1.5-4.5		9
4.5-9		7
9-15	5	5
15-22.5		3
22.5-30		2
> 30		1
A	**Weight**	**Evaluation**
Karst limestone		10
Sand and gravel		8
Solid sandstone		6
Altered metamorphic	3	4
Metamorphic		3
Metamorphic		1
Sand and fine gravel		5
T (slope %.)	**Weight**	**Evaluation**
0-2		10
2-6		9
6-12	1	5
12-18		3
> 18		1
C (m/s)	**Weight**	**Evaluation**
> 9.4×10^{-4}		10
4.9×10^{-4} - 9.4×10^{-4}		8
32.9×10^{-5} - 4.7×10^{-4}	3	6
14.7×10^{-5} - 32.9×10^{-5}		4
4.7×10^{-5} - 14.7×10^{-5}		2
4.7×10^{-7} - 4.7×10^{-5}		1
R (mm)	**Weight**	**Rayting**
>25.5		9
25.5- 17.5		8
17.5-10	4	6
10-5		3
5-0		1
S	**Weight**	**Rayting**
Thin or absent		10
Sands		9
Sandy loam	2	6
Silt		4
Silty loam		3
Clays		1
I	**Weight**	**Reyting**
Karstic limestone		10
Sand and gravel		9
Sand and gravel with silt and clay	5	8
Sandstone		6
Limestone		6
Silt and clay		1

For each used models we have applied the following formulas:

- DRASTIC:

$$\mathrm{ID} = \mathrm{D_r} \times \mathrm{D_w} + \mathrm{R_r} \times \mathrm{R_w} + \mathrm{A_r}\mathrm{A_w} + \mathrm{S_r} \times \mathrm{S_w} + \mathrm{T_r} \times \mathrm{T_w} + \mathrm{I_r}\mathrm{I_w} + \mathrm{C} \times_{\mathrm{C}} \mathrm{C_P} \qquad (1)$$

where D: depth, R: net recharge; A: aquifer media, S: soil media, T: Topography, I: unsaturated zone; C: hydraulic conductivity, and the subscripts r and w are the corresponding rating and weights, respectively:

- SI:

$$\mathrm{I_S} = \mathrm{D_C} \times \mathrm{D_P} + \mathrm{R} \times_{\mathrm{C}} \mathrm{R_P} + \mathrm{A_C} \times \mathrm{A_P} + \mathrm{S_C} \times \mathrm{S_P} + \mathrm{T_C} \times \mathrm{T_P} + \mathrm{lu_C} \times \mathrm{lu_P} \qquad (2)$$

where D, R, A, S, T, and Lu are the parameters of the SI method, p the weight of the parameter, and c the associated score.

The land cover parameter (Lu) was obtained by processing the sentinel satellite image taken in July 2020. This image was used to establish the land cover map of the study area. Tables I-III are used to elaborate the maps of the parameters of the DRASTIC and SI methods.

TABLE II. WEIGHTS ASSIGNED TO THE SI METHOD PARAMETERS [8]

N°	Parameters	Weight
1	D: Depth	0.186
2	R: Net recharge	0.212
3	A: Aquifer media	0.259
4	T: Topography	0.121
5	LU: Land Use	0.222

TABLE III. VULNERABILITY ASSESSMENT CRITERIA OF THE DRASTIC AND SI METHODS [7,12,13,8]

Vulnerability index	DRASTIC	SI
Very low	< 80	---
low	180-120	<45
Moderate	121-160	45-64
High	161-200	65-85
Very high	>200	>85

B. Elaboration of Maps of the Specific Parameters of the Vulnerability of the Aquifer

In order to use the DRASTIC and the SI methods, the following steps must be followed:

- Data collection
- Data digitization
- Calculation of scores (Score × Weight)
- Assignment of scores
- Classification and reclassification of the 7 specific parameters of the groundwater
- Map development for each specific parameter of the tablecloth on Raster mode
- Calculation of the global vulnerability index by the sum of the 7 raster maps of the specific parameters of the vulnerability of the tablecloth
- Classification and development of the final vulnerability map

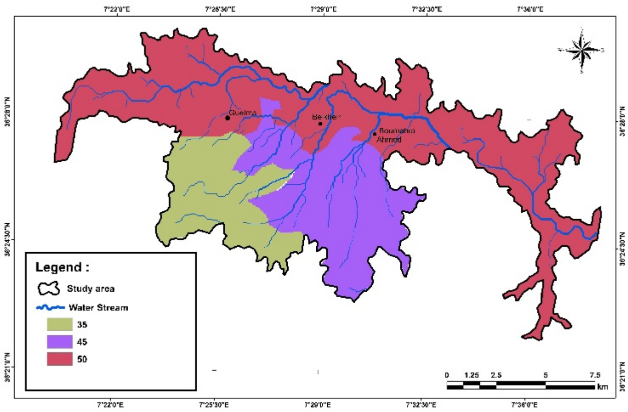

Fig. 3. Map spatial distribution of depth to water.

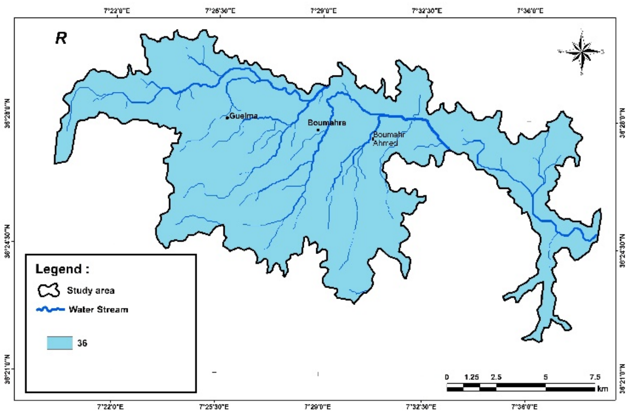

Fig. 4. Spatial distribution of net recharge.

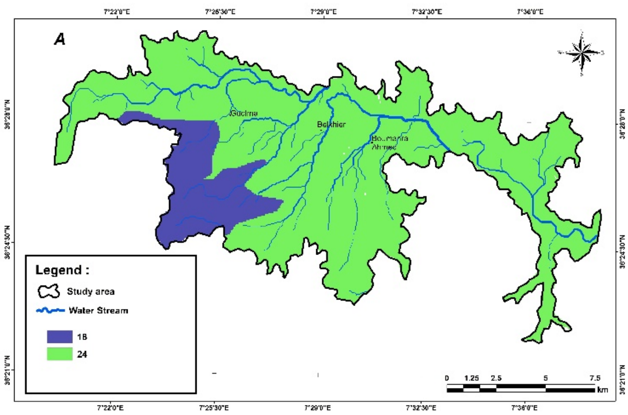

Fig. 5. Spatial distribution of aquifer materials.

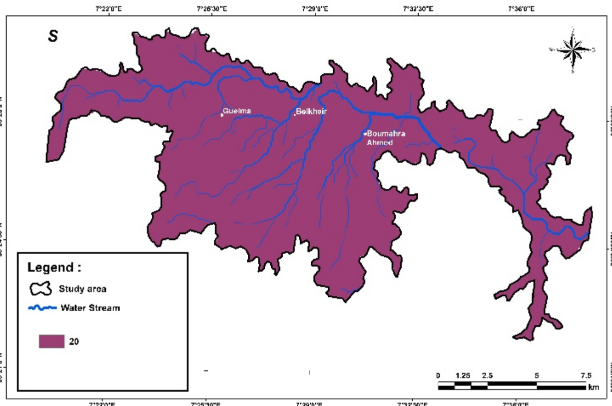

Fig. 6. Slope spatial repair.

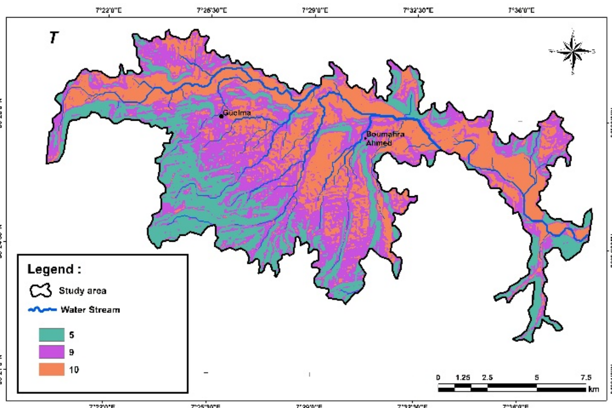

Fig. 7. Spatial distribution of soil type in the region.

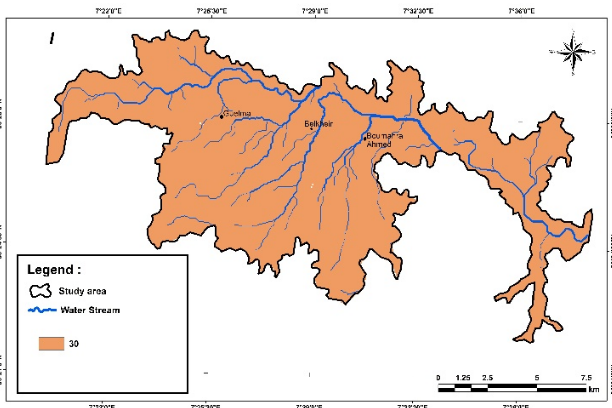

Fig. 8. Distribution of values of the nature of the vadose zone index.

V. RESULTS AND DISCUSSION

A. Synthesis Map by the DRASTIC Method

The application of the DRASTIC method at the Guelma plain has allowed the realization of the vulnerability map of Figure 11, from which we can distinguish three classes of different degrees of vulnerability. We notice that the areas of low vulnerability are encountered in the southeast of the plain. This can be explained by the nature of the soil that is characterized by a fine texture and the slope that varies from medium to strong. Similarly, the areas of medium vulnerability are located in the center of the plain to the south, more precisely in the southeast or at the wastewater discharges (drainage of wastewater by the various tributaries of Oued Seybouse) and at the level of settlements which contain a large number of boreholes for agricultural development.

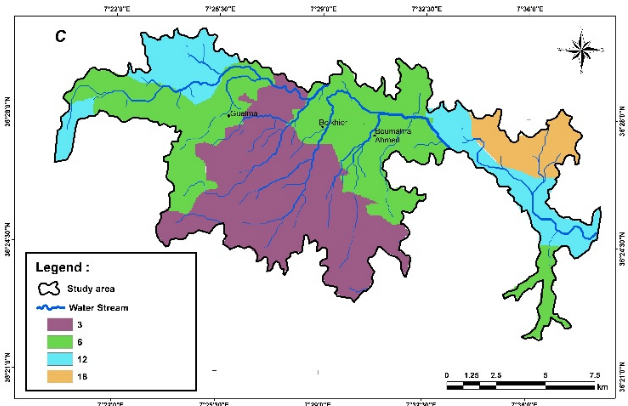

Fig. 9. Distribution of hydraulic conductivity values.

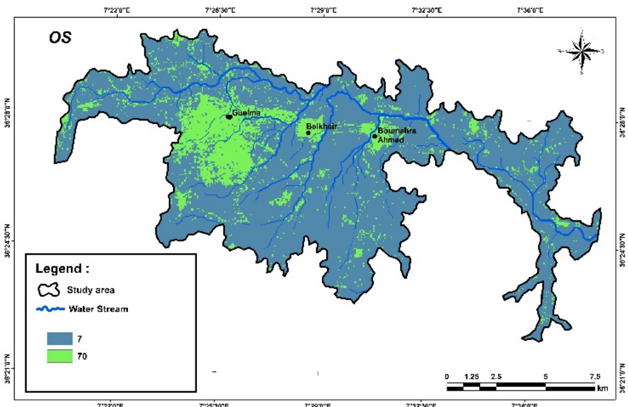

Fig. 10. Land cover map.

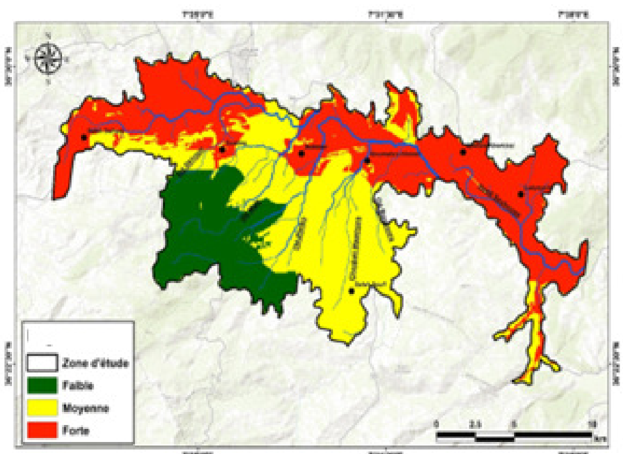

Fig. 11. Aquifer vulnerability map (DRASTIC method).

The area of high vulnerability is noticed at the North-East and North-South edges, which can be explained by the drainage of wastewater by the main wadi (Seybouse) interrupted by a site of medium vulnerability. This elevation is explained by the gravelly nature of the soil of the vadose zone, the materials of the aquifer which are very permeable, and the urban discharges**.**

B. Synthesis Map by the SI method

The application of the SI method at the Guelma plain has allowed the realization of the vulnerability map of Figure 12, from which we can again distinguish three different classes of degrees of vulnerability. The areas of low vulnerability are distributed throughout the plain but the large area of this class is located in the south, affirming the result found in the case of the DRASTIC method, which is explained by the nature of the soil at an important depth that can reach 25m. A sector of medium vulnerability is distributed all over the plain, where the wastewater discharges are located and at the level of the agglomerations. The area of high vulnerability is mainly noticed all along the wadi Seybouse (drainage of wastewater by Oued Seybouse) and even in the center going south, where there is the presence of an unauthorized dump site and in the industrial area between Oued Skhoun and Oued Maiz.

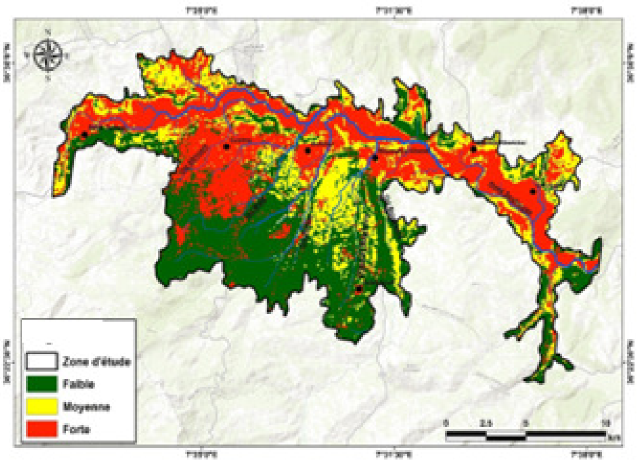

Fig. 12. Aquifer vulnerability map (SI method).

VI. CONCLUSION

Surface and ground water are the main resources of drinkable water [14]. With the ever-increasing demand for water and the increasing lack and deterioration of water quality, the need for vulnerability mapping methods is necessary. Due to the large number of methods in use, it is essential to recognize which ones are the most reliable and effective.

The plain of Guelma is made up of agricultural land that is irrigated from the Seybouse wadi, which is the receiving medium for all the urban and industrial wastewater from the city of Guelma and its agglomerations. The contamination of the plain's groundwater has been brought to light by this study. In order to achieve this goal, the application of the DRASTIC and SI methods allowed the vulnerability assessment of the pollution of the Guelma alluvial groundwater. This vulnerability increases from the center of the plain to the northern edges and especially along the Oued Seybouse and its tributaries (Oued Maiz, Oued Zimba, Chaabet Maamora). The distribution of pollution sources has induced this growth. The analysis of the two vulnerability maps resulting from the application of these methods revealed three distinct classes of low, medium, and high vulnerability. Although the two vulnerability maps are relatively close, the vulnerability map made from the SI method reflects more the reality of the groundwater pollution of the Guelma plain, which can be explained by the high vulnerability area located in the southern part (presence of an industrial area and an unauthorized dump site). As the pollution of groundwater in the study area is confirmed, consequently the most vulnerable perimeters from now on must be subjected to a rigorous control in order to define protection measures to avoid and stop the degradation of this natural source.

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