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Evaluation of groundwater vulnerability to seawater intrusion using Galdit method in coastal aquifer: case study (Collo, Northern-East Algeria)

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ABSTRACT-Groundwater within coastal aquifers is considered a very sensitive natural resource since its quantity and quality is threatened by anthropogenic activities as well as climate changes. The main purpose of this study is to use GIS technique to identify, quantify and assess the aquifer vulnerability to seawater adopting Galdit new approach for the coastal plain aquifer system of Collo situated in the Northern-East of Algeria. An influential thematic map such as groundwater occurrence (aquifer type), aquifer conductivity, depth to groundwater level above the sea, distance from the shore and river, the impact of existing status of seawater intrusion in the area, and thickness of the aquifer, was generated using related weight and important rating. Finally, the result of the study shows the high vulnerability corresponding to the 38.60 %, moderate vulnerability corresponding to 51.13 %, and lower vulnerability corresponding to the 10.25 % of the total area.

I. INTRODUCTION

The widespread scarcity of freshwater resources, their progressive destruction and increasing pollution in many parts of the world, as well as the gradual intrusion of incompatible activities, require integrated planning and management of water resources.The littoral zone is a very sensitive environment. It is subject to various anthropogenic pressures (urban growth, intensive agriculture, industrial and tourism development, sand and gravel extraction) and various natural phenomena (erosion, climate change), causing severe degradation. Intensive use, which is superior to the water recharge capacity, can cause a significant reduction in groundwater levels causing invasions of saline marine waters in coastal aquifers. Since the 1970s, the Collo aquifer is in great demand, which has led to a decrease in the piezometric level in some areas. It was also at this time that the effects of climate change were manifested (decrease in precipitation). These two phenomena are difficult to distinguish and have contributed to the appearance of a salinization of the aquifer. Thereby, assessment of the coastal aquifer vulnerability represents a challenging task. Hence, it is proposed to delineate the areas which are susceptible or vulnerable to contamination by seawater intrusion. It is necessary, beforehand, to know the pre-anthropic state of the saline intrusion in this aquifer. The concept of groundwater vulnerability can be classified in two basic parameters: intrinsic vulnerability and specific vulnerability [2]. Vrba and Zaporozec (1994) [3] defined the intrinsic vulnerability of an aquifer as" the ease with which a contaminant reach and diffuse in groundwater". Vulnerability assessments prioritize areas for further protection and monitoring. Groundwater vulnerability assessment commonly gives a map divided into several areas indicating the different potential magnitude of these areas to be contaminated. Recently, a variety of vulnerability assessment methods has been developed and applied to assess the aquifer vulnerability. The most common ones are the GOD system [4], the AVI rating system [5], the SINTACS method [6], the ISIS method [7], Epik[8], Gladit index method [9], and PI [10]. To this end, the method proposed in this study is the Gladit index model. This model combines important map able factors to assess general seawater intrusion potential for hydrogeological settings. The key contribution of this work includes a comprehensive assessment of seawater intrusion in the study area.

II. STUDY AREA

The study area is geographically located between 6° to 7° eastern longitude and 36° to 37° northern latitude and situated at the northern east of Algeria and is part of the North Constantine sub-watershed (fig.1). The plain of

Collo is part of the sub-watershed of the WadiGuebli which is in a zone with temperate Mediterranean climate,with a very humid winter where precipitations oscillate between 800 and 1000 mm / year and can reach the 2000 mm / year on the massifs. Average annual infiltration is about 30.09 mm, and surface runoff is about 228.91 mm [11].

The geology of the study area is occupied by quaternary terrain [12], constitued by current and recent alluvial deposit: silts, sands, gravels and pebbles [12] (fig.1) and limited at the bottom by a marl layer. The thickness of this aquifer is between 15 and 45 m [12]. The lithology is characterized on a large part of the study area by an average hydraulic conductivity, the highest values trace the beds of rivers and major's part of the coastal zone. The transmissivity was calculated using the pumping test data obtained from General Company of Geophysics (CGG, 1965). Transmissivity values vary between 5.3 10^{-2} and 10^{-2} m²/s.

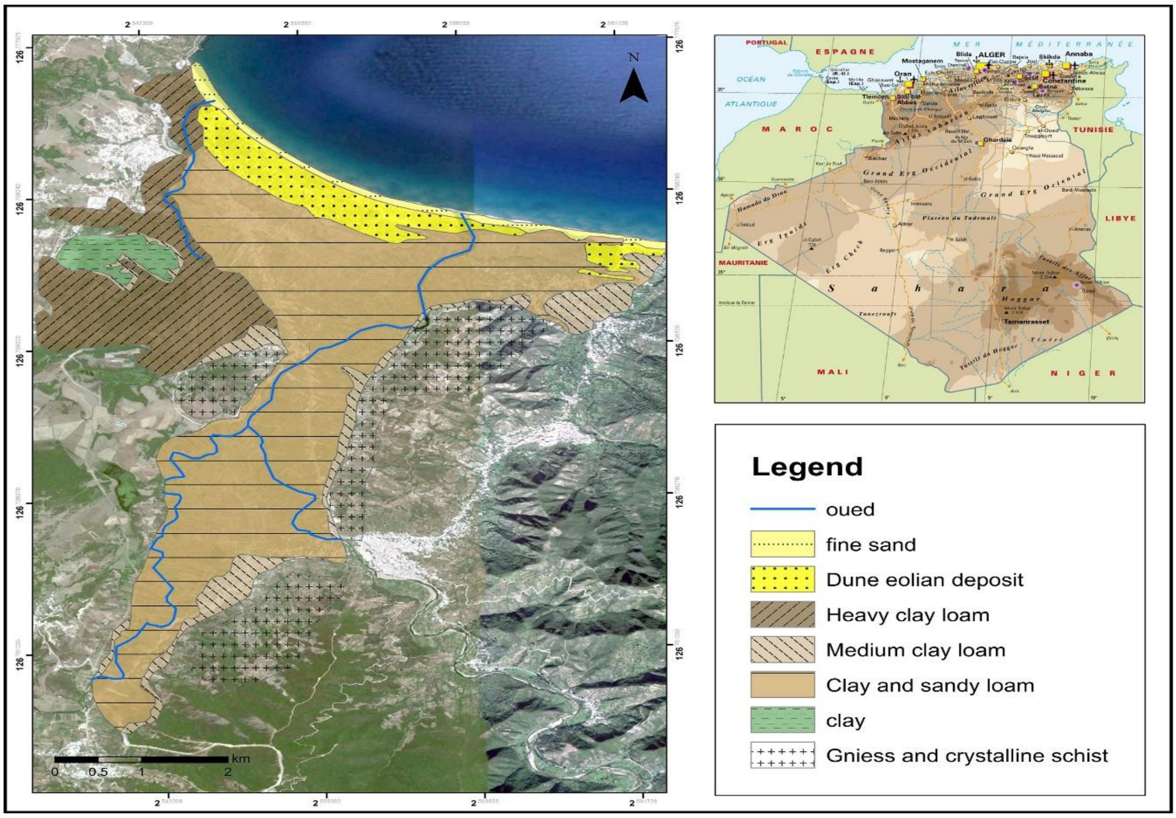

Figure 1: Location Map and Geology of Study area

III. METHODOLOGY

GALDIT is an index method of aquifer vulnerability mapping proposed by Chachadi and Lobo ferreira (2001) to map and identify a potential area of seawater intrusion in coastal areas. This has been derived from based mainly on the intrinsic aquifer properties and hence the time independent measure of aquifer vulnerability of an area to seawater intrusion problems. Because of its simplicity, the GAIDIT method is very useful in areas where specific data are scarce or non-existent.

The maps able factors that control sea water intrusion considered in this method are, groundwater occurrence (aquifer type; unconfined, confined and leaky confined), aquifer hydraulic conductivity, depth to groundwater level, distance from the shore (distance inland perpendicular from shoreline), impact of existing status of sea water intrusion in the area and thickness of aquifer which is being mapped. The acronym GALDITis formed from the highlighted and underlined letters of the parameters given above for easy reference. The GALDIT factors represent measurable parameters for which data are generally available from a variety of sources and necessary fieldwork. The parameters are weighed and rated according to their relative importance as per the procedure of Chachadi and Lobo Ferreira (2001). The weights of parameters according to their relative importance and the range and rating of each parameter are given in Table 1.

1. **Groundwater occurrence (aquifer type) (G)**: In nature groundwater generally occurs in the geological layers and these layers may be confined, unconfined or leaky confined (semi-confined) nature. This

basic nature of groundwater has an influence on the extent of seawater intrusion. The ratings for leaky confined, unconfined and confined aquifers are 5, 7.5 and 10 respectively.

2. **Aquifer hydraulic conductivity (A):** The aquifer hydraulic conductivity is used to measure the rate of flow of water in the aquifer. The rating and range of this parameter are given in Table l.

3. **Depth to groundwater level above sea (L):** The level of groundwater with respect to mean sea level is an important factor in the evaluation of sea water intrusion in an area primarily because it determines the hydraulic pressure availability to push the sea water front back. The range and rating are given in Table1.

4. **Distance from the shore (D):** The impact of seawater intrusion generally decreases as one move inland at right angles to the shore. The rating and range are given in Table 1.

5. **Impact of existing status of seawater intrusion (I):** The area under mapping invariably is under stress and this has already modified the natural hydraulic balance between seawater and freshwater. This fact should be considered while analyzing aquifer vulnerability to seawater intrusion in an area. The rating and impact status are given in Table 1.

6. **Thickness of aquifer being mapped (T):** Aquifer thickness or saturated thickness of an unconfined aquifer plays an important role in determining the extent and magnitude of seawater intrusion in the coastal areas. It is well established that, larger the aquifer thickness smaller the extent of seawater intrusion and vice versa. The range and rating are given in Table 1.

Each of the GALDIT factors has fixed pre-assigned weights, which are represented by Eq. (1). Consequently, the GALDIT index is computed utilizing the estimated values of each GALDIT factor and their corresponding weights following Eq. (1) for each of the sampling well locations.

$$Galdit = (W_1 \times G_R) + (W_2 \times A_R) + (W_3 \times L_R) + (W_4 \times D_R) + (W_5 \times I_R) + (W_6 \times T_R). \quad \text{Eq. (1)}$$

Where W_1 to W_6 are the weights assigned to each hydrogeological factor G_R, A_R, L_R, D_R, I_R and T_R represent the corresponding rating of each of the parameters.

A numerical ranking system was developed to produce the vulnerability map using GIS environment. For each GALDIT index, a thematic map was generated using related weight and importance rating present in table by applying equation (1). The attributed weight for each indicator represents the importance of this indicator respect to the other indicators to assess the seawater intrusion. The Indicator variables, shown in the table, demonstrate the ranges used to classify each indicator. Using the raster reclassify tool in GIS, thematic maps were reclassified based on the importance ratings shown in table 2.

		ıting			
	Weight	2.5		5	0
Groundwater Occurrence	1	Bounded aquifer	Leaky confined aquifer	Unconfined aquifer	Confined aquifer
Aquifer Conductivity (m/day)	3	< 5	5 -10	10-40	>40
Height of the ground water level (m)	4	> 2	1.5 -2	1-1.5	< 1
Distance from the shore (m)	4	>1000	1000-700	700-500	<500
Impact of existing status (mg/l)	1	< 1	1 –1.5	1.5 –2	> 2
Aquifer Thickness	2	< 5	5 –7.5	7.5-10	>10

Table (1) of Galdit parameter weights, rates and ranges (chachadi and laboferriera 2001)

Vulnerability classes	GALDIT Index Range
High vulnerability	>7.5
Moderate vulnerability	5 –7.5
Low vulnerability	<5

Table (2) Classification of the GALDIT Vulnerability index

IV. Results and discussion

The six GALDIT index parameters were employed to determine the seawater vulnerability of the plain of Collo. Firstly, the map of groundwater occurrence or aquifer type (Fig 2.) shows that the Collo is made up of two types of aquifer: the unconfined covering and the confined. The whole alluvial deposit in the north part of the Collo was classified as unconfined. This aquifer type was rated 7.5 because seawater can easily invade unconfined aquifer due to low pressure compared to other types of the aquifer [13]. The confined aquifer of the Collo, mostly the hilly part which constitutes interbedded, clayey and sandy loam, sand, clay loam, black clay, gneiss and granite, with a lesser chance of seawater infiltration as compared to the earlier, therefore, was rated 10.

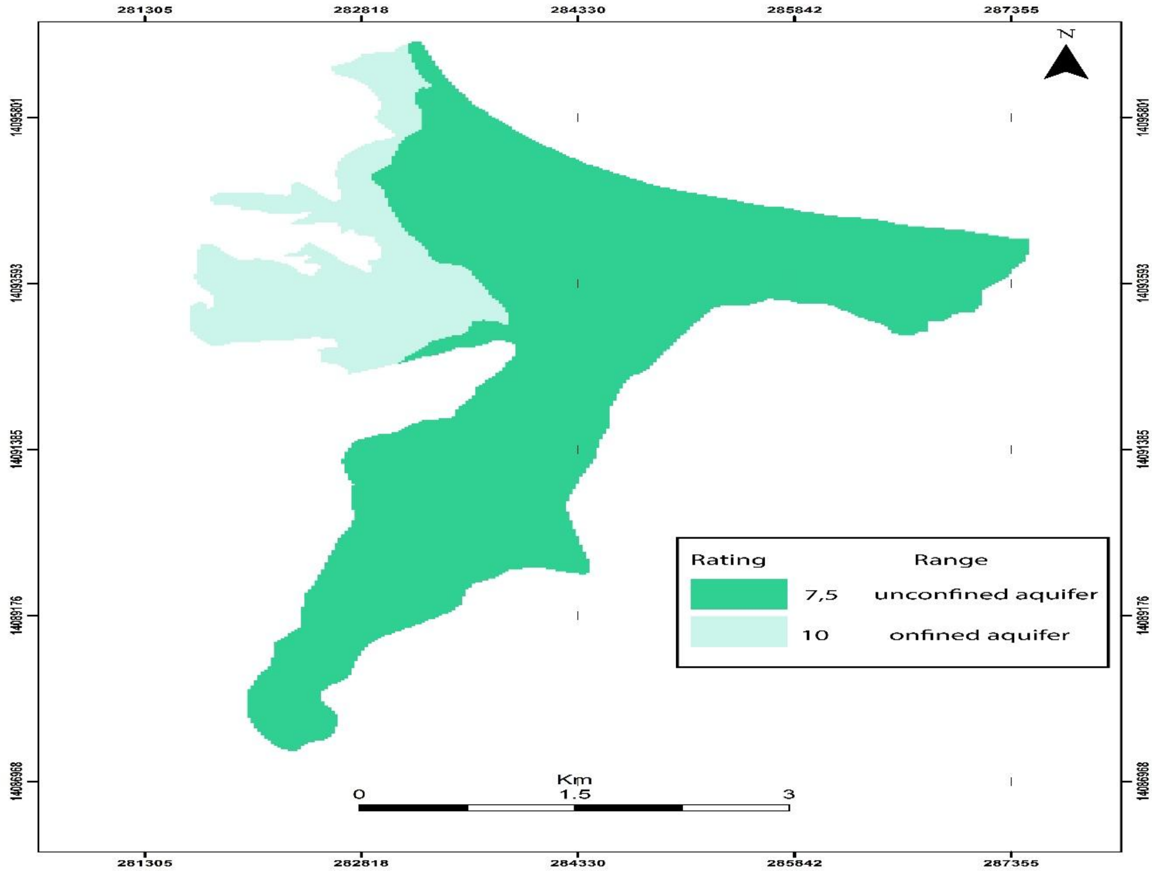

Fig 2: Parameters of the GALDIT method: aquifer type (G)

The hydraulic conductivity data (A) was extracted from pumping test on wells by CGG (1965) covering all the study area. Values range from 0.08 to 264 m / day. The lowest hydraulic conductivity is found in the southern part and the highest in the northern part of the study area (Figure 3). The hydraulic conductivity was classified into four classes and was rated 2.5, 5, 7.5 and 10.

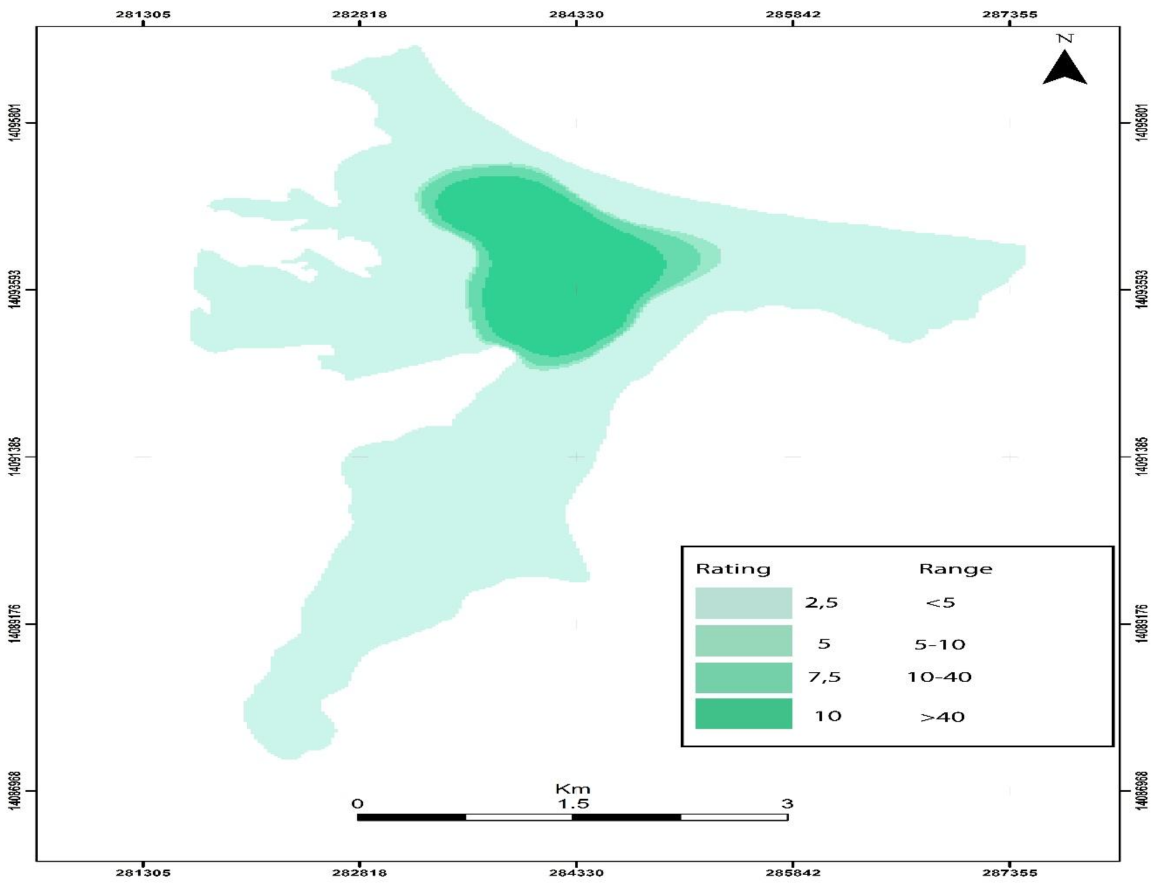

Fig 3: Parameters of the GALDIT method: hydraulic conductivity (A)

The height of groundwater above means sea level (L) is calculated from groundwater well measurements during 2014. The values range from 1 to 7 m (Fig. 4). The maximum height is recorded at the southern part of the study area which gives the aquifer more pressure to push away the seawater from coming in. The minimum height is recorded at the northern near the sea, indicating the likelihood of more pressure from the seawater to break the equilibrium interface that lies between the fresh and seawater. The rating (R) of the parameter (L) varies between 2.5, 5, 7.5 and 10.

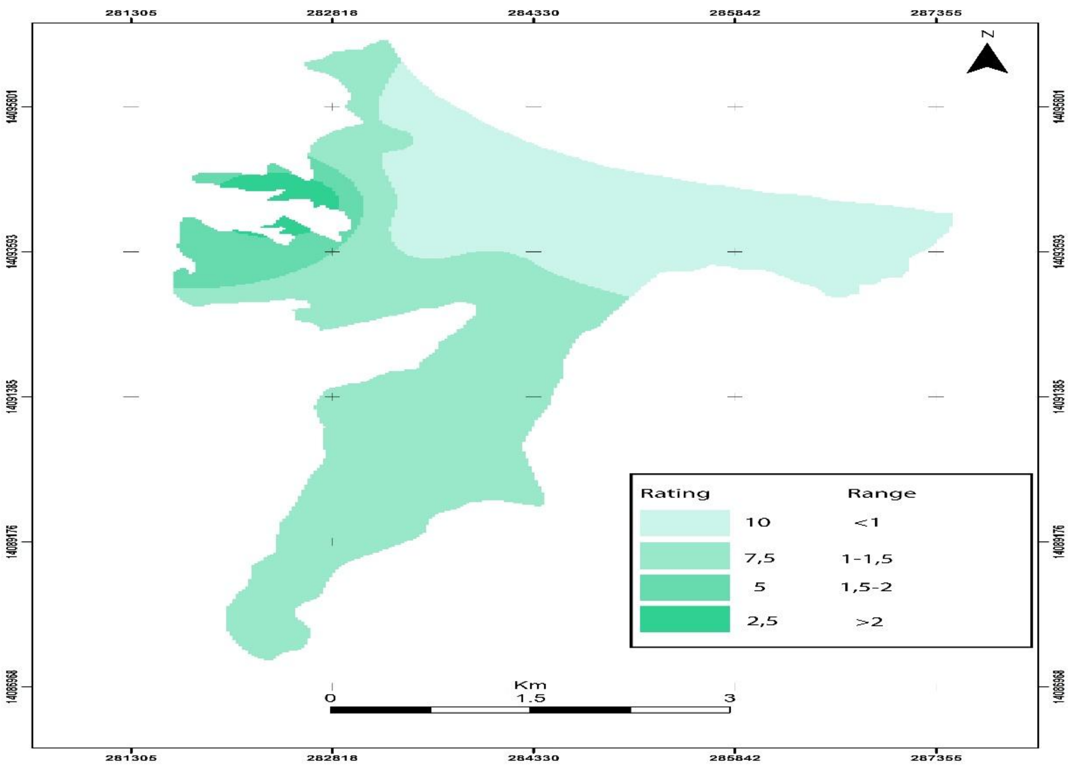

Fig 4: Parameters of the GALDIT method: height of groundwater level above sea level (L)

The distance from the shore (D) was estimated according to three distances to the coastline ranges (500, 750 and 1000 m) (Fig 5). The maximum estimate of 10 is adopted for a distance lower than 500 m whereas the minimal (2.5) is allotted for distance higher than 1000 m. In fact, the impact of the intrusion of seawater decreases when moving perpendicularly from the shore towards the land. As groundwater is further away from the shoreline, the pressure of the seawater decreases to infiltrate the aquifer.

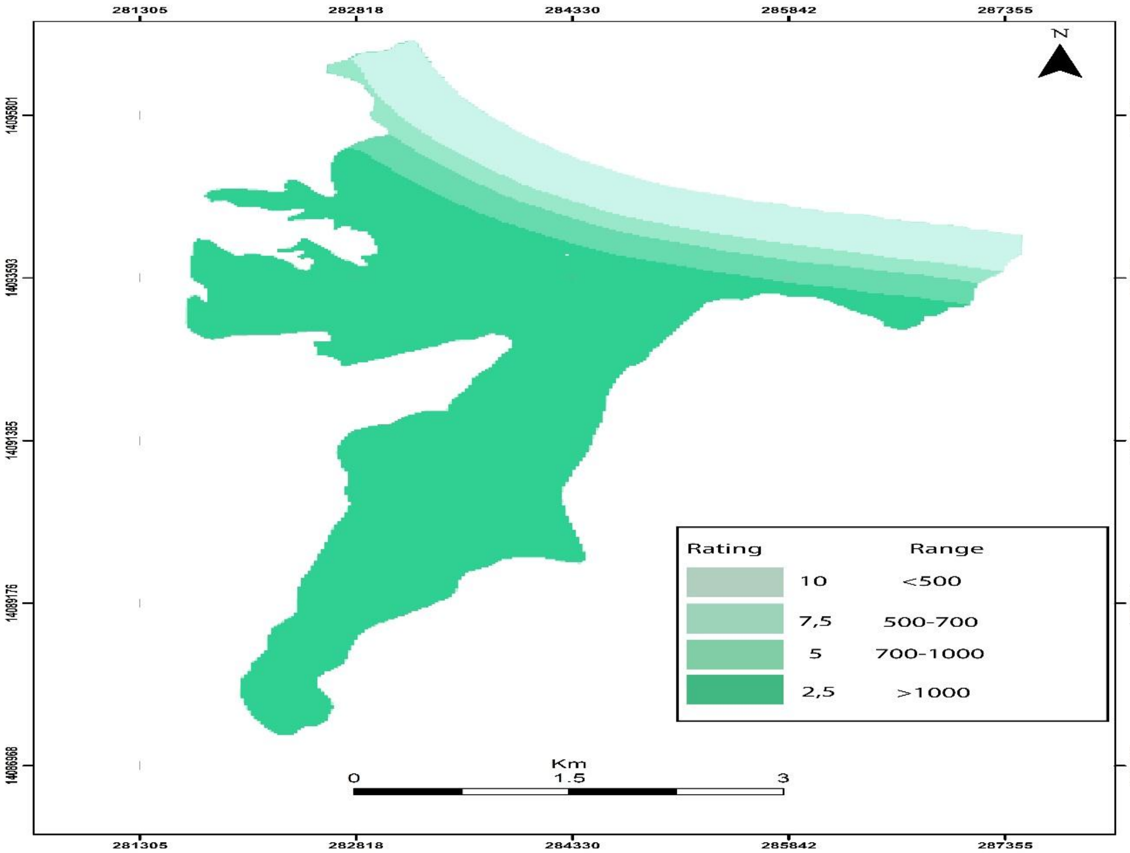

Fig 5: Parameters of the GALDIT method: Distance from the shore (D)

Impact of existing status of seawater intrusion is calculated by a ratio Cl / HCO_3 and it's a criteria to identify the extent of seawater intrusion into the coastal aquifers and can be used if the chemical analysis data is available. Chloride is the most dominant ion in sea water and normally occurs in small amounts in ground water, while HCO3 is usually the most abundant negative ion in groundwater but it occurs in minor amounts in the seawater. Thus, the Cl / HCO_3 ratio used to delineate the interface is calculated for all the wells and is divided into four categories such as < 1, 1-1.5, 1.5-2, >2 (Fig 6).

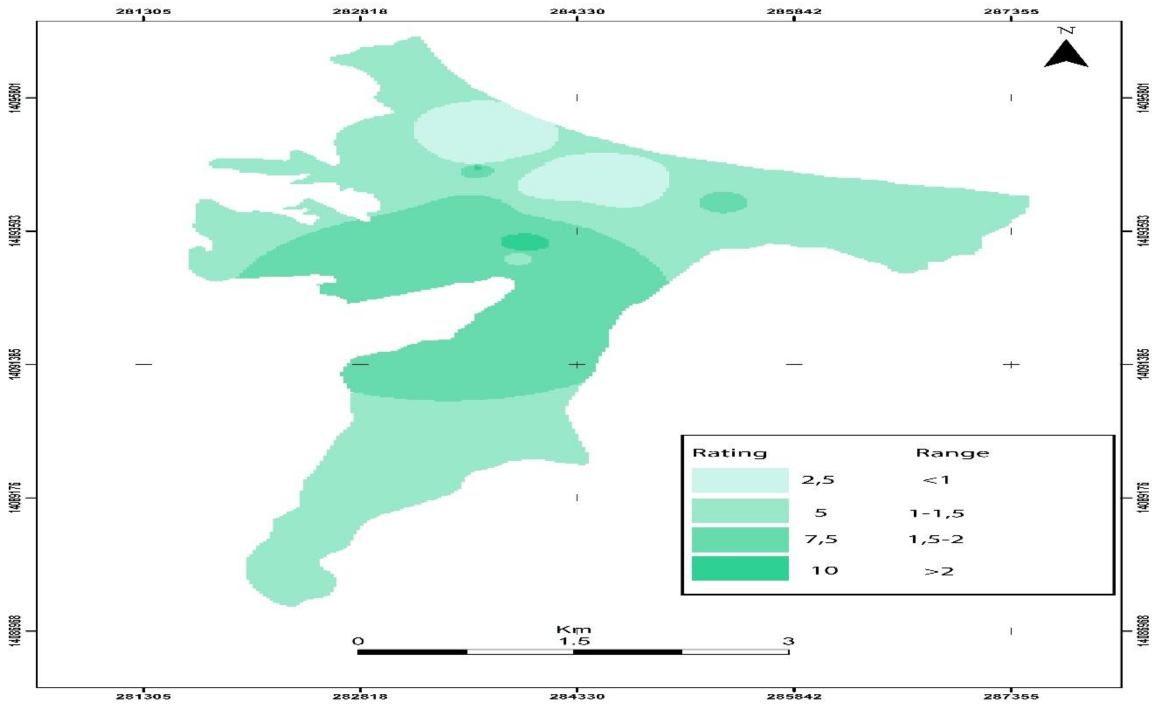

Fig 6: Parameters of the GALDIT method: impact of existing status of seawater intrusion in the area (I)

Aquifer thickness or saturated thickness of an unconfined aquifer plays an important role in determining the extent of vulnerability of seawater intrusion in the coastal areas. The thickness of aquifer (T) is calculated from a groundwater well data (Fig. 7). The study area showed a saturated thickness are vary between 3 to 20 m and was assigned a rate value 2.5 to 10.

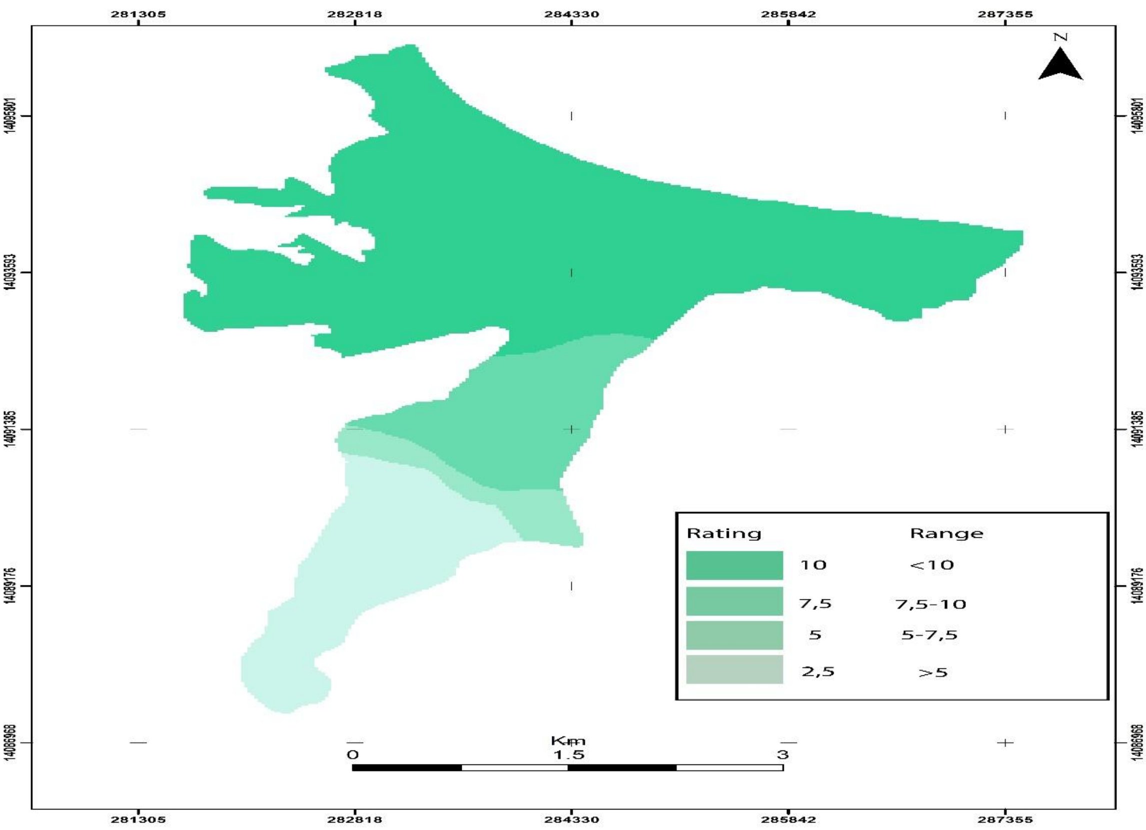

Fig 7: Parameters of the GALDIT method: thickness of aquifer (T)

The GALDIT vulnerability map(Fig. 8) depicts the different degrees of the aquifer sensitivity to seawater intrusion along the Collo coastal aquifer. The map divides the Collo into three vulnerability zones. The red zone represents a high vulnerability level in the Northern part of the aquifer, corresponding to the 38.60 % of the total area. Yellow color indicates the distribution of moderately vulnerable zones, which cover 51.13 % of the total area. This is due to the lower groundwater levels and the high hydraulic conductivity in these zones. The green colored zones indicate a lower vulnerability, corresponding to the 10.25 % of the total area.

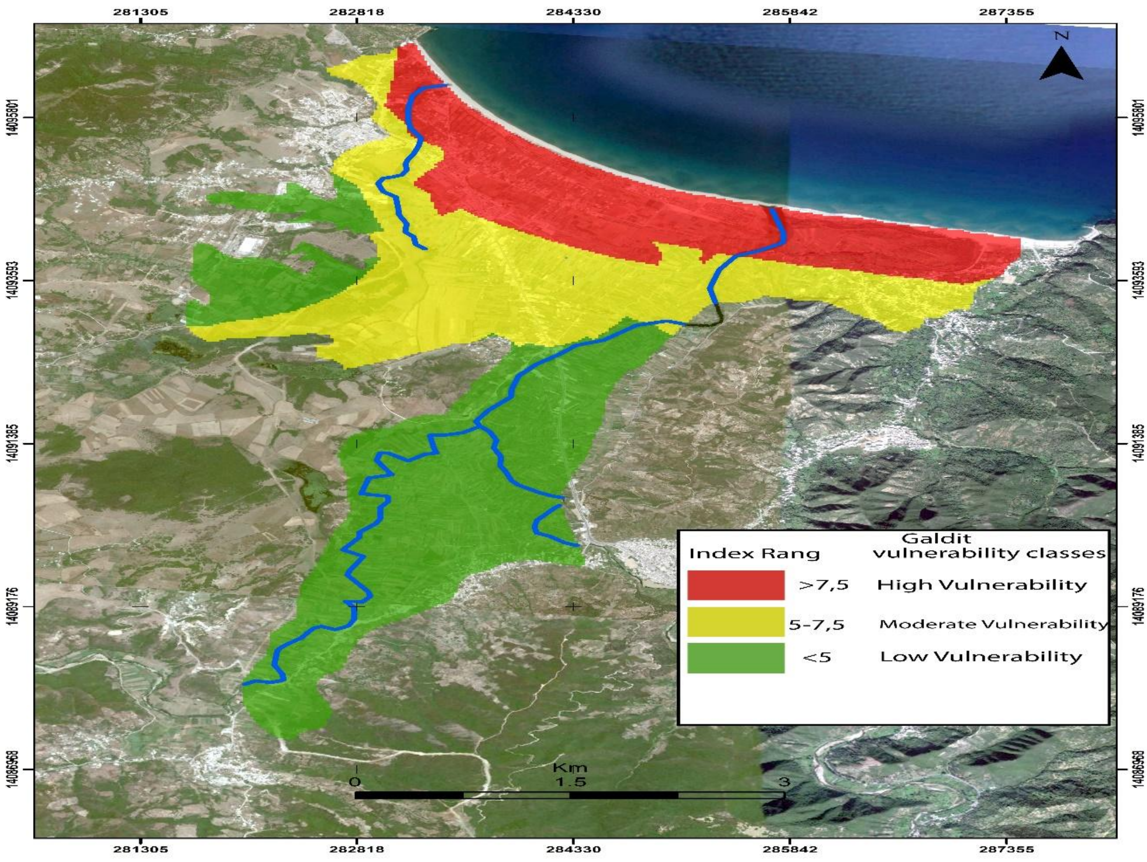

Fig 8: GALDIT vulnerability map of the study area

V. Conclusion

The GALDIT index method, developed by Chachadi and Ferreira (2001), for the assessment of coastal aquifer vulnerability to sea water intrusion, has been successfully performed in the Collo. The six indicators influencing seawater intrusion described previously were analyzed individually, and using the weight and the importance rating of each indicator to compute the index vulnerability map, the thematic GALDIT index maps were carried out. Based on these Index maps, the aquifer vulnerability index mapping was computed. GALDIT index was estimated and found to have a minimum value of 65 and the maximum value of 145. The extent of the freshwater / saltwater interface according to the GALDIT modelrepresented by the high-vulnerability beach corresponds roughly to that recognized with the geophysical method.This configuration closely follows the parameter distance from the sea.However, between the two wadis, the very vulnerable part appears wider, it is influenced here by the high chloride contents.It should be noted that this classification of the zones according to the degree of vulnerability does not support the pumpage and the recharge (eventually climate change). The GALDIT index vulnerability map shows the impact of seawater intrusion along the Collo coastal aquifer. The vulnerability map can be used as a management tool for the actual and future situation of the Collo coastal aquifer and in priority settings for areas where the aquifer is more vulnerable and should be monitored more frequently. Furthermore, the vulnerability map delineates areas favorable for artificial recharge in order to increase the ground water potential which that will be helpful to minimize and prevent the sea water intrusion. The vulnerability map can be used also in ascertaining the wellhead protection areas near the shoreline to prevent seawater intrusion.

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