

## **GROUNDWATER VULNERABILITY AND RISK MAPPING FOR THE PHREATIC AQUIFER IN THE OUARGLA OASIS OF ALGERIAN SAHARA USING GIS AND GOD METHOD**

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### **ABSTRACT**

The issue to preserve water resources threatened by many natural and anthropological factors guide us in this study to deal with the vulnerability and groundwater pollution risks in the oasis of Ouargla. The numerous homes of pollution (urbanization, agriculture, dumps...etc.) that took out of proportion outside any attempts to protect the environment and water resources which are exposed to a potential risk of contamination, and they are particularly threatened by insufficient recharge volumes (extreme aridity, permanent drought). A preliminary assessment of vulnerability to groundwater contamination in phreatic aquifer was undertaken. Information on the hydraulic confinement, overlying strata in terms of their lithological character and depth to groundwater table (or to groundwater strike in confined aquifers) that affect and control groundwater contamination were incorporated into the GOD model, to produce groundwater vulnerability maps. Geographical Information System (GIS) was used for indexing and overlaying the different data sources and to create a groundwater vulnerability map. The final vulnerability map indicated that the analysis of the obtained map identified two zones of moderate vulnerability that occupies 31.57 % of the total area, while the zone of high vulnerability occupies 68.43 % of the overall surface. The superposition of different potential sources of pollution on this map has allowed us to highlight areas at risk of contamination to the waters of the aquifer.

**KEYWORDS:** Aquifer Vulnerability, GIS, Pollution Risk, GOD, Algeria

### **INTRODUCTION**

Contamination of groundwater has become a major concern in recent years. Since testing of water quality of all domestic and irrigation wells within large watersheds is not economically feasible, one frequently used monitoring strategy is to develop contamination potential maps of groundwater, and then prioritize those wells located in the potentially highly contaminated areas for testing of contaminants. Groundwater vulnerability assessment is done on the idea that the aquifer is not of same features at all the locations and that some specific land area are more vulnerable to deterioration in terms of quality and quantity (Saidi et al., 2011; Abdalla, 2012). The aquifer vulnerability is of two types. The first is intrinsic vulnerability which is due to the geology of the aquifer like clay layer thickness, overlying media... etc (Vierhuff, 1981; Evans et Mayers, 1990; Chrysochoou et al., 2012). And second one is, "specific" or "integrated" vulnerability, which is obtained for a specific contaminant (Fobe and Goossens, 1990; Ozdemir, 2011) or some integrated sources combined with the integrated vulnerability (Vrba and Zoporozec, 1994; Oh et al., 2011). The city of Ouargla, installed in the palm grove of a desert area, has recently experienced significant population growth and important agricultural expansion, which

generated an irrational mobilization of groundwater which proves detrimental to an environmental ready plagued by untreated abundant discharges which contributed to make the oasis a perfect place of the accumulation and stagnant waters (Slimani, 2006). However, under the influence of climatic conditions and a shallow groundwater at shallow depth, the natural environment is changing rapidly to excessive salinity conditions, so the region of Ouargla depicts an ecosystem context particularly fragile where the water resources management must be carried out with a maximum care (Hamdi-Aïssa et al., 2004; Slimani, 2006; Idder, 1998). The study carried out here, aims to locate on a map vulnerable areas of phreatic aquifer by applying the GOD method coupled with GIS, and to take inventory of the causes of potential or real pollutions from anthropic or natural origin. This tool allows decision makers to solve the problems of degradation of water quality, and can be considered as an excellent support for locating all kinds of human activities taking into account the risk of groundwater contamination.

**MATERIALS AND METHODS**

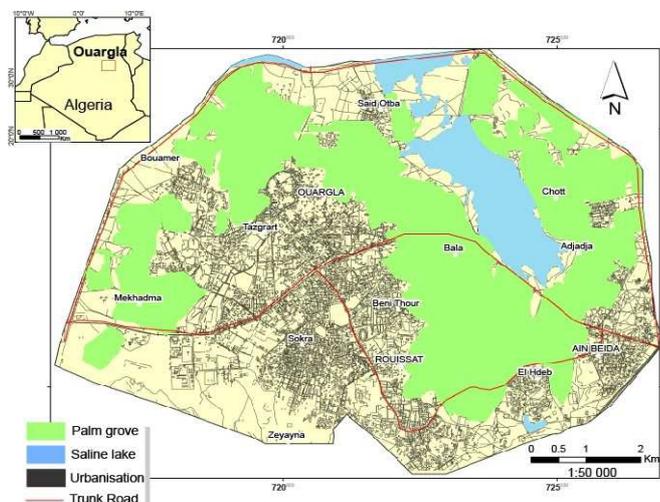
**Study Area**

The study area is located in the south-east of Algeria at a distance of 800 Km from the capital, it occupies an area of 163.2 Km<sup>2</sup> (Figure 1) whose administrative boundaries are: in the north the wilaya of El Oued and djelfa, in the south the wilaya of Tamanrasset and Illizi, in the east the wilaya of El Oued and the algero-tunisian border and in the west the wilaya of Ghardaia.

The climate of Ouargla is particularly contrasted despite the relatively northern latitude. The aridity is expressed not only by high temperatures 22.5 °C and low rainfall 43.6 mm/yr, but especially by a very intense evaporation 2,138 mm/yr reinforced by hot winds (Dubief, 1963; Le Houérou, 2009; ONM, 2013).

Geologically Ouargla’s region consist of sedimentary formations. The basin is carved into Miopliocene deposits which alternate with red sands, clays and sometimes marls; gypsum is not abundant and dated from Pontian (Cornet and Gouscov, 1952; Dubief, 1953; Ould Baba Sy and Besbes, 2006). The continental Pliocene constitutes the back bone’s regs under the form of a local limestone crust with poudingue or lacustrine limestone.

The Quaternary is lithologically composed of alternating layers of permeable sand and relatively impermeable marl (Aumassip et al., 1972; Chellat et al., 2014).



**Figure 1: Location of Study Area**

The Hydrography of Ouargla is characterized by its endorheism (Dubief, 1953). Watersheds of Oued Mya, Oued Mzab and Oued N’sa form the hydrographic system which led to Sebkhata Safioune, in the north of the region. In the subsoil of the valley, there are three great aquifers which are from bottom to top (OSS, 2008):

- Continental Intercalaire (CI) also said Albian aquifer which is strongly artesian and located at 1100 - 1200 m depth;
- Complex Terminal (CT) aquifer consisting of three different aquifers which are from top to bottom Miopliocene, Senonian and Turonian;
- The phreatic aquifer, his level which is often close to the surface, is generally between 1 and 2 m, but can exceed 18 m in the south of Ouargla or under reliefs.

**Intrinsic Vulnerability Mapping**

One of the most commonly used methods for evaluating aquifer vulnerability to pollution is the grid-cell based overlay and index model called GOD (Foster, 1987; Mimi et Assi 2009). The three parameters of GOD model were weighted to evaluate the intrinsic vulnerability index (Betts et al., 2014; Güler et al., 2013). Map label units were assigned according to the common geological and hydro-geological characteristics. The index is calculated by multiplying the coefficients of the three parameters:

$$IGOD = C_i * C_p * C_a$$

C<sub>i</sub>: coefficient of the type of aquifer (Groundwater occurrence);

C<sub>p</sub>: coefficient of the groundwater depth (Depth to groundwater table);

C<sub>a</sub>: coefficient of the lithology of aquifer (Overall aquifer class).

In the evaluation of GOD vulnerability, each composing parameter is assigned a value between 0 and 1, where 0 represents minimum vulnerability and 1 represents maximum vulnerability. For example, G parameter will approach 1 if the aquifer is unconfined and will decrease towards 0 if aquifer confinement increases. Parameter O will be low when the unsaturated zones composed of impermeable or consolidated materials (e.g. clays, relatively fresh granites) and high when that horizon is made of permeable or loose sediments (e.g. clean sands, gravels). Finally, D parameter will increase as the depth to groundwater level decreases (Foster et Hirata, 1991). GOD vulnerability is the product of composing parameters, the classification of which is in keeping with Table 1.

**Table 1: Vulnerability Classes of GOD Method**

GOD Index	Vulnerability Class
0 - 0.1	Insignificant
0.1 - 0.3	Low
0.3 - 0.5	Moderate
0.5 - 0.7	High

The methodology used in this paper consists of two major stages: (1) data acquisition/processing and integration into a GIS database for derivation of thematic map layers used in the GOD model; and (2) creation of GOD vulnerability maps;

### Acquisition of Field Data

Sampling must also fit in with the mapping needs vulnerability (Lithology, depth and type of the water) and thus increase its density in some rich areas in observation and/or likely to be vulnerable. Data acquisition was done from direct observation. Some are descriptive, comprehensive and others are directly related to the indexing criteria. Water levels since 2013 to 2014 from 86 piezometers were considered. To indexing spatial information a variety of GIS analysis and geo-processing framework has been applied using ArcGIS 9.2 software. This work can be greatly eased by using a GIS for overlaying the different data sources. GIS allows spatial data gathering, at the same time, gives a means for data processing such as georeferencing, digitizing and spatial analysis.

### The GOD Method Index

The vulnerability of water depends on the type of the aquifer (free or captive), and the mode of circulation of water in the aquifer. Groundwater in the study area is free type. The absence of impermeable horizon between the surface and the roof of a water table makes it more vulnerable than confined aquifer protected by impermeable formations character (Bézèlgues et al., 2002).

### Lithology and Permeability of the Aquifer

The movement and the spread of a pollutant in the saturated zone depend on the texture and lithology distribution layers of the aquifer (Banton, 1997; Castany, 1998; Ozdemir, 2011; Chenini et al., 2015). This one is obtained by correlation and interpolation of borehole and piezometers data. In high topographic situation, alluvial soils located above 130 m present in surface or in depth crusting gypsum characteristic, in patches that may exceed 1 m thick. Below 130 m, alluvial soils present different characteristics: they are lands of chott on aerial for their dark color (Hamdi-Aïssa et Girard, 2000). Their structure is also lumpy but their texture is sandy clay with a large amount of clays (Figure 2). The groundwater flows through the sand dunes of Oued Mya.

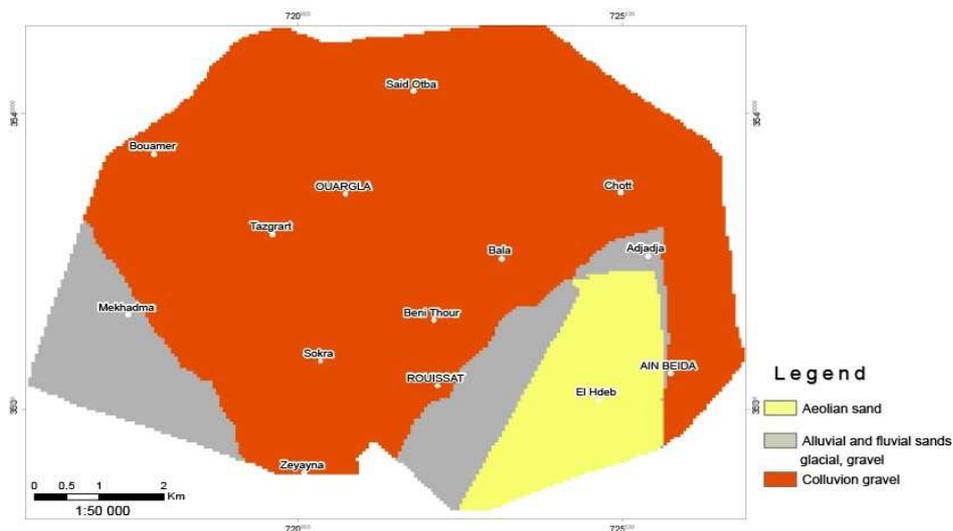


Figure 2: Lithology Map of the Groundwater in Ouargla

### Depth to Water

The depth of water is defined as the distance in which the pollutants move through the soil media before reaching the groundwater table (Edwards, 1996; Saidi et al., 2009; Fay, 2011). Depth of groundwater data are collected from

boreholes log stratigraphic, direct measurement of water level of existing shallow boreholes and drilling wells from ground surface. The observation of the depth map shows that the water level of the aquifer does not regionally exceed 10 m. Three class intervals depth of the water are recorded (Figure 3): the first concerns the areas where  $5\text{ m} < P < 10\text{ m}$  located in the northeast of the study area at Chott. The Northwest, the Southwest and the Southeast part are of two classes where  $2\text{ m} < P < 5\text{ m}$  and  $P < 2\text{ m}$ . The lower depths (between 0.15 m and 0.25 m) were measured near the Chott and Oum Er Raneb in the period of high water, in the period of low water, the level drop 6 to 13 cm by capillary rise and evaporation.

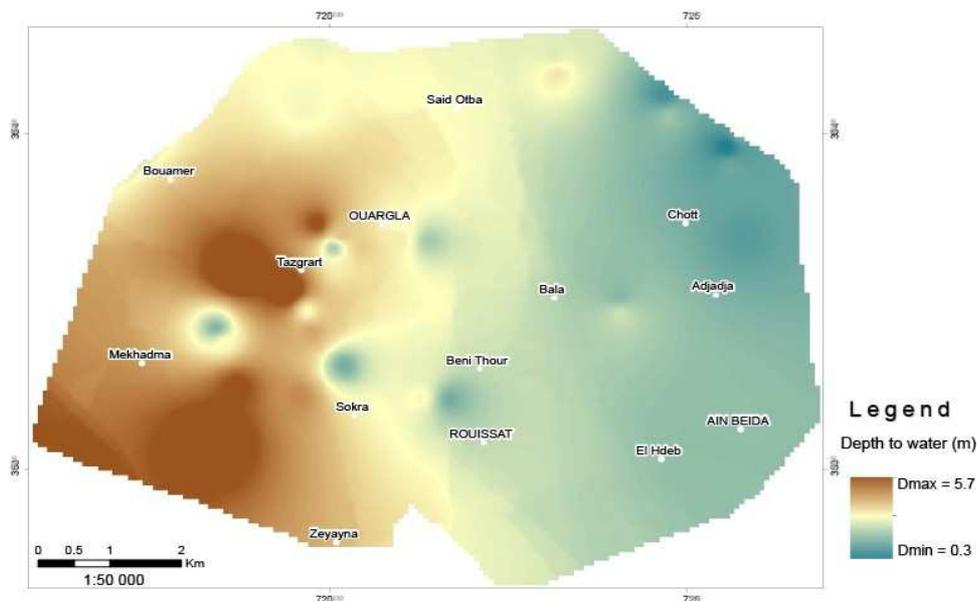


Figure 3: Depth to Groundwater Map (2014)

## RESULTS AND DISCUSSIONS

### Vulnerability Assessment of the Water Table by the Method of GOD

The expanses of moderate and high vulnerability, setting in evidence on the map reflect the degree of vulnerability to which is submitted the groundwater. This vulnerability increases from the south to the northeast, northwest and southeast. The analysis of these expanses reveals two classes of vulnerability (Figure 4):

- **Moderate Class:** It represents 31.57% of the total area, this class meets at southwest of the study area and covers areas such as Zyayna, Mekhadma, Bouamer and Tazgrart. It guarantees a less severe pollution in case of contamination of groundwater from the fact of the depth of the aquifer between 9 and 11 m and the nature of the unsaturated zone consisting of medium sand clay.
- **Strong Class:** It 68.43% of the total area and occupies 3/4 of the study from southeast to cover almost the entire northern area, with the most important proportions to the places called Chott and Adjadia. It is due to the depths of the aquifer between 2 m and 3 m and the nature of the unsaturated zone consists of sand.

### Study of Risk of Pollution of Water

The risk of groundwater pollution resulting from the interaction between the aquifer vulnerability to pollution and anthropogenic activities, such as sources of contamination (Ducci et Sellerino, 2013). To determine the risk areas in the region of Ouargla we superimposed the vulnerability map with the different sources of pollution, represented by the different layers of soil occupation and human activities. The combination of these parameters reveals the degree of risk,

taking into account the degree of vulnerability and the absence or presence of pollutant sources that may affect the quality of groundwater. This combination allows classifying the degree of risk in five classes Table 2.

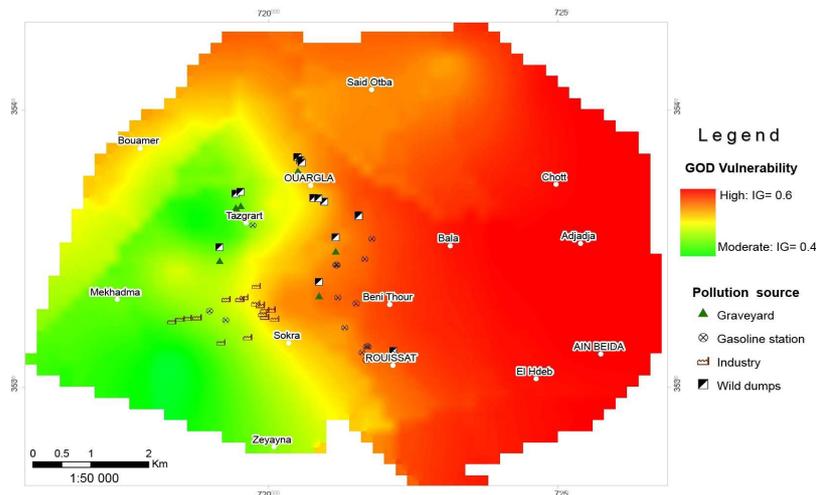
**Table 2: Classification of Degree of Risk (Smida et al., 2012)**

Degree of Vulnerability	Pollution Source	Degree of Risk
Very low	+	Low
Very low	-	Very low
Low	+	Average
Low	-	Very low
Average	+	High
Average	-	Low
High	+	Very high
High	-	Average
Very high	+	Very high
Very high	-	High

**Zone of Very High Risk:** Concerning the center part of the study zone namely the localities of Ouargla, Tazegart, Benitour and Rouissat. The very high degree of risk is explained by the combination of two important namely are latively low depth and high concentration of human activity factors.

**Zone of High Risk:** Which concerns the entire eastern part as Chott and Ain Beida because of the shallow depth of the aquifer and the absence of human activity; note also the same degree of risk to communities like Tazegart and Sokra which are present in the western part of the study area in fact of the density of human activity.

**Zone of Medium Risk:** It covers the southwest of the study zone as the localities of Mekhadma and Zyayna because of a depth rather important of the aquifer and lack of human activity.



**Figure 4: Aquifer Vulnerability Map Based on GOD Method**

## CONCLUSIONS

A rating system method was applied for groundwater vulnerability to pollution in phréatique aquifer of Ouargla region. The vulnerability mapping reveals two areas of vulnerability moderate and strong , a risk map is obtained by the superposition of different sources of pollution which helped to highlight three areas at risk of contamination to the waters of the groundwater by the combination of two key factors, such the depth of the water and the density of human activity, namely an area of high risk which affects the center of the study area, a high-risk area which covers eastern and western part, and an area of medium risk which affects communities southwest. Applying GOD method showed that the relatively simple methods could provide similar results to the complex ones. It could be confirmed that this method are best suited for designing large areas (used in land management). The GIS technique has provided an efficient environment for analyses and high capabilities in handling a large quantity of spatial data. GOD indexes were easily computed in GIS environment.

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