GIS Application for Groundwater Vulnerability Assessment: Study Case of Hammam-Bou-hadjar Area-NW of Algeria

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Abstract: This study deals with the vulnerability and pollution risk in the Hammam bouhdjar aquifer (Algeria). The plain has been threatened by numerous pollution sources (urbanization, industry, farms, dumps, etc.) which have unfortunately increased in the area, due to a lack of environmental protection measures, especially for water resources. A map of groundwater vulnerability of the zone was carried out according to method (GOD) using GIS processing. The obtained vulnerability map shows three zones of differing vulnerability degrees accordingly to low, medium and high vulnerability which occupy respectively 51, 45 and 3 % of the total area.

1 INTRODUCTION

The socioeconomic development of a region predominantly depends on the availability of good quality water .The evaluation of vulnerability is a mean to gather complex hydrogeological data in a way that can be used by non-specialist people such as decision-makers (Hosseini M et al., 2018).The development and sustainable management of groundwater resources requires the application of modern techniques.In recent years, vulnerability assessment of groundwater aquifers considered as an essential part for putting suitable plans to protect groundwater aquifers around the world (Al-Abadi A.M et al., 2014). An integrated approach is implemented due to the new geo-spatialization techniques and the geographical information system (GIS).

In the current context of the sustainable management of water resources, the prediction of the risk of pollution and the protection of these resources are of paramount importance. For this, the medium and long-term safeguarding of the quality of these resources is necessary. This protection can be done, first by delimiting the areas likely to be affected by pollution (Amharref M et al., 2007). Groundwater reservoirs are easily affected by pollution. The process is slow but its effects are very dreadful (Baghvand et al., 2010).

In agricultural areas, in particular, an excessive use of fertilizers has directly or indirectly affected the groundwater quality (Huang et al., 2012). But beyond the quantitative aspect, it is also advisable to remain vigilant on the level of the water quality consumed by the populations (Diodato et al., 2013). However, the prevention against groundwater pollution constitutes an important phase to which scientists are doing their best notably in studying the vulnerability of the groundwater. They therefore, created classical scientific methods (Etienne et al., 2009)

2 THE STUDY AREA

In this study we focus on the Hammam-Bou-hadjar aquifer which is situated between Latitudes 35.23° to 35.46° N and Longitudes 0.85° to 1.09° E in the southwestern part of the Oran watershed Basin, located in the Northern West of Algeria (Figure 1).

The area is generally gently sloping low-lying and is characterized by dry and wet climatic seasons which spans from April to October and wet season between November and March. Occasional rainfalls are often witnessed within the dry season due to its proximity to the Mediterranean Sea. Rainfall forms the major source of groundwater recharge in the area; mean annual rainfall is greater than 200 mm. The mean monthly temperature ranges from 36°C in July to 20°C in February. Because of its proximity to the coast, the area is under the influx of sea salt and aerosols sprayed from the Mediterranean Sea; this can potentially increase the salinity of the subsoil.

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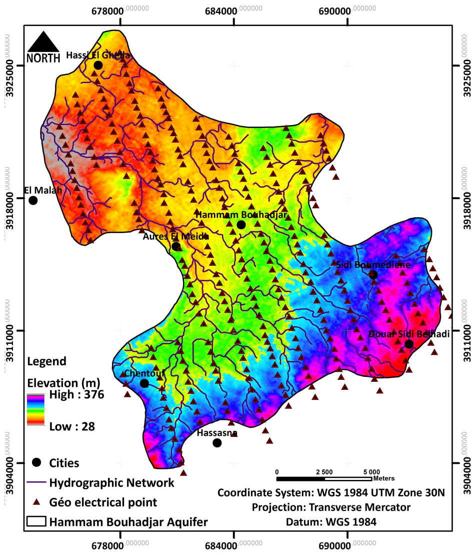

Figure 1: Localization of Hammam-Bou-hadjar aquifer.

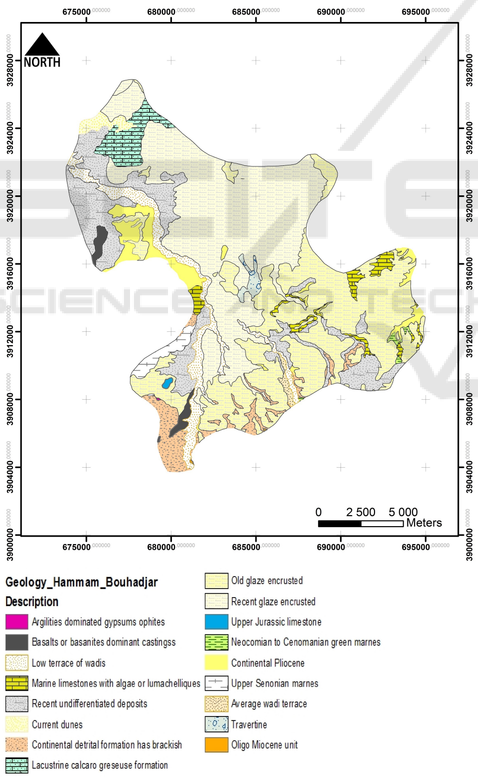

Figure 2: The Study area geological map.

3 MATERIALS AND METHODS

In this work, the GOD method was chosen based on the encouraging results obtained in previous project carried out in our department. to assess the vulnerability of groundwater to pollution (Knouz N et al, 2017) This system was developed by Foster in 1987, it is illustrated by Figure 2 which presents the vulnerability of the aquifer to the vertical percolation of pollutants through the unsaturated zone and does not deal with the lateral migration of pollutants in the saturated zone.

Table 1: Attribution of notes for GOD model parameters.

G (Groundwater occurrence)	
Characteristic's	Note
None aquifer	0
Artesian	0.1
Confined	0.2
Semi-confined	0.3
Free with cover	0.4-0.6
Free with cover	0.7-1
O (Overall lithology of aquifer)	
Characteristic's	Note
Residual soil	0.4
Limon alluvial, loess, shale, fine limestone	0.5
Acolian sand, siltite, tuf, igneous, rock	0.6
Sand and gravel, sandstoe, tufa	0.7
Gravel	0.8
Limestone	0.9
Fracture or karstic limestone	1
D (Depth to water table)	
Characteristic's	Note
< 2	1
2-5	0.9
5-10	0.8
10-20	0.7
20-50	0.6
50-100	0.5
> 100	0.4

This method is based on the identification of three criteria:

- Groundwater type.
- Type of aquifer in terms of lithological factors (Overall aquifer class);
- Depth to groundwater table.

The necessary elements for the groundwater protection scheme and for the classification of aquifer vulnerability are, according to this method; the soil type, the geological formations of the unsaturated zone and the depth of the aquifer.
The vulnerability index (I) is obtained according to the following equation:

$$I = Ca * Cl * Cd \tag{1}$$

Of which: Ca: Aquifer type rating, CI: Lithology rating and finally Cd: Depth of the water table.
The vulnerability increases with the index and the classification is made in five categories, ranging from

0 to 1. According to the table 1, the range of possible values varies minimum vulnerability (0 values) to maximum vulnerability (1 value).

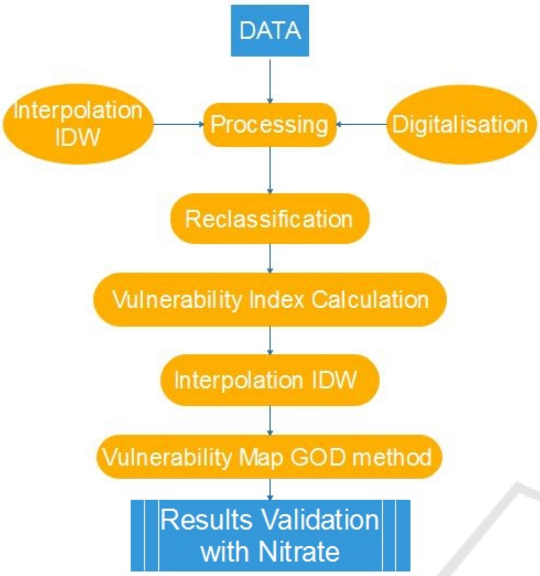

Figure 3: Procedure for developing the vulnerability map using the GOD method.

4 RESULTS AND DISCUSSION

4.1 Groundwater Occurrence (G)

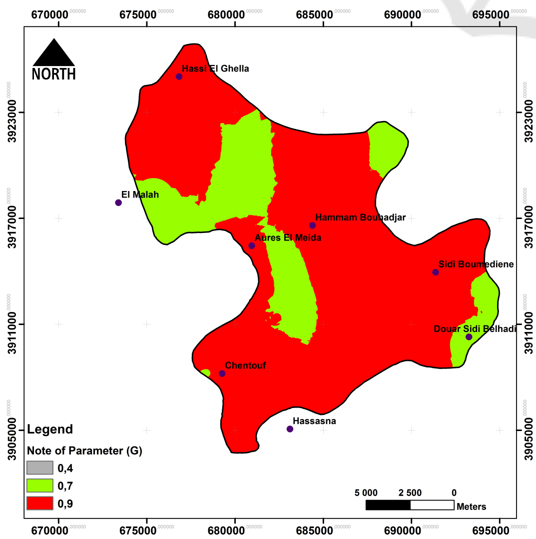

Figure 4: Groundwater occurrence map (parameter G).

The map of aquifer type was developed by interpreting using Inverse Distance Weighting IDW between 298 geoelectrics test of boreholes in the study area.

Figure 4 shows different class according to the degree of confinement, a reclassification by rate gave us the map of the parameter groundwater occurrence.

Generally, the study area is characterized by two types of groundwater occurrence, Aquifer with fairly permeable cover specifically in the Eastern zone and unconfined aquifer in the West of El Malah and the SW of Hammam-Bou-hadjar.

4.2 Overall Lithology of Aquifer (O)

Using the results of geoelectric's tests the lithology for each point was classified and the rate was attributed, the map was created after interpolation.

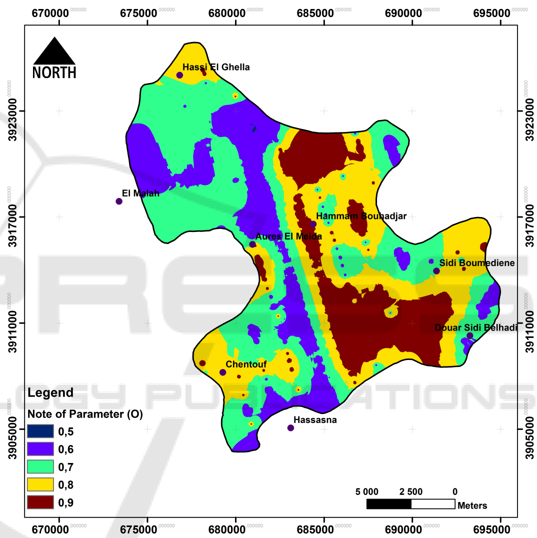

Figure 5: Overall lithology of aquifer map (parameter O).

According to the map, the study area is characterized by several type of lithology, the map obtained from the digitization of the geological map 1/50000 of the study area and a conversion to raster mode (Enabling the reclassification according to the rating system of the GOD method).

After reclassification, the map obtained (Figure 5) shows that the study area contains different classes of lithology, in the West side of Hammam-Bou-hadjar the majority of soils are alluvial composed by clay and silt, in the West of Douar Sidi Belhadi and the North of Hammam-Bou-hadjar the limestone soil was characterized.

4.3 Depth to Water Table (D)

Figure 6 shows the map of the depth to the water table parameter, which was established from the interpolation of the piezometric measurements using the IDW method.

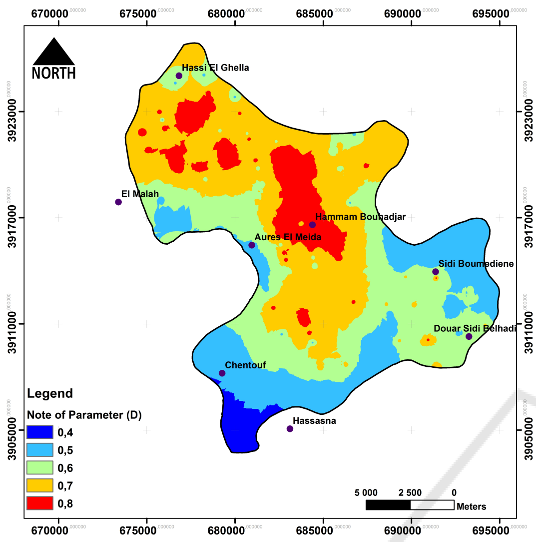

Figure 6: Depth to water table (parameter D).

After the interpolation of the water levels of the water table, a reclassification of each pixel was then carried out according to the rating system of the GOD method (Knouz N et al, 2017) The depth of the water table decreases gradually from the SW and Est to the north exactly in Hammam-Bou-hadjar area characterized by the lower depth between 2 and 5 meters.

5 THE VULNERABILITY MAP

The vulnerability map using (GOD) method has been established after calculation the GOD index using equation (1). The values of this index range from 0 to 0.7. They are reclassified according to the classification system of the GOD method shown in Table 2 below:

Table 2: Classes of GOD Vulnerability Index.

Vulnerability Index	Class of vulnerability
0	No vulnerability
0-0.1	Negligible
0.1-0.3	Low
0.3-0.5	Medium
0.5-0.7	High
0.7-1	Very High

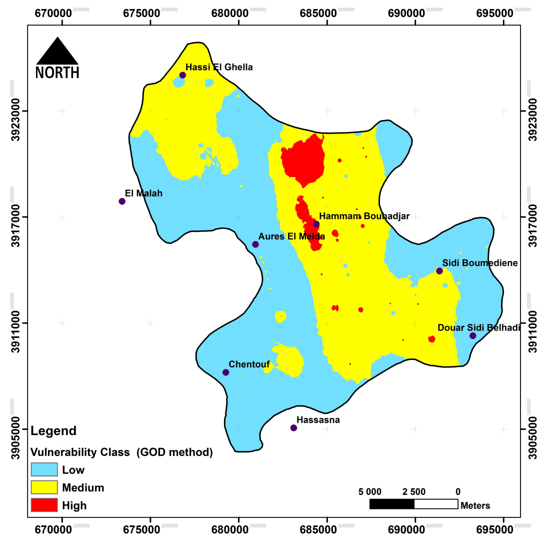

Figure 7: Vulnerability map using GOD method of Hammam-Bou-hadjar zone.

The analysis of figure 7 reveals that low-vulnerability areas account for 51% of the total study area, moderately vulnerable occupy 45.76 %, while high-vulnerability areas occupy 3.2%; the high vulnerability is located exactly in the North and around Hammam-Bou-hadjar city, medium vulnerability is the extension of the high class to the South in the West of Sidi Boumediene and Douar Sidi Belhadi.

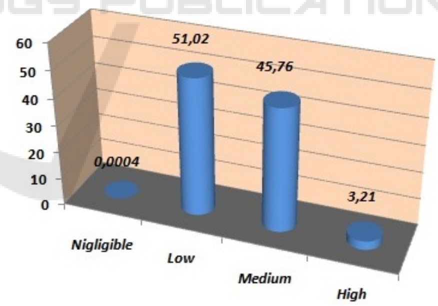

Figure 8: Spatial distribution of vulnerability class in percent.

6 RESULT VALIDATION

Nitrate is one of the most common indicators of human impact on groundwater resources (White P and al., 2013). Nitrate is not naturally present in groundwater over concentration of 5-8 mg L-1 and higher concentrations have obviously been attributed to anthropogenic pollution (Busico G and al., 2019).In the study area, agriculture is the most common activity between the populations; the crops are irrigated and fertilized without monitoring the water quality and fertilizer, specifically nitrogen. For this purpose we have tried to validate the vulnerability map by the GOD method by analyzing the distribution map of nitrates. The spatial analyst of nitrate distribution shows according the map (Figure 9) that the area around Hammam-Bou-hadjar is characterized by high concentration of nitrate, in the North very high concentration are observed in Hassi El Ghella, the same case in the SE in Sidi Boumediene zone.

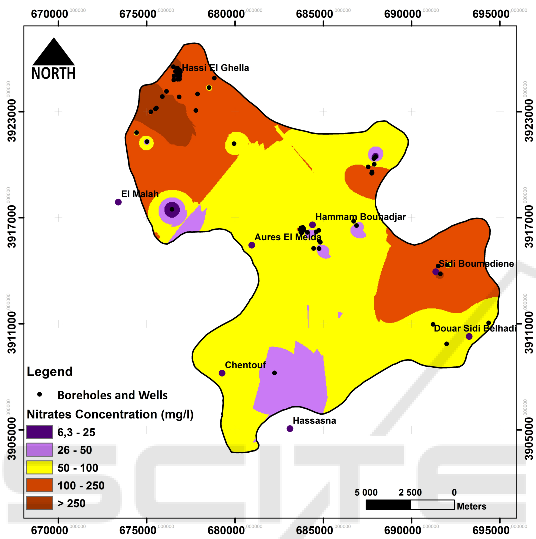

Figure 9: Spatial distribution of nitrate concentration.

7 CONCLUSION

Vulnerability-study results of Hammam-Bou-hadjar aquifer using GOD method show that the vulnerability degree increases from South to the North and N-E due to composition of unsaturated zone, 49% of area is exposed to a medium to high vulnerability. Lithological composition and type of aquifer make Hammam-Bou-hadjar zone exposed to groundwater pollution. intensive anthropogenic activity like uncontrolled fertilization accelerate the groundwater pollution. The protection of groundwater reservoir is a priority to conserve the quality of water, this objective can be achieved by the protection of groundwater's perimeters, monitoring of fertilization process in agriculture and installing an evacuation plan of waste water.

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