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APPLICATION OF THE METHOD GALDIT FOR THE CARTOGRAPHY OF GROUNDWATERS VULNERABILITY: AQUIFER OF CHAOUIA COAST (MOROCCO)

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Abstract

This study focuses on the application of the new method, GALDIT, for the cartography of aquifer vulnerability due to seawater intrusion in the area of Chaouia coast (Morocco) which is characterized by intense agricultural activity and low depth of the groundwater. The method was developed by Chachadi and Lobo-Ferreira in 2001 after that modified in 2005 and is specific for coastal aquifers. The computing of the GALDIT index (GI) is based on six parameters: Groundwater occurrence (aquifer type); Aquifer hydraulic conductivity; Depth to groundwater level above the sea; Distance from the shore (distance inland perpendicular from shoreline); Impact of existing status of seawater intrusion in the area; and Thickness of the aquifer. This GALDIT is the indicator scores and summing them and dividing by the total weight for determining the relative role of each one. The results of this study show a vulnerability of the aquifer to the seawater intrusion with a high risk in the fringe littoral areas and areas in proximity to the estuary of Oum Er-Rbia River and can reach 3 km towards land.

Keywords: aquifer of Chaouia coast, seawater intrusion, GALDIT index, aquifer vulnerability mapping

I. INTRODUCTION

Environmental preservation of the coastal regions constitutes a socio-economic element of major importance for both the present and the future. These areas have been weakened because of various pressures exerted including over exploitation of groundwater for agricultural purposes and intensive domestic use of soil and fertilizer. This resulted in a decline of resources such as soil and groundwater resources and in their quality and also in the increase of their vulnerability to different impact factors.

Generally, the term of vulnerability refers to the potential degree of damage that can be expected depending on the characteristics of an element at risk with respect to a certain hazard (Varnes, 1984). Relating to groundwater, the vulnerability is defined by Lobo-Ferreira and Cabral (1991) as "the sensitivity of groundwater quality to an imposed contaminant load, which is determined by the intrinsic characteristics of the aquifer". Thus, the vulnerability of groundwater to different pollutants or to seawater intrusion constitutes a subject of analysis in several studies (Chachadi et al., 2002; Cardona et al., 2004; Lobo-Ferreira et al., 2005). Also, the vulnerability of soil to salinization is demonstrated in many studies (George et al., 1997; Kotb et al., 2000; de Paz et al., 2004; Zhang et al., 2011). The main purpose of this study is to determine the vulnerability of the groundwater in the southwestern part of the Chaouia coast (Morocco) against seawater intrusion in relation to the current sea level.

II. STUDY AREA

The study area is located in the northwest of Morocco, between longitudes 8°20’ W - 8°8’ W and latitudes 33°25’ N - 33°16’ N, in the downstream part of the plain of Chaouia (Fig. 1).

This area is a coastline bordered to the northwest by the Atlantic Ocean, south west of the Oum Er-Rbia River and east of the plain of Berrechid. The climate is arid to semi-arid (Bentayeb, 1972) summer with rare and strong precipitation, evaporation and cold winter.

In the southwestern end of the study area near Azemmour and Oum Er-Rbia, the Plio-Quaternary formations rest on the limestone of the Cenomanian (Cretaceous). In the rest, the study area is based on Plio-Quaternary formations that constitute the primary foundation of a pervasive thin film thickness of 5 to 30 m (DRPE, 1994) of Early and Late Quaternary (marine sandstones and dunes consolidated). The bedrock is formed by Paleozoic completely impermeable or of low permeability in the upper fringe. The predominant primary formations are

schists and quartzites to whom are associated sandstones. All of these sites are attributed to the Cambrian and Ordovician (Fig. 1). The aquifer contains a free groundwater which runs out towards the Atlantic Ocean and the Oum Er-Rbia River, crossing three geological formations.

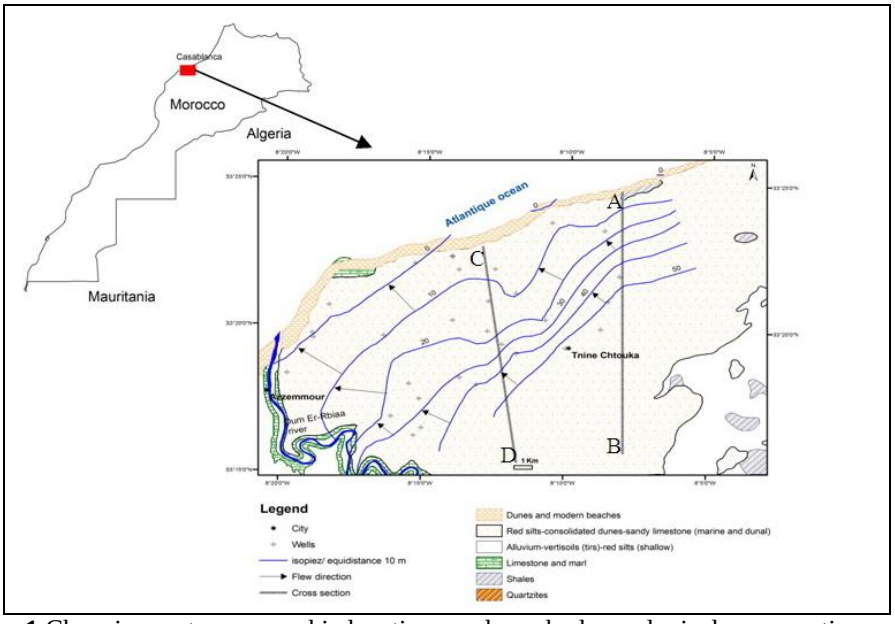

Fig. 1 Chaouia coast – geographic location, geology, hydrogeological cross sections and water sampling locations

Two hydrogeologic cross sections (Fig. 2) according to mechanical drillings were built. Generally the groundwater crosses the grounds Plio-Quaternary in the littoral fringe, Cenomanian in the western south between Tnine Chtouka and Azemmour and the Paleozoic faded schists. These schists are generally impermeable, only close to surface the existence of a faded part allows water circulations whose importance depends on the degree of deterioration; this deterioration does not exceed 40 to 50 m (Amraoui, 1988). The whole of these three aquifers levels is in hydraulic and side communication (Moustadraf, 2006).

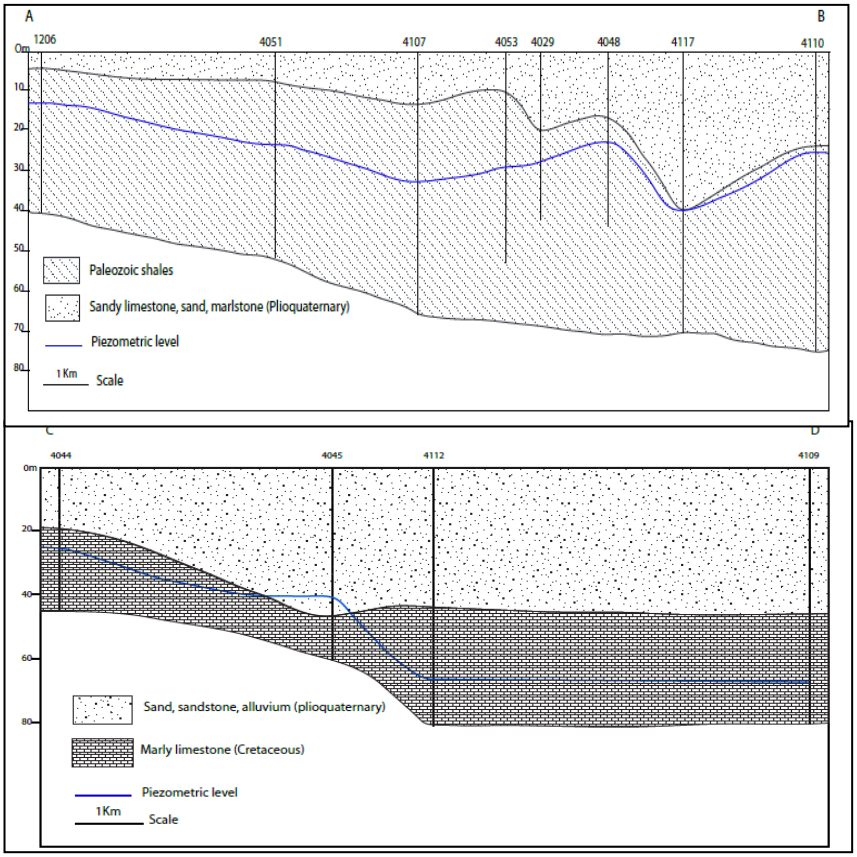

Fig. 2 Hydrogeological cross sections (A-B) and (C-D)

III. METHODOLOGY

In this study we carry out the application of the GALDIT method to aquifer SW of Chaouia coast; it acts as a specific method to characterize the vulnerability of the coastal aquifers, based on six parameters presented below (Table no. 1).

The parameters of the intrusion of sea water were described by Chachadi and Lobo-Ferreira in 2001. Each of GALDIT indicators is evaluated by respecting the other; this with an aim of determining the relative role of each parameter.

Several studies have applied successfully this method. Among these may be mentioned the studies on Portugal coast - Monte Gordo aquifer (Chachadi and Lobo-Ferreira, 2001; Lobo Ferreira et al., 2005), North Goa coast -Bardiz aquifer (Chachadi et al., 2002; Chachadi, 2005), Morocco coast - Tétouan aquifer (Niazi,

2007), Greece coast - SW Rhodope aquifer (Kallioras et al., 2011), Indian coast - Netravathi basin (Shetkar and Mahesha, 2011).

Table 1. Parameters of GALDIT

Parameters	Weight	Rating			
		Very low	Low	Medium	High
		2.5	5	7.5	10
G : Groundwater occurrence (aquifer type)	1	Bounded aquifer	Leaky confined aquifer	Unconfined aquifer	Confined aquifer
A : Aquifer hydraulic conductivity (m/day)	3	<5	5 - 10	10 - 40	>40
L : Height of groundwater level above sea level (m)	4	>2	1.5 - 2	1- 1.5	<1
D : Distance from the shore (m)	4	>1000	1000-750	750 -500	<500
I : Impact of existing status of seawater intrusion	1	<1	1-1.5	1.5 - 2	>2
T : Thickness of aquifer being mapped (m)	2	<5	5 – 7.5	7.5 - 10	>10

Computing the individual indicator scores and summing them and dividing by the total weight as per the following expression gives the GALDIT Index (Chachadi, 2005):

$$GI = \sum_{i=1}^{6} \{W_i/R_i\}/\sum_{i=1}^{6} W_i$$

The minimum and maximum GALDIT Index varies between 2.5 and 10, and obviously the highest value indicates a greater vulnerability to the seawater intrusion (Table no. 2).

Table 2. GALDIT vulnerability classes (Chachadi, 2005)

Series number	GALDIT Index Range	Vulnerability classes
1	> 7.5	High vulnerability
2	5 to 7.5	Moderate vulnerability
3	< 5	Low vulnerability

IV. RESULTS AND DISCUSSIONS

Groundwater occurrence (aquifer type)

The parameter G (aquifer type) affects the degree of advancement of the marine water into the groundwater. For example, an unconfined aquifer, in natural conditions, is more affected by marine water intrusion than a confined one. It is underneath an aquitard and its pressure is higher than the atmospheric pressure. In the study area, the aquifer is unconfined (Bentayeb, 1972; Marjoua, 1995) and corresponds to class 7.5.

Aquifer hydraulic conductivity

Hydraulic conductivity or the permeability is the aptitude of a soil or rock to let itself cross by water under the effect of a hydraulic gradient (Castany, 1982). A layer of containment is a geological unit of low or very low hydraulic conductivity (< to 10^{-7} m/s) whereas the formations considered as aquifers. It consists of materials whose hydraulic conductivity exceeds 10^{-4} m/s (Lefebre, 2006 in Niazi, 2007). It is based on the data of test of pumping carried out by Bentayeb in 1972 to consider the conductivity hydraulic of the aquifer in the study zone (Fig. 3).

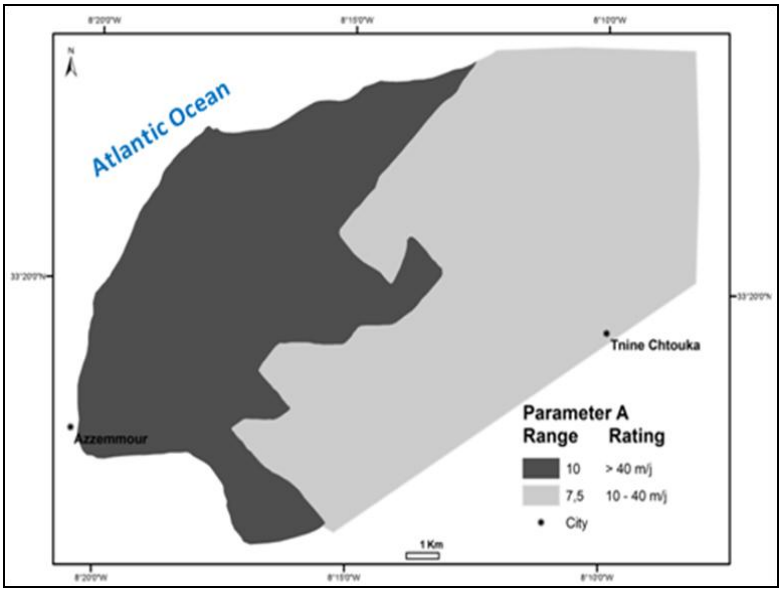

Fig. 3 Representation of A parameter (hydraulic conductivity) in the aquifer of Chaouia coast

Height of groundwater level above sea level

The level of groundwater compared to the average altitude of the sea is a very significant factor in the evaluation of the sea water intrusion in any area. By this it determines the possibility of the water pressure to move back the sea front (Chachadi et al., 2002). In general the minimal values of groundwater level below the sea level remain most significant, because they provide the strongest possible vulnerability to this marine water intrusion. For the altitude of the groundwater of the study zone, we used the data relating to the period of the piezometric January 2012 campaign (Fig. 4).

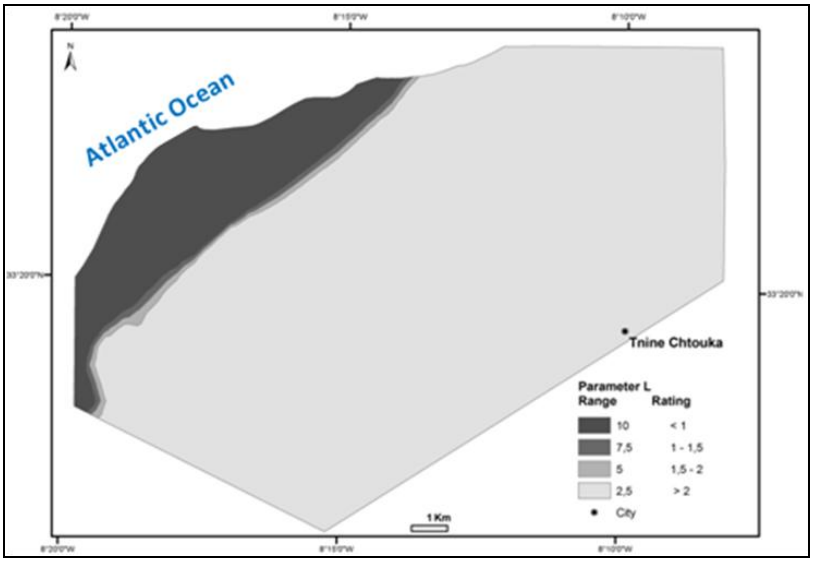

Fig. 4 Representation of L parameter

Distance from the shore

The impact of the intrusion of sea water generally decreases when moving perpendicularly to the shore towards the interior. This parameter was estimated according to three distances (500 m, 750 m and 1000 m) perpendicular to the line of coast and the rivers of the Oum Er-Rbia River. The maximum estimate of 10 is adopted for the distance lower than 500 m of the coast, whereas the minimal one (2.5) is allotted for all those higher than 1000 m. The values of 7.5 and 5 are given, respectively, with the distances from 500 to 750 m and from 750 to 1000 m. The

distribution of the parameter D of GALDIT of the aquifer of Chaouia coast is represented on figure 5.

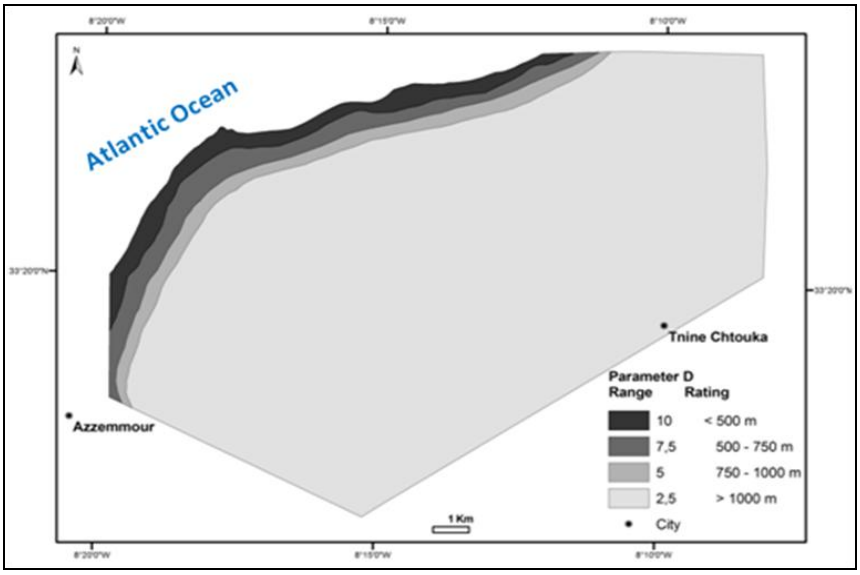

Fig. 5 Representation of D parameter

Impact of existing status of seawater intrusion

The existing imbalance in the seawater - freshwater interface should be considered while mapping the aquifer vulnerability to seawater intrusion (Chachadi, 2005). Chloride is the dominant ion in the seawater and it is only available in small quantities in groundwater while bicarbonate, which is available in large quantities in groundwater, occurs only in very small quantities in seawater. The ratio $Cl^-/ [HCO3^- + CO3^-]$ is a criteria to identify the extent of seawater intrusion into the coastal aquifers (Revelle, 1941) and can be used if the chemical analysis data is available.

The evaluation of this parameter was given starting from an ionic analysis of chromatography at the laboratory of the national research center and sciences and technology (Centre national de recherche scientifique et technique, CNRST) in Morocco in January 2012. The distribution of this parameter GALDIT is presented in figure 6.

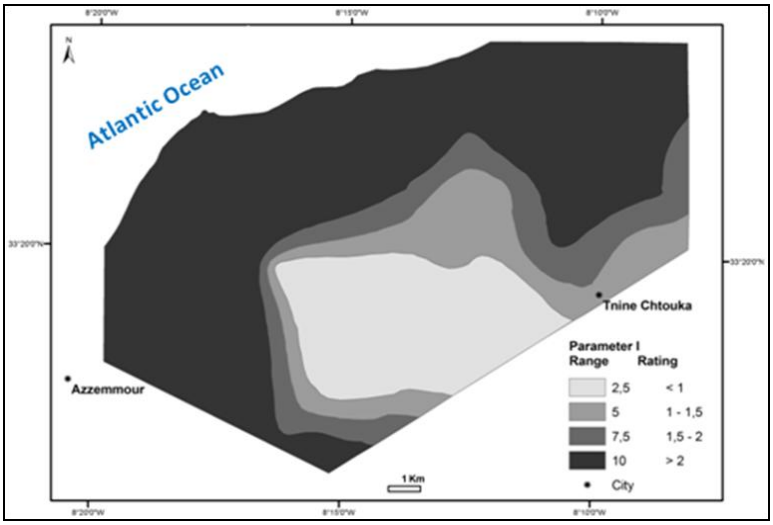

Fig. 6 Representation of I parameter: Impact of existing status of seawater intrusion

Thickness of aquifer being mapped

The analysis of the profiles of piezometric depression established on ten hydrogeologic cross sections using the results of the electric drillings (Bentayeb, 1972), shows that the thickness saturated within the grounds Plio-Quaternary is 10 m and 20 m in the coastal band. The thickness of the ground water is higher than 10 m and corresponds to class 10.

Computing the GALDIT index

The calculation of GALDIT Index and the superposition of the various layers of the parameters in a Geographical Information System (GIS) make it possible to identify the significant and susceptible areas that could be affected by a seawater intrusion. The map derived for this study area is shown in figure 7.

From the figure it is evident that the fringe littoral areas and areas in proximity to the estuary of Oum Er-Rbia River are highly vulnerable to seawater intrusion. This high vulnerability is explained by the high salinity obtained in January 2012 groundwater in the study area because groundwater overexploitation for irrigation.

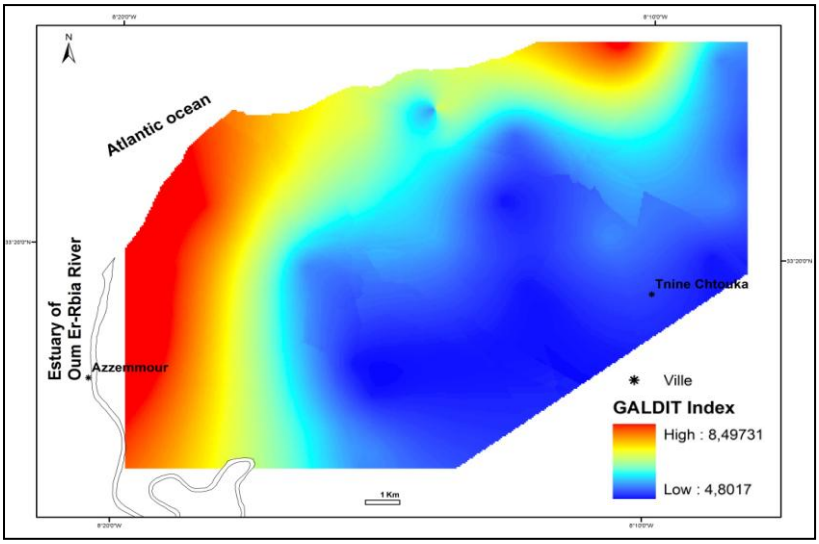

Fig. 7 Seawater intrusion vulnerability map for southwestern Chaouia coast

V. CONCLUSION

The groundwater of coastal Chaouia is an aquifer system formed by Plio-Quaternary sandy limestones in the littoral fringe, Cretaceous marly-limestones in the SW and Paleozoic schists in the remainder of the zone. These three aquiferous formations are in vertical communication.

The application of GALDIT method to the SW of the groundwater of Chaouia coast made it possible to evaluate the impact of the increase of salted level. The groundwater is characterized by a low vulnerability in upstream and a high vulnerability in downstream with a strong contamination of the marine intrusion in the coast zone and in proximity of Oum Er-Ribia River. According to GALDIT method the aquifer is highly vulnerable up to 3 km towards the interior in almost the entire coastal area taken into consideration.

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