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HYDROGEOLOGY AND VULNERABILITY ASSESSMENT OF GROUNDWATER RESOURCES IN THE MOSTAGANEM PLATEAU, NORTHWESTERN ALGERIA

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This study utilized the GIS technique and the DRASTIC method to assess the vulnerability of groundwater resources to contamination in the Mostaganem plateau, northwestern Algeria. The DRASTIC groundwater vulnerability map shows regional groundwater areas that are sensitive to contamination on the basis of hydrogeologic conditions. Seven hydrogeologic factors were used for the vulnerability assessment. There are depth to water table, net recharge, aquifer media, soil media, topography, impact of the vadose zone, and aquifer hydraulic conductivity. The vulnerability maps were constructed using MAPINFO software. The areas of highest contamination vulnerability are Mostaganem city and Mazagran city. The areas of lowest contamination vulnerability are located in the northern part of the study area. A risk of pollution map is deduced from the combination of vulnerability map with the sources of pollution map.

INTRODUCTION

The groundwater usage in the Mostaganem plateau is increasing as a result of city expansion and industrial growth. In the future, groundwater contamination could become a serious problem. A groundwater vulnerability assessment of the basin is needed to manage and reduce the potential of groundwater contamination. The International Association of Hydrologists (1994) proposed the definition of vulnerability as an intrinsic property of a groundwater system that depends on the sensitivity of that system to human and/or natural impacts. Results of a vulnerability assessment are portrayed on a map that shows various homogeneous areas, each of which has unique relative levels of vulnerability. The most widely used groundwater vulnerability mapping method is an empirical model called DRASTIC. The DRASTIC model was developed for the U. S. Environmental Protection Agency by Aller et al. (1987) to be a standardized system for evaluating groundwater vulnerability to pollution. The DRASTIC model has been used to produce maps in many parts of the United States (United States Geological Survey, 1999; Harman et al., 2000; Osborn et al., 1998; Kumar et al., 2003), in Portugal (Lobo-Ferreira and Oliveira, 2003), in Sweden (Rosen, 1994), in Australia (Piscopo, 2001), in Thailand (Kwansiririkul et al., 2004), in India (Shahid, 2000; Jasrotia and Singh, 2005), and in Jordan (Al-Adamat et al., 2003). The DRASTIC model has four assumptions: 1) the contaminant is introduced at the ground surface, 2) the contaminant is flushed into the groundwater by infiltration, 3) the contaminant has the mobility of water, and 4) the area being evaluated by DRASTIC is 100 acres or larger (Osborn et al., 1998; Wyoming Water Resource Center, 1998, 1998a; Piscopo, 2001).

The purpose of this study was to provide a vulnerability map and information on the groundwater resource in the Mostaganem plateau, which, in turn, could be incorporated into groundwater protection planning. The DRASTIC model was used to compute the relative vulnerability of groundwater to contamination from surface sources of pollution. The model results can be used to provide assistance in planning groundwater-related activities. Maps were developed by using geographic information system computer mapping hardware and software to combine data layers. Groundwater vulnerability was determined by assigning point ratings to the individual data layers and adding the point ratings together when these layers were combined into a vulnerability map.

STUDY AREA

Geographical characteristics

Mostaganem is a port city and capital of Mostaganem province, in the northwest of Algeria (Figure 1). Population is 150,000 as of 2005. The city, founded in the 11th century, lies on the Gulf of Arzew, Mediterranean Sea and is 72 km ENE of Oran. The area of Mostaganem plateau is 700 km^2. The Mostaganem plateau has two main rivers; the Aïn Sefra and Kheir Rivers. The area has three dams, Sidi Moussa, Seddaoua and Temamet.

It is bordered from the north by the Chelif River, which is the longest and most important river in Algeria. The Chelif river rises in the High Plateau, crosses the Tell Atlas, and flows through an east-west trough to reach the sea east of Mostaganem. The Chelif has been so intensively exploited for irrigation and drinking water that it has ceased to flow in its lower reaches during the summer months. In the south, the Mostaganem plateau is bordered by the Bordjias plain; in the east by the Ennaro and Bel Hacel mountains; and in the west by the Mediterranean Sea.

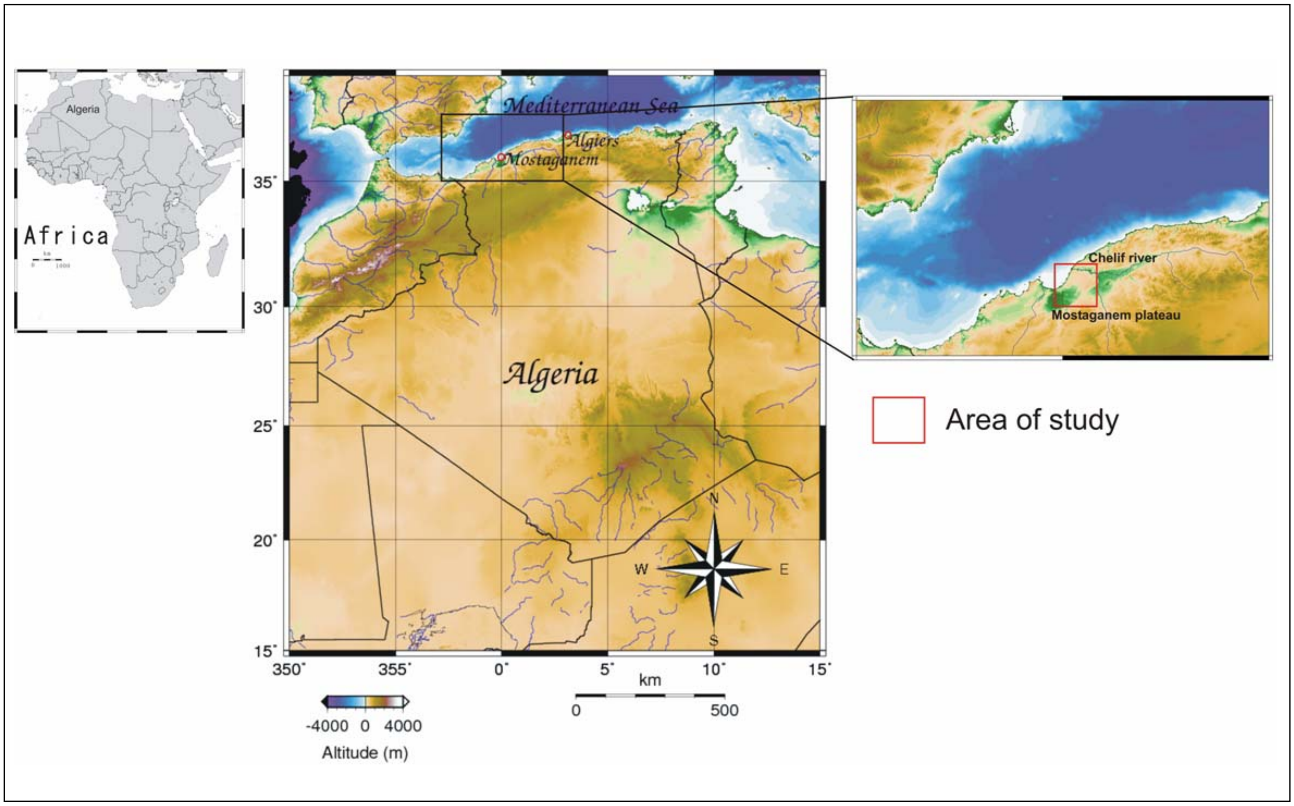

Figure 1. Location of Mostaganem in Algeria.

Hydrogeology

The main aquifer is contained in the Calabrian sandstone layer (ANRH, 1971) (Figure 2). The thickness of the aquifer is about 100 to 200m. In the Mostaganem plateau, there are more than 200 wells, 16 drill holes, and 57 springs. Transmissivity, storage coefficient, and permeability were identified during pumping and recovery using Boulton's method. The values are reported in Table 1 (Saibi, 2000). Figure 3 shows the hydraulic head contour map of the Mostaganem plateau based on data of 89 wells. The main direction of groundwater flow is NE-SW.

An electrical resistivity survey was conducted in the area. The number of measurements is 887 and the electrode spacing varies from 100 to 1000m. From the results (Table 2), we can observe a variation of resistivity between sandstone, wet sand of the Calabrian (main aquifer), and the marly basement rocks.

Hydroclimatology

The Mostaganem area is characterized by a Mediterranean climate, mild, wet winters with hot and dry summers. In the plateau, there are eight meteorological stations. In this section, we present some climatologic characteristics of the Mostaganem stations (Tables 3 and 4). The annual precipitation is around 300 mm (Figure 4). The meteorological data are from the ONM (1999).

Table 1. Hydrogeological aquifer characteristics of Mostaganem plateau (Saibi, 2000).

Aquifer physical parameters	Values
Transmissivity (m^2/s)	$2\ 10^{-3} – 18\ 10^{-4}$
Storage coefficient (-)	$2.6\ 10^{-2} – 2\ 10^{-1}$
Permeability (m/s)	$2.5\ 10^{-5} – 3.2\ 10^{-5}$

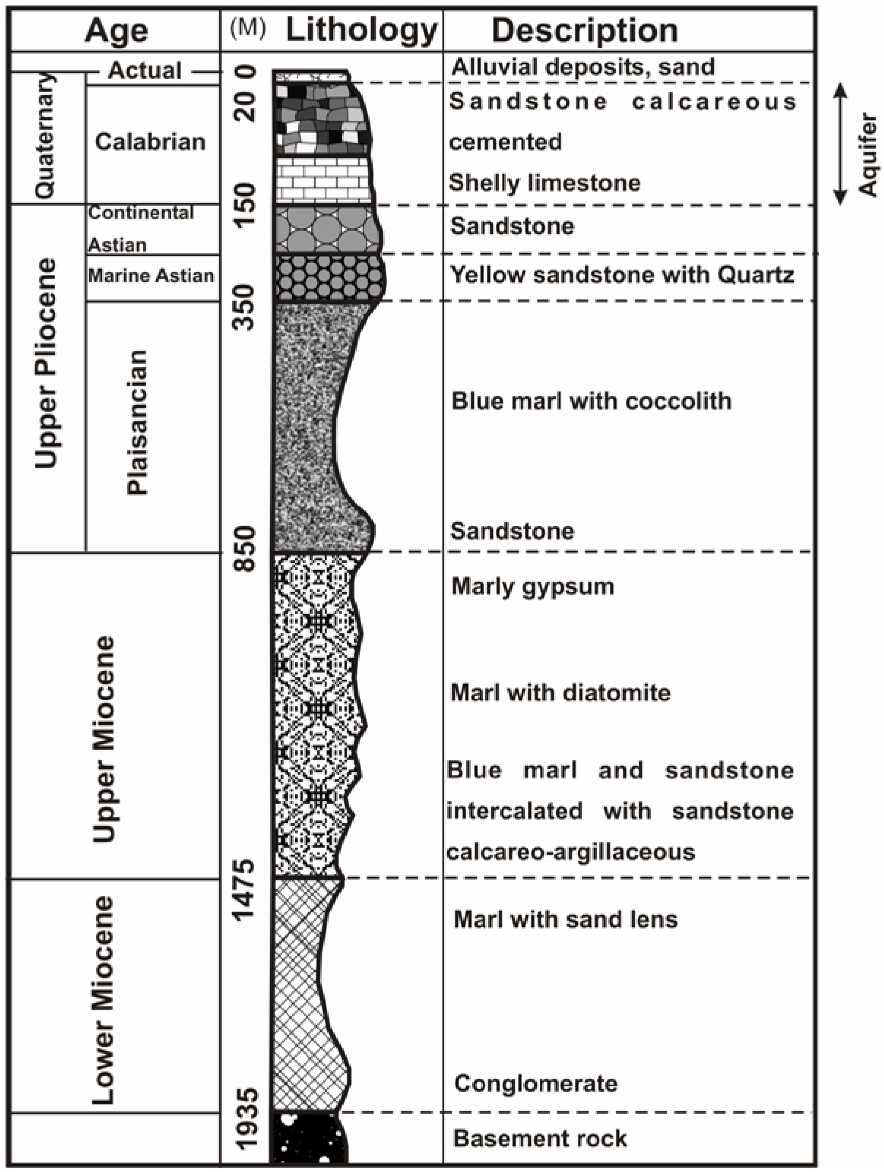

Figure 2. Well log stratigraphy at Mostaganem plateau (ANRH, 1997).

Table 2. Resistivity of the different geological layers in the Mostaganem plateau (CGG, 1969).

Nature of formation	Electrical Resistivity (Ohm-m)
Silt, sandy clay	20 – 200
Sand and sandstone: - dry - wet	 200 – 1500 50 – 200
Intercalation of sandy clay in the covering layers	5 – 30
Marl with sand of the Substratum	2 – 25

Hydrochemistry

Waters from the Mostaganem plateau are divided into two groups:

1- Chloride-sodium facies (Na-Cl) waters (94.12%),

2- Bicarbonate-sodium facies ($Na-HCO_3$) waters (5.88%).

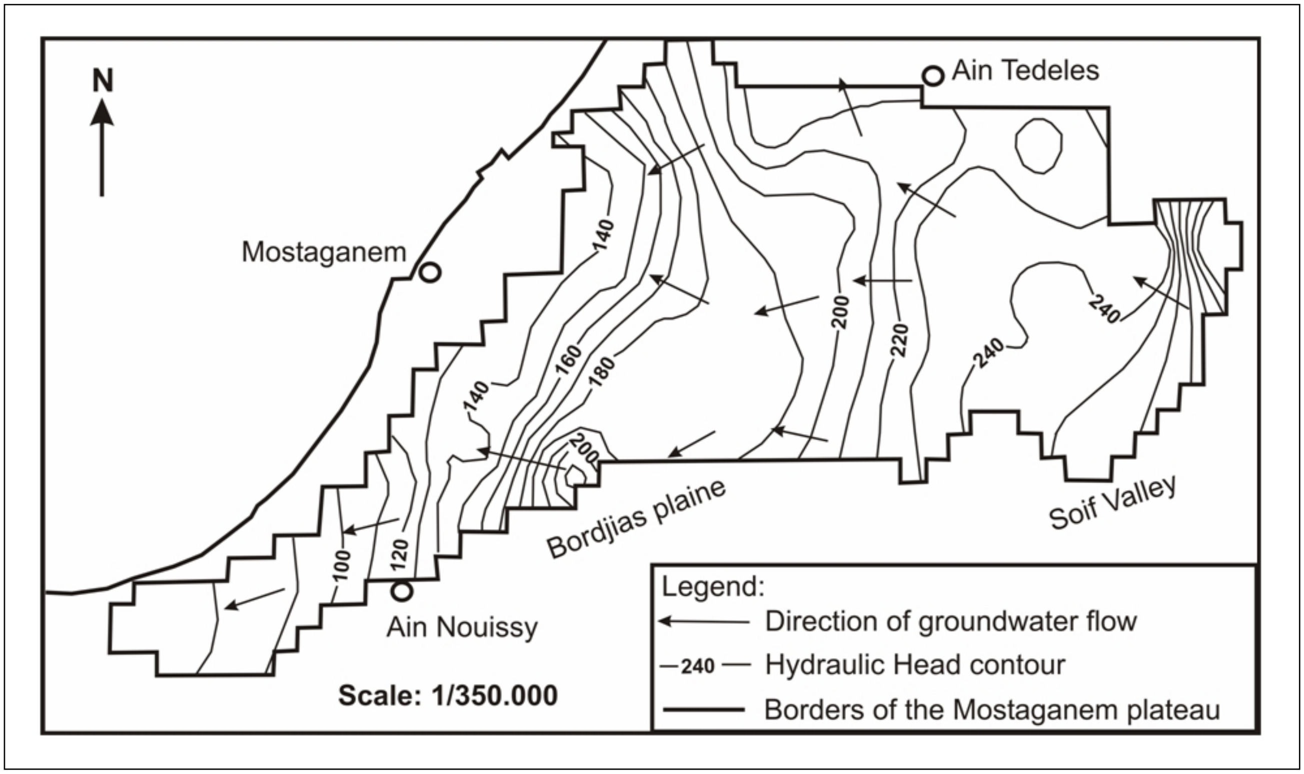

Figure 3. Hydraulic head contours map of Mostaganem plateau established on data of April 1997 (Saibi, 2000).

Table 3. Meteorological station of Mostaganem (ONM, 1999).

Code	Coordinates		
	Long.	Lat.	Altitude (m)
C040612	00°04'00''E	35°50'00''N	146

Table 4. Hydroclimatic characteristics of Mostaganem plateau (Saibi, 2000).

Parameters	Values
Precipitation (mm)	340
Average atmospheric temperature (°C) for the period: 1913-1998	17.5
Annual relative evaporation (mm)	112.35
Real Evapotranspiration (mm)	304.08
Infiltration (mm)	14
Running off (mm)	12
Relative Humidity (%)	57.55

The waters have a high conductivity ranging from 1327 to 4310 mmhos at 25°C. The Total Dissolved Solid is more than 1500 mg/L.

THE DRASTIC METHOD

DRASTIC, proposed by the US Environmental Protection Agency (Aller et al., 1987) is a method to evaluate the vertical vulnerability based on the following seven parameters: Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone, and hydraulic Conductivity. Each mapped factor is classified either into ranges (for a continuous variable) or into significant media types (for thematic data) which have an impact on pollution potential. Weight multipliers are then used for each factor to balance and enhance their importance. The final vulnerability index is a weighted sum of the seven factors.

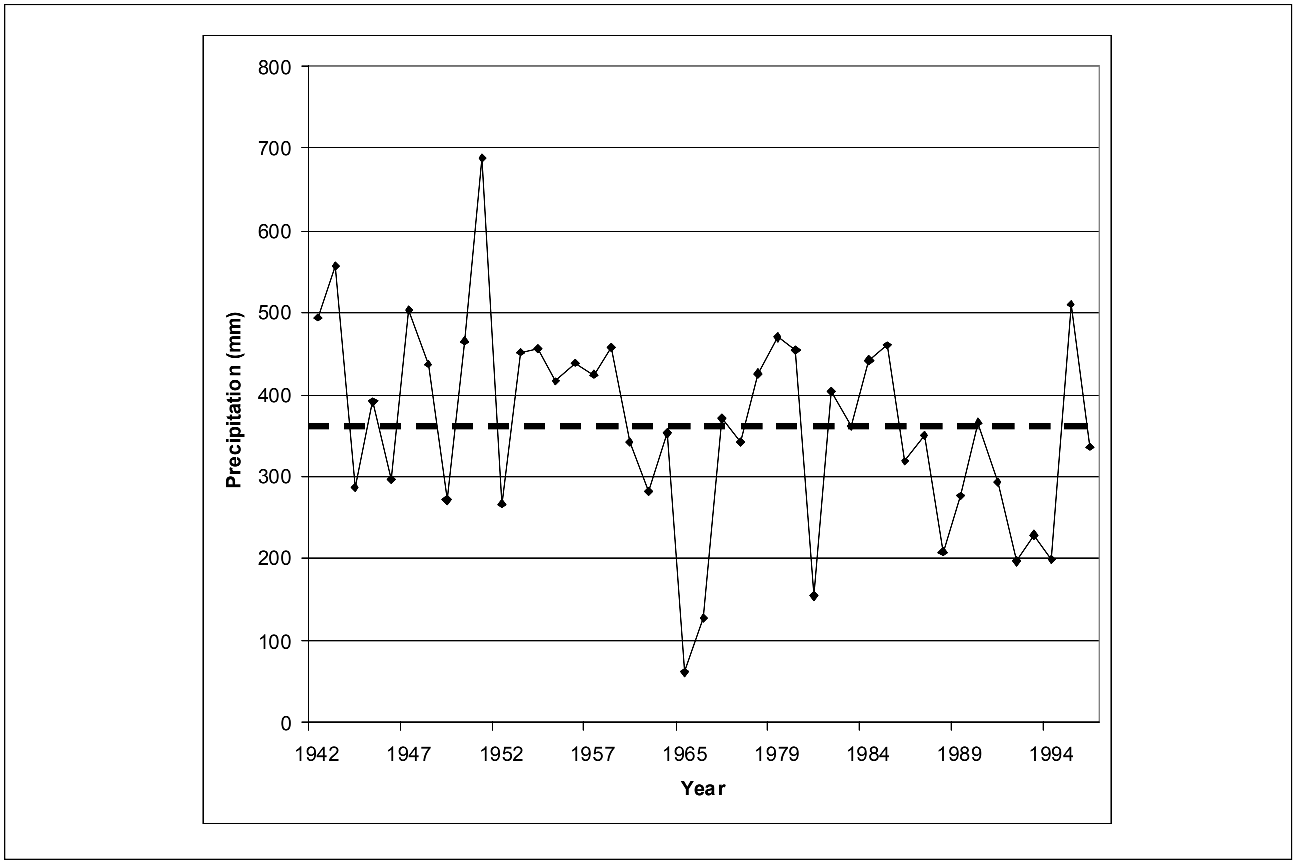

Figure 4. Annual precipitation at Mostaganem station from 1942 to 1996. The dashed line indicates the average value (Saibi, 2000).

The DRASTIC index (D_I) can be computed using expression (1):

$$D_I = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \tag{1}$$

where D, R, A, S, T, I, and C are the seven parameters, r is the rating value of the analyzed subarea, and w is the weight associated to each parameter.

To assess groundwater vulnerability, a numerical ranking is used on the DRASTIC features. This ranking considers weights, ranges, and ratings. Figure 6 shows the processing steps to establish the vulnerability map and detect the regions of high risk of pollution.

Weights

Weights of 1 to 5 relative to each of the seven factors are assigned in order of importance. Table 5 shows the assigned weights for these DRASTIC factors (Aller et al., 1987).

Ranges

Each DRASTIC factor has an upper and lower limit of variability within the Mostaganem plateau. This variable range has been devised on the basis of its impact on pollution potential.

Ratings

The hydrogeologic factors are assigned a rating value lying between 1 to 10 on the basis of their range values. These ratings provide a relative assessment among the ranges of each factor.

The ranges and ratings for the seven hydrogeologic factors are presented in paper of Aller et al., 1987. The resulting DRASTIC indices represent a relative measure of groundwater vulnerability.

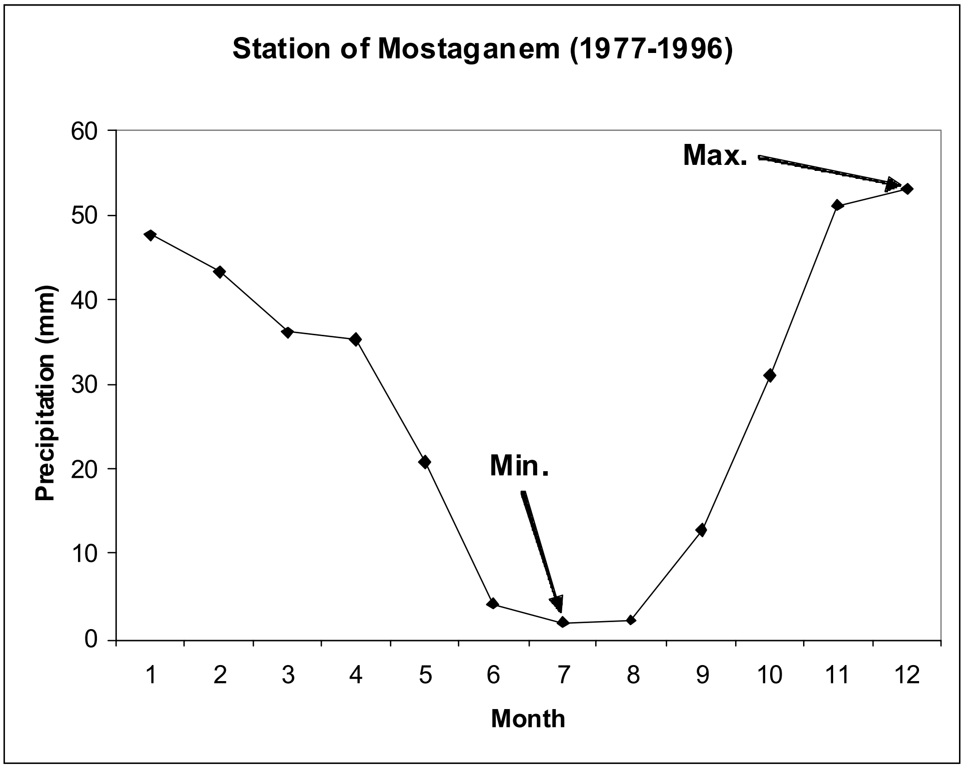

Figure 5. Monthly variation of the monthly precipitation at Mostaganem station for the period of 1977-1996 (Saibi, 2000).

Table 5. Weights of DRASTIC hydrogeologic factors (Aller et al., 1987).

Hydrogeologic Factor		Weight
D	Depth to water	5
R	Recharge (net)	4
A	Aquifer media	3
S	Soil media	2
T	Topography	1
I	Impact of vadose zone media	5
C	Hydraulic conductivity of aquifer	3

The higher the DRASTIC index, the greater the vulnerability of the aquifer to contamination. A site with a low DRASTIC index is not free from groundwater contamination, however, but it is less susceptible to contamination compared with the sites with high DRASTIC indices.

RESULTS AND CONCLUSIONS

This study divided vulnerability rankings into three classes that describe the relative probability of vulnerability of the groundwater resources. These three are: low, moderate, and high. The vulnerability map of the Mostaganem plateau is shown in Figure 8. Standard DRASTIC colors were used for the map. The colors range from red for the highest vulnerability to green for the lowest vulnerability.

A regional scale is useful for comparing the relative vulnerability of groundwater resources. DRASTIC indices range from 23 for the least vulnerable to 226 for the most vulnerable (Figure 7).

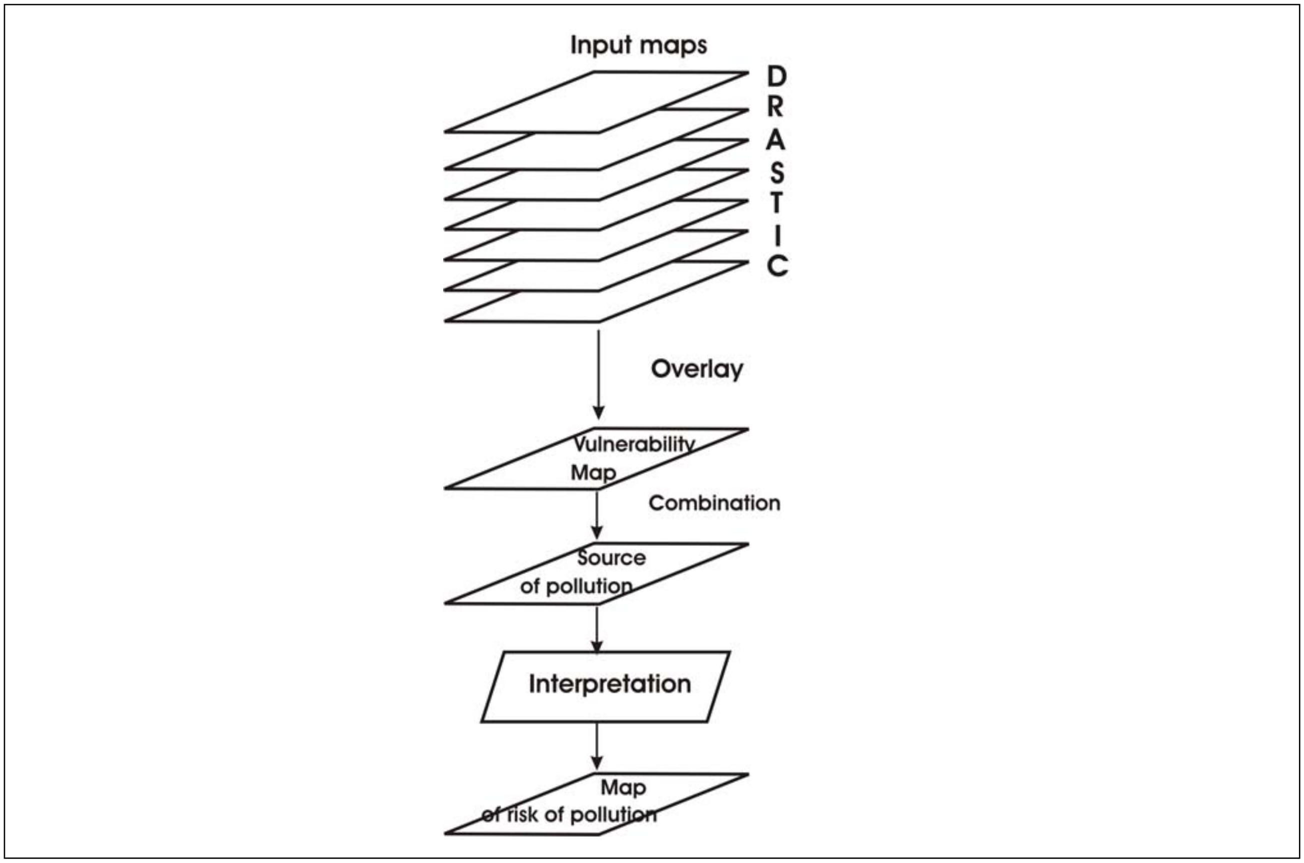

Figure 6. Processing strategy used in our study.

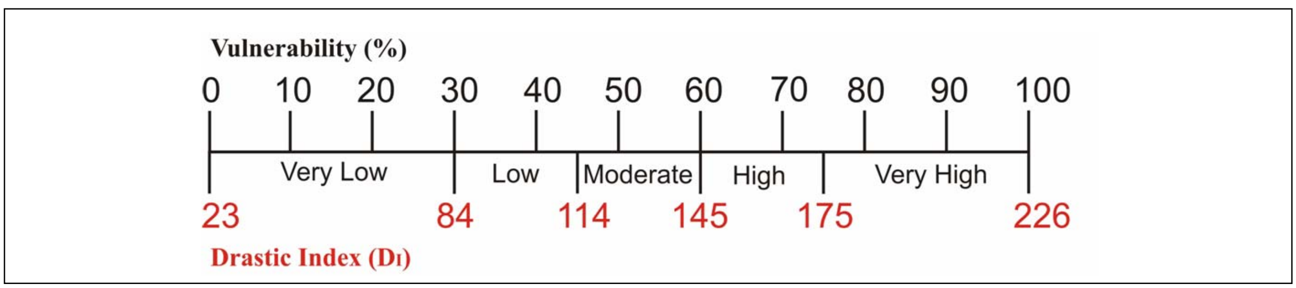

Figure 7. Vulnerability index and percentage.

High

High vulnerability of the groundwater resources is found in the central-eastern and southwestern part of the study area. These areas are characterized by a high permeability and low slope (0.8–2%). The area is 136.95 km^2, 13% of the total plateau area. The high vulnerability areas are located in the sandy soils.

Moderate

Moderate vulnerability ranked groundwater resources is the predominant classification in the Mostaganem plateau with an area of 832.1 km^2, 80.7% of the total area.

Low

There are a few areas of low vulnerability ranked groundwater resources in the plateau. These occur in the northern part of the area where we have outcrops of Plaisancian marl and Miocene formation which is an impermeable layer. The area is 61.753 km^2, which is 6% of the total area.

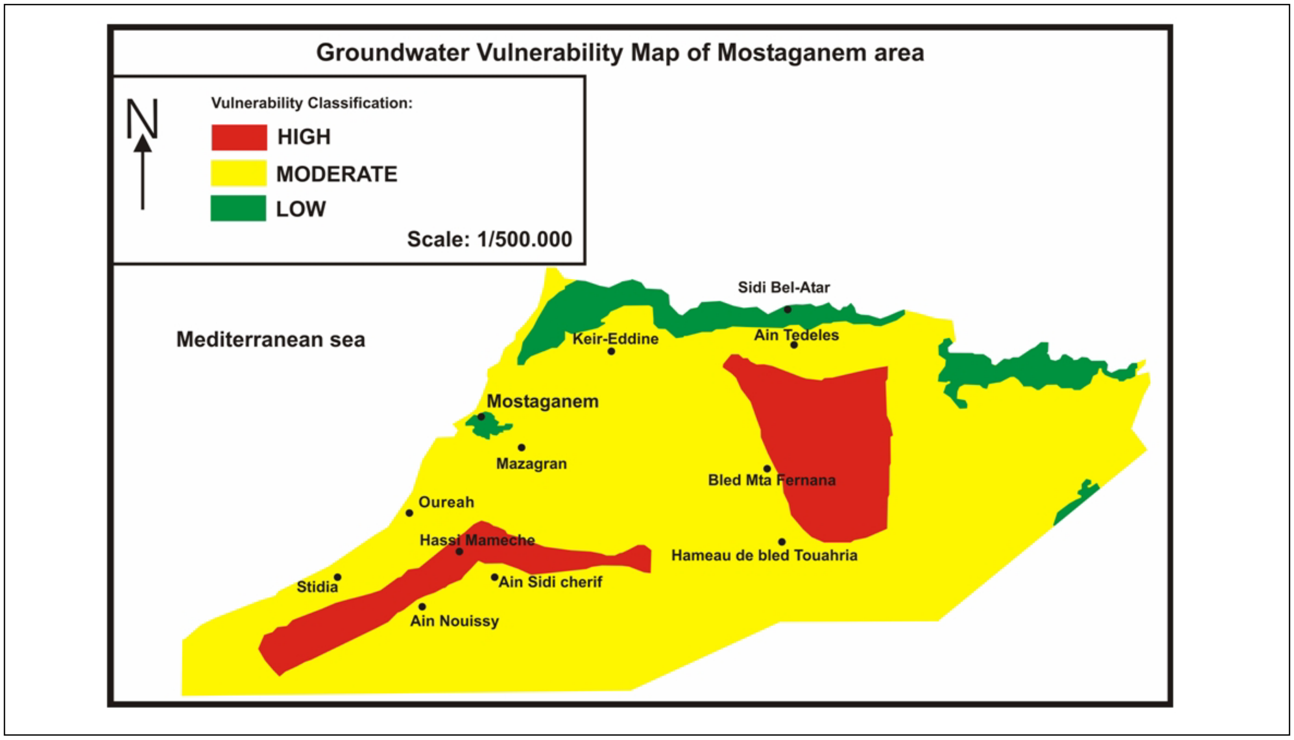

Figure 8. Groundwater vulnerability map.

Figure 9 shows the different sources of pollution in the Mostaganem plateau. Water pollution has many sources. In Mostaganem area, there are three main sources:

1) Domestic sewage which refers to waste water that is discarded from households. Also referred to as sanitary sewage, this water contains a wide variety of dissolved and suspended impurities.

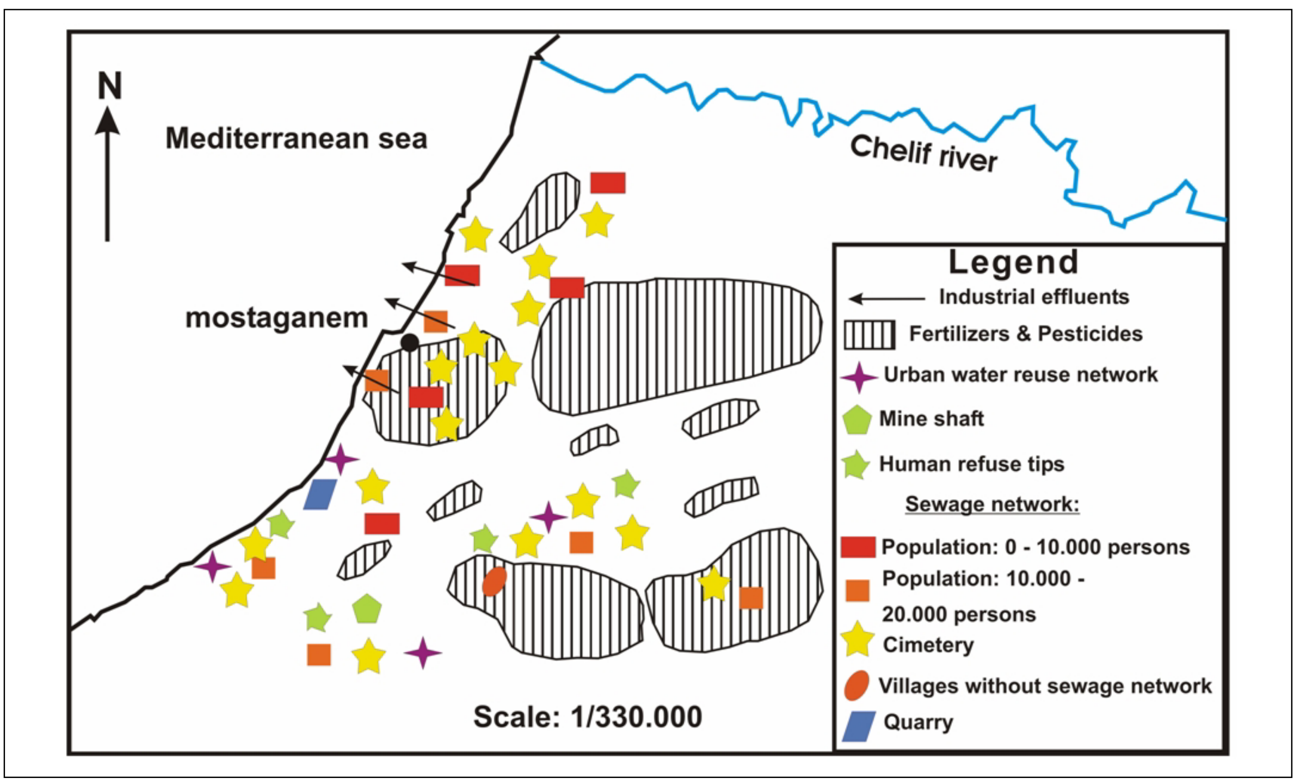

Figure 9. Map of source of pollution in Mostaganem plateau (Saibi, 2000).

2) Agricultural runoff: In the Mostaganem area, there are more than 4400 hectares of arboriculture and 8000 hectares of truck farming that use many fertilizers and pesticides.

3) Industrial effluents, or waste water from manufacturing or chemical processes in industries, contribute to water pollution. In Mostaganem there are many factories of the sugar and paper industries.

Combining this map and the vulnerability map, we can show the areas of high risk of pollution. There are three groups regarding the degree of risk of pollution:

1- High risk of pollution: Mostaganem and Mazagran areas

2- Moderate risk of pollution: Ain Sidi Cherif, Ain Nouissy, Hassi Mameche and Stidia

3- Low risk of pollution: Northern part of the Mostaganem plateau.

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