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Study of Intrinsic Vulnerability to Pollution by the GOD-Foster Method: Application to Temara Groundwater (Morocco)

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Abstract

In Morocco, groundwater is of major importance in national economic policy, that's why groundwater management programs are periodically installed to prevent their qualitative and quantitative degradation. Our work comes to contribute to this program by studying the inherent vulnerability to pollution of the Skhirate-Temara region (NW Morocco) using the GOD-Foster method. The latter defines the vulnerability of aquifers based on the resistance to pollutant penetration and the mitigation capacity of the underlying layer of the saturated zone while neglecting the lateral migration of pollutants into the saturated zone. The vulnerability map will delineate areas vulnerable to pollution and will serve as a decision-making tool to take the necessary action.

Keywords

Groundwater, Geograpgic Information System, Vulnerability, GOD-Foster Method

1. Introduction

In Morocco, groundwater is an important part of the country's water heritage (Belghiti et al., 2013), because of its importance in the field of drinking water supply or irrigation. However, the latter is experiencing an alarming deterioration due to the accelerated population and urban growth experienced by large cities such as Rabat, the political capital of the country, which belongs largely to our study area. To cope with this critical situation, many water quality management programs are installed on a regular basis and adapted to the socio-economic development and climate change that the country is experiencing.

In this sense, several research studies using effective tools such as geographic information systems have been developed to study the vulnerability of these waters to pollution, with a view to delineating the most vulnerable areas, assessing pollution risk and creating vulnerability maps that constitute an essential information base facilitating decision-making (Sinan et al., 2003; Rahman, 2008; Ferrak et al., 2014; Arshad et al., 2019; Onwe et al., 2020).

There are many methods for assessing groundwater vulnerability to pollution (Neshat et al., 2014; Kumar et al. 2015; Rebolledo et al. 2016; Vidal Montes et al. 2016; Ribeiro et al. 2017; Ncibi et al., 2020), according to (Civita & De Maio, 2004), they could be divided into three groups:

- Parametric system methods: GOD, EPIK, DRASTIC, SINTACS, CALOD, SI, COP.
- Methods of analog relationships and numerical models: AVI.
- Comparative methods: subdivided either according to the specific or intrinsic characteristics of the aquifer taken into account or according to the use or not of a weighting system for the criteria involved.

There are many reasons why one method should be chosen over another. For example, a method may be chosen because of the objectives of human activities and existing pollutants, or for practical reasons such as the availability of the required information (some methods require little data compared to others).

The choice of the method of establishing the groundwater vulnerability map to pollution depends on the quality and quantity of data manipulated. The aim of this work is to identify and delineate the different pollution zones through vulnerability maps that serve as a decision-making tool.

2. Study Area

The Skhirat Temara region (**Figure 1**) includes the city of Rabat, the political capital of the Moroccan Kingdom, and is part of the coastal strip of northern Morocco. The overall population of this area is 1,049,672 according to General Census of Population and Habitat, 2014 (ABHBC, 2019).

Its groundwater developed in the formations of the tertiary cover. It is a well-individualized water table on the hydrogeological level, it stretches for nearly 350 km and is inserted between the deep valleys of Oued Bouregreg and these tributaries of Oueds Akrach and Ikem and the Atlantic Ocean (Amraoui, 2000).

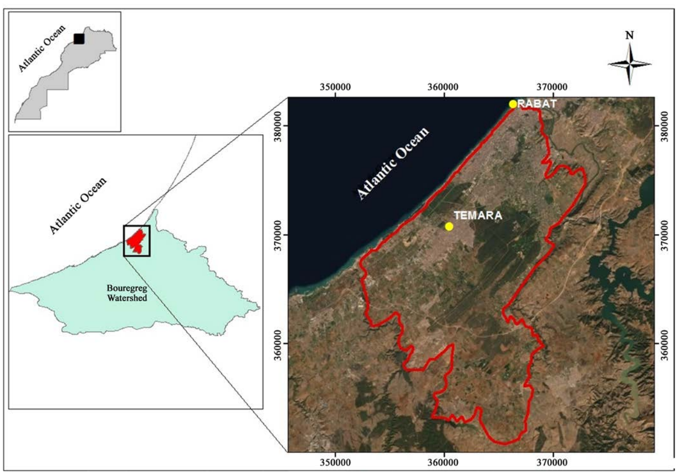

Figure 1. Geographical Location Map of Skhirat-Temara groundwater.

The Temara groundwater is the main groundwater resource in the Skhirat-Temara region. It has been used for many decades to meet the needs of various uses including the Potable Water Food in the center of Temara. It is also used for the irrigation of many plots exploited for the development of market gardening. It is characterized by a semi-arid climate with an average annual temperature ranging from 17˚C to 18˚C, evaporation ranging from 1500 to 1600 mm/year, and irregular and low precipitation on a national scale (ABHBC, 2019).

3. Geological Context

The Temara groundwater belongs to the coastal Meseta formed from highly pleated, tectonized and shaved primary lands (Combe, 1963). It features land (**Figure 2**) formed by:

- Thin sandstone benches topped with Plio-quaternary calcarenistic levels;
- Detritus yellow sands topped grey marls of the Mio-pliocene;
- Carboniferous limestone sandstone formations;
- Devonian reef or pre-reef limestone.

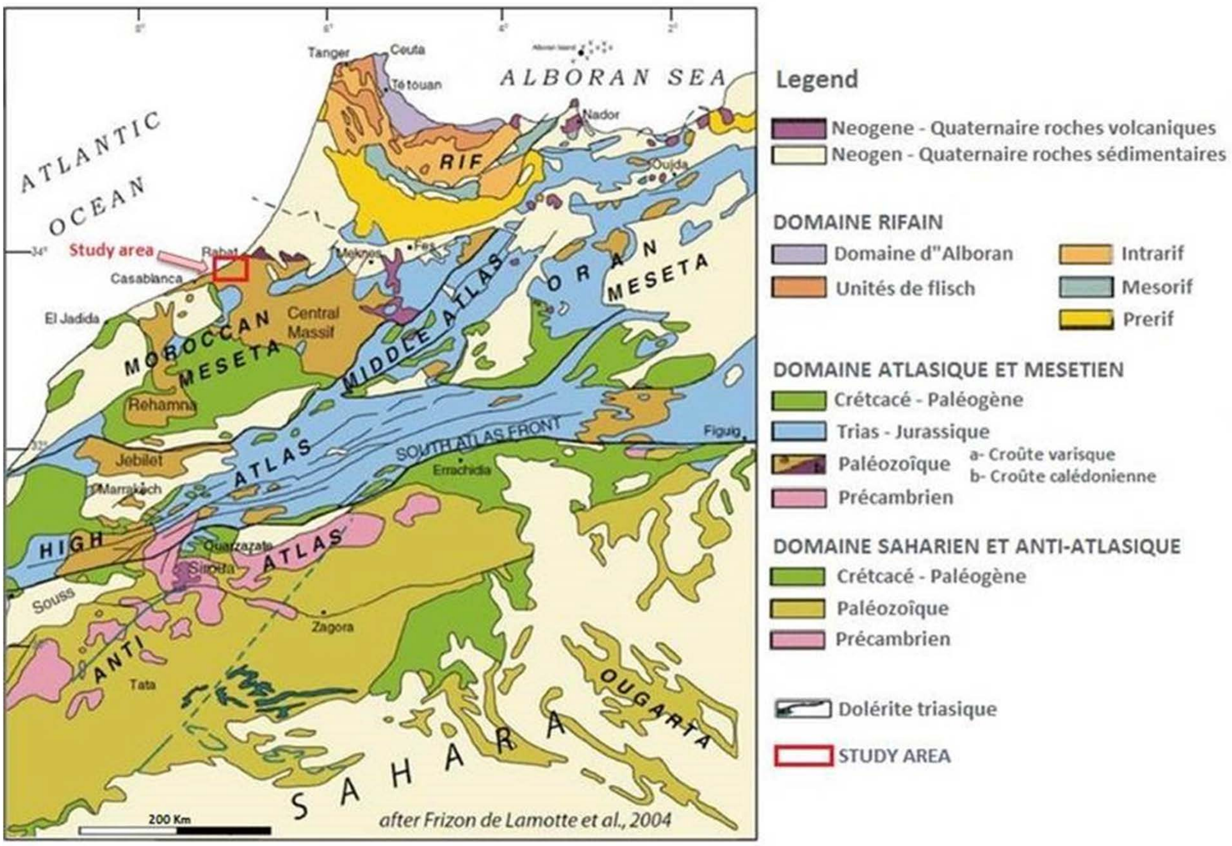

Figure 2. Geological map of coastal meseta (Frizon de Lamotte et al., 2004).

4. Hydrogeological Context

The Temara groundwater is well individualized from a hydrogeological point of view. There are three groundwater circulation zones (**Figure 3**) at the Temara groundwater (ABHBC, 2019):

- Zone A: which extends over the northern half of the Temara groundwater area, where water circulations occur in the sandstone, sand, limestone and sandy marls of the Plio-quaternary;
- Zone B: where the cover areas of the Plio-quaternary are completely pitted, and groundwater circulations are made in the altered fringe of the shale and the rights of fractures and faults;
- Zone C: which constitutes the natural extension of the second, water circulations, are done in the sandstones, sands and conglomerates of the Plio-quaternary and in primary shale and limestone.

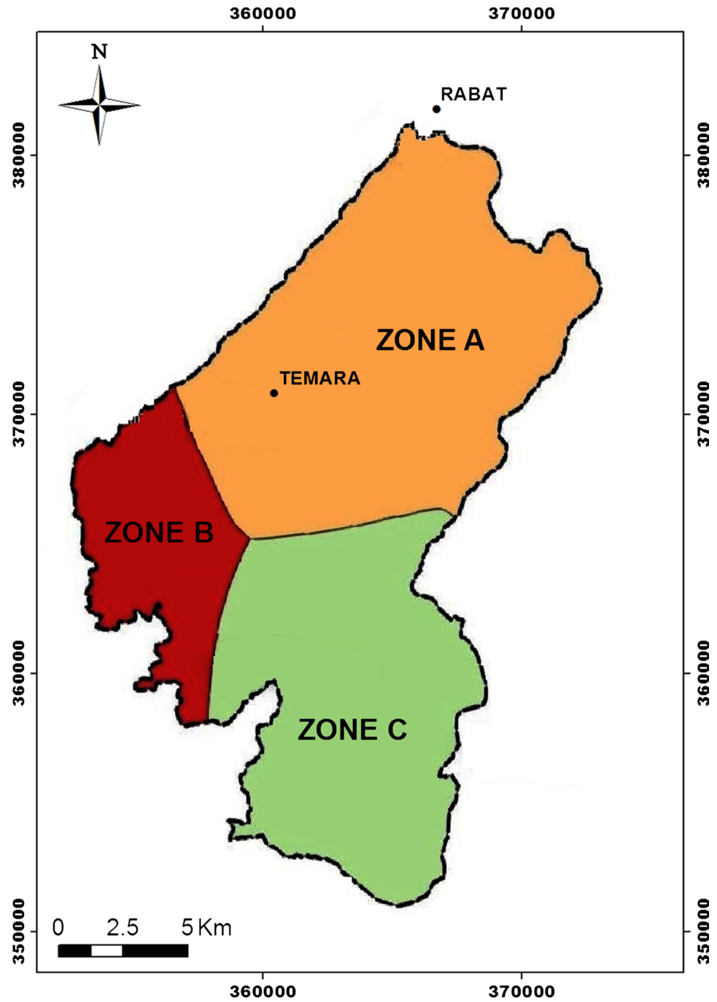

Figure 3. Distribution map of different hydrogeological zones (ABHBC, 2019).

Through the analysis of geological documents and reconnaissance survey data (85 wells) provided by Bouregreg and Chaouia Hydraulic Basin Agency (2019) for 85 wells (ABHBC) and the results of the field surveys carried out, we observed the presence of sedimentary gaps with lateral variation in places.

The depth of the groundwater does not usually exceed 20 meters (eastern, southern and western areas of the plain). The depth of more than 20 meters is located over large areas of the plain, particularly the central area of the study area (**Figure 4**).

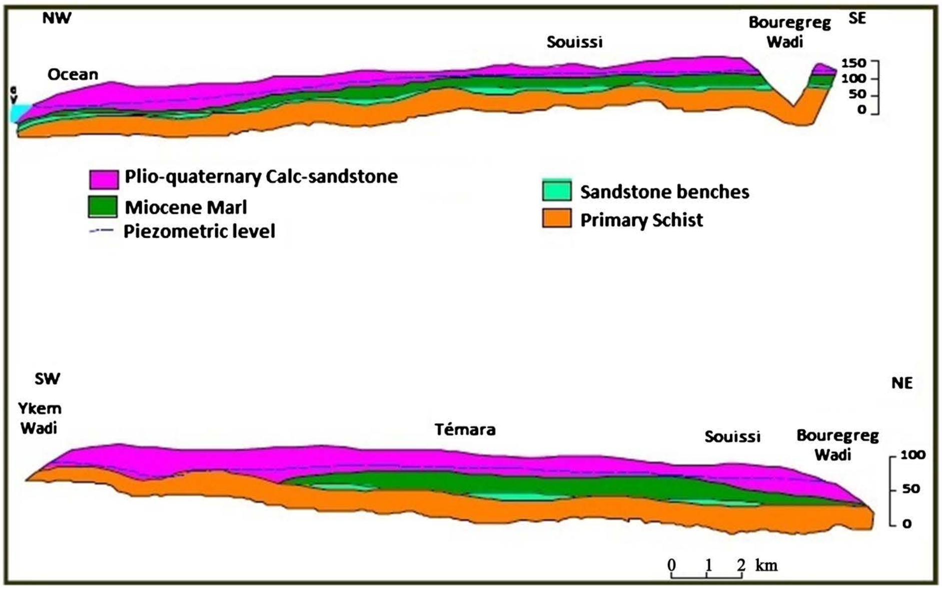

Figure 4. Lithological cuts of the study area (Amraoui, 2000).

The vulnerability index is therefore proportional to the permeability of aquifer formation. The values of the permeable selected generally vary between 10^{-2} and 10^{-4} m/s and depend on the lithological nature of the facies. The recharge area of the groundwater is limited to an area of nearly 260 km^2; recharge is estimated at 16 Mm^3/year (ABHBC, 2019).

5. Methodology

The GOD-Foster method is the most widely used in assessing vulnerability to pollution, sedimentary aquifers. The GOD method (Groundwater occurrence "G", Overall class of aquifer 'O' and Depth to groundwater table 'D') was developed by Foster in 1987 presenting the vulnerability of the aquifer to the vertical percolation of pollutants across the unsaturated zone, while neglecting the lateral migration of pollutants in the saturated zone (Lobo Ferreira & Oliveira, 2004; Fraga et al., 2013; Ghazavi & Ebrahimi, 2015; Benabdelouahab et al., 2018; Boulabeiz et al., 2019).

The approach used for this three-parameter model:

- Type of aquifer depending on its degree of containment C_a,
- The depth of the groundwater C_d, shows the depth of unsaturated zone.
- The lithology of the aquifer C_l, determined the characteristics of the layers overlying the saturated zone of the aquifer with respect to their relative degree of porosity, permeability and to their water content.

The weights assigned to the classes of the different parameters are less than or equal to 1. The GOD Index (GI), which assesses the vulnerability of the aquifer to pollution, is obtained by multiplying the three parameters (Murat et al., 2003).

$$GI = Ca \times Cd \times Cl$$

The following diagram (**Figure 5**) shows the steps taken to achieve the Skhirat-Temara groundwater pollution vulnerability map.

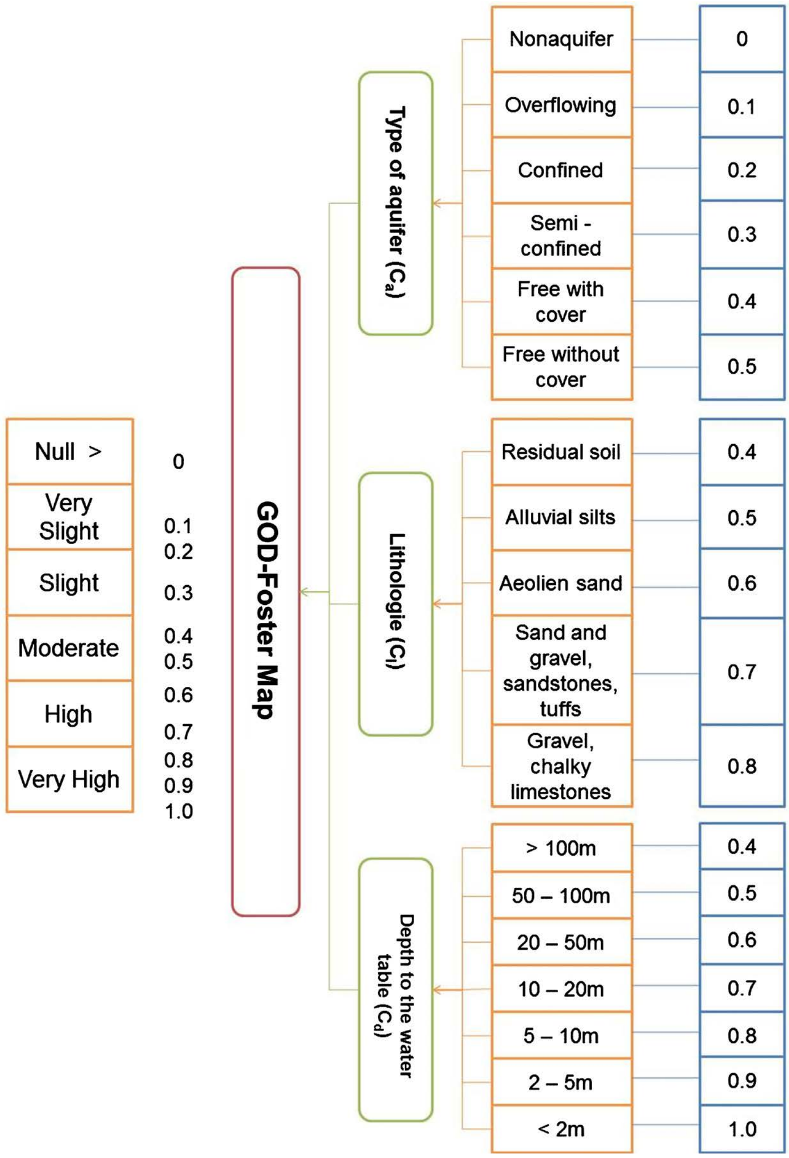

Figure 5. GOD-Foster method.

- aquifer criterion:

The purpose of this criterion is to identify the type of aquifer based on its degree of Ca containment. The Temara groundwater is a free tablecloth (**Figure 6**), linked very closely to the hydrological regime of the wadi. It flows uniformly to the sea, i.e. from the South East to the North West, a set of low plateaus inclined towards the coast (Combe, 1963).

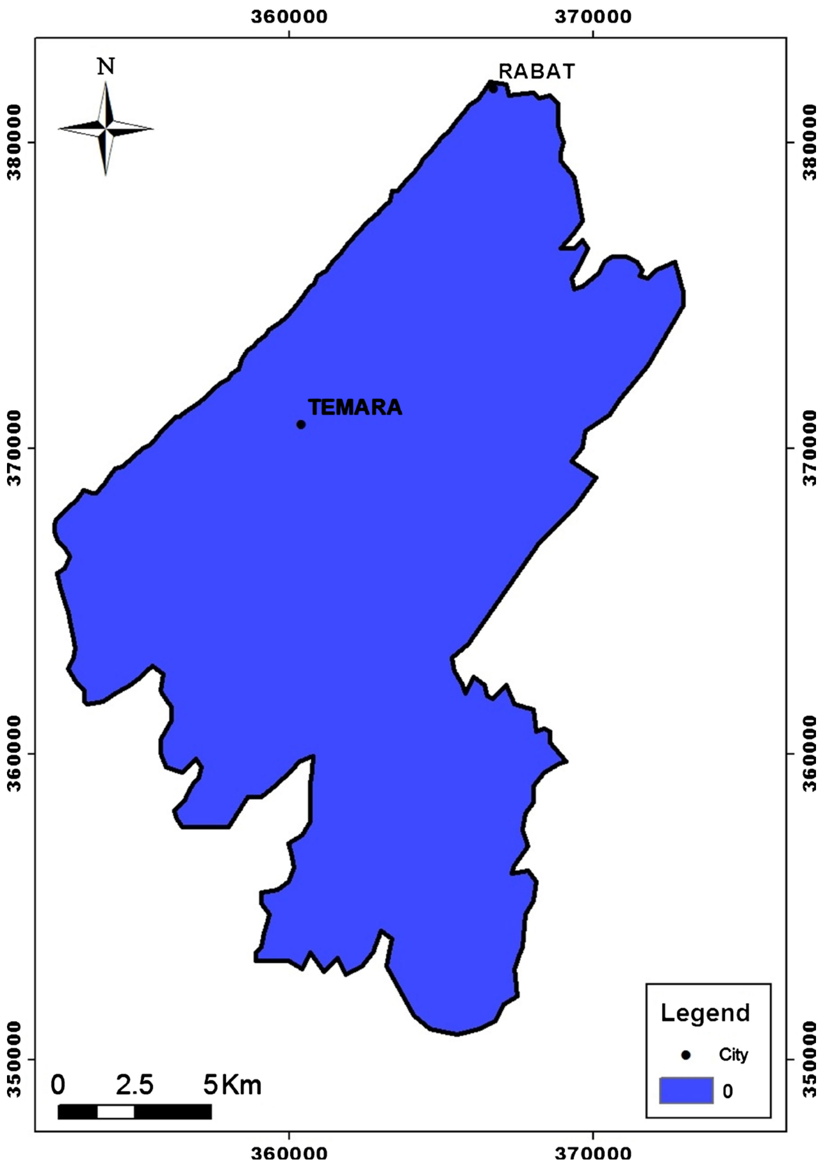

Figure 6. Skhirat-Temara groundwater criterion Map.

Criterion aquifer is an important criterion in the study of vulnerability, as any mitigation of the pollutant occurs in relation to depth. The depth of the aquifer was deduced based on the difference between the potential for elevation of the earth's surface (Z) and the potential for elevation of the piezometric surface (h).

- Depth criterion:

The groundwater has a variety at the depth of the water, covering the total area of the Basin, ranging from 0 to 234 m, the depth levels are illustrated in the depth map (**Figure 7**) by the red color for the deep depths located at the level of Zone C and the southeastern part of Zone A, and the green color for the low values that are scattered in some surfaces of zones A and B. That said, the most important depths exceeding 20 m extend in particular to the center of the study air.

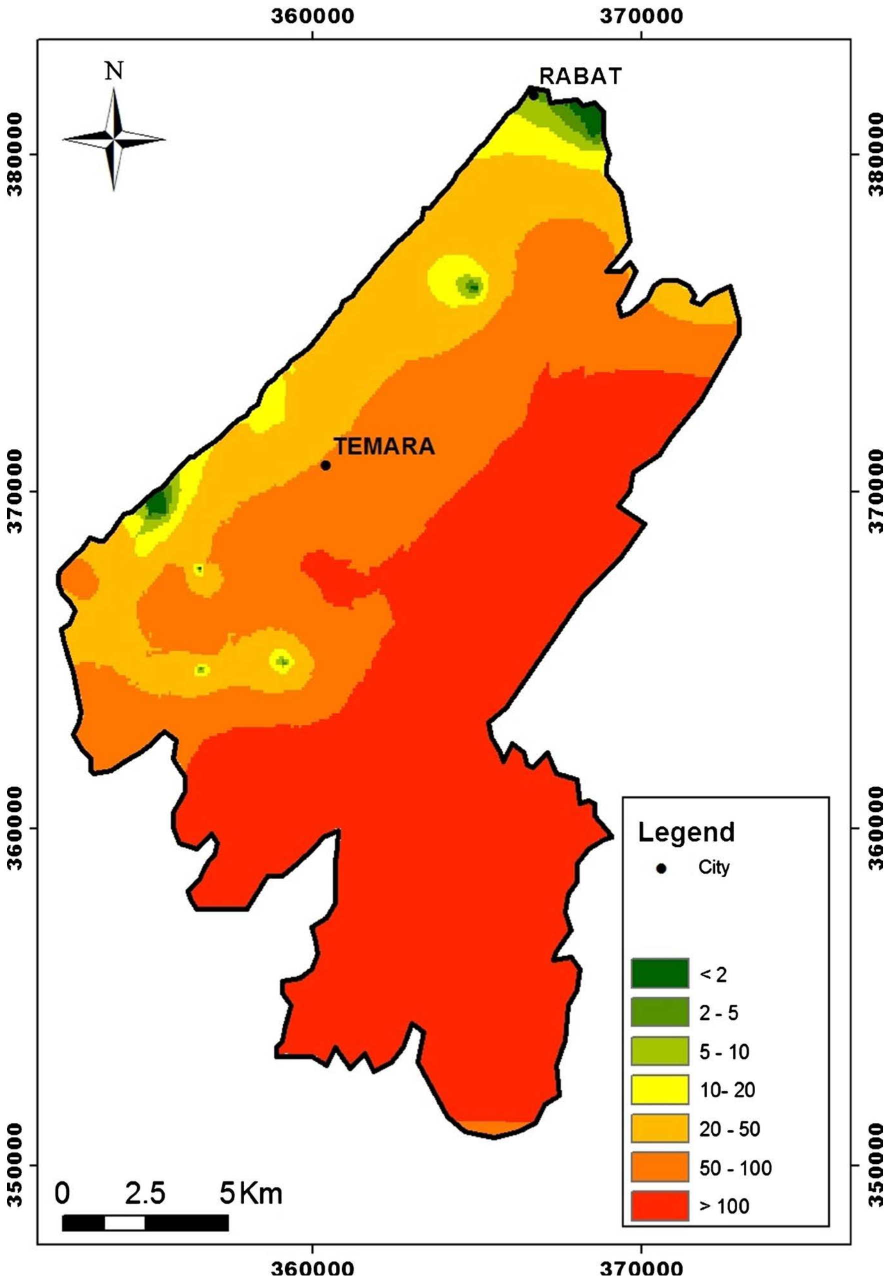

Figure 7. Depth Criterion Map of Skhirat-Temara groundwater.

- Lithological Criterion:

Criterion Map of the Temara groundwater is part of the coastal Meseta strip developed in the Tertiary cover (Figure 8).

It is a well individualized aquifer on the hydrogeological level is formed by:

- Thin, sandstone benches topped with Plio-quaternary calcarenistic levels;
- Detritus yellow sands topped grey marls of the Prepliocene self;
- Carboniferous limestone sandstone formations;
- Devonian reef or pre-reef limestone.

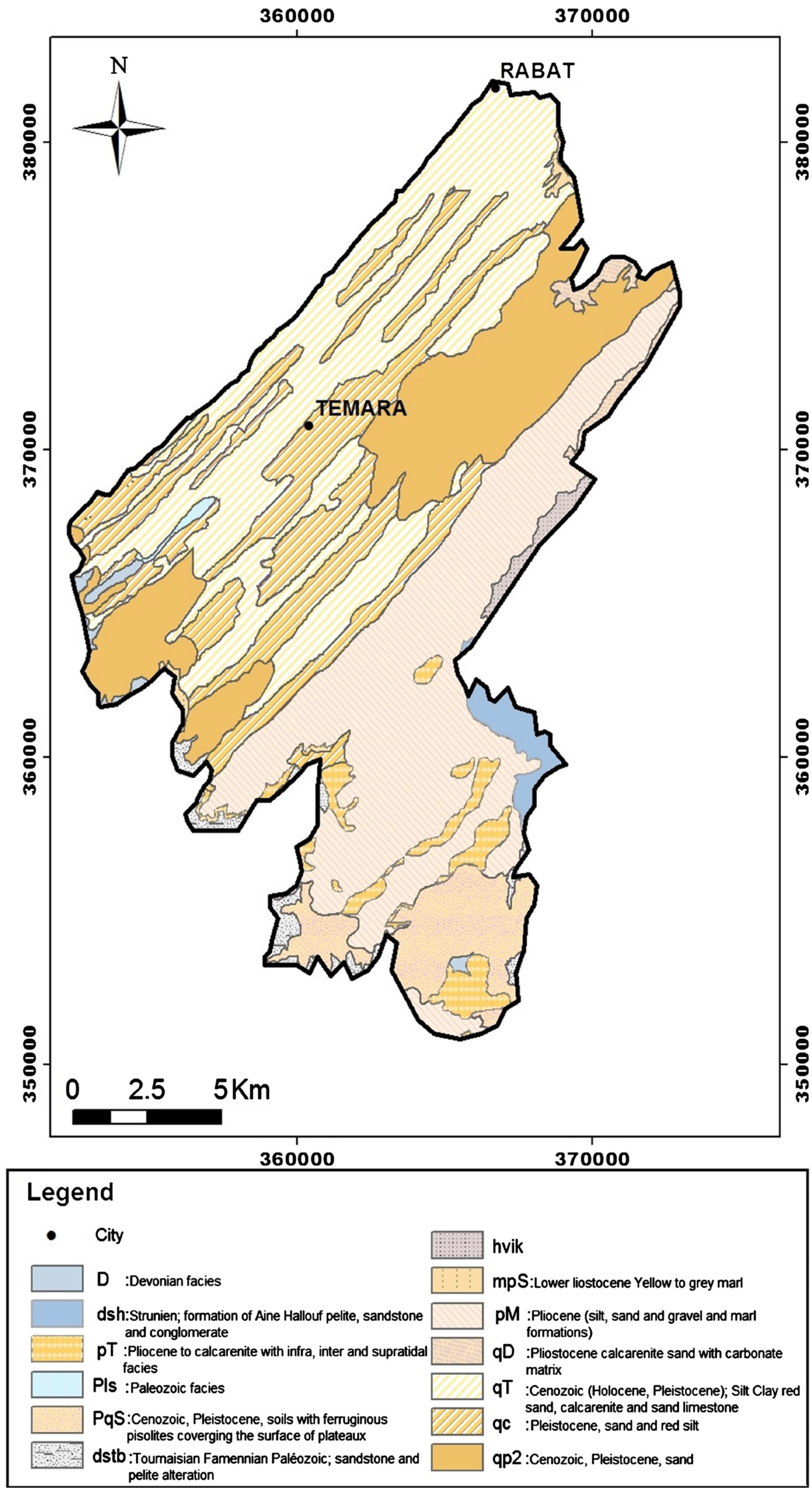

Figure 8. Lithological Criterion Map of Skhirat-Temara groundwater.

6. Results and Discussion

The criterions that are introduced in the GOD-Foster method are weighted according to the following table:

Table 1. The criteria of the GOD-Foster method with weighting.

	CRITERION	CLASSE	WEIGHT
G	Type of aquifer depending on its degree of containment Ca,	Free wthout cover	1.0
		Gravel, chalky limestones	0.8
		Sand and gravel, sandstone, tuffs	0.7
O	The lithology of the aquifer Cl	Clay	0.6
		Alluvial silts	0.5
		Residual soil	0.4
		<2	1
		2 - 5	0.9
		5 -10	0.8
D	The depth of the water table Cd	10 - 20	0.7
		20 - 50	0.6
		5 - 100	0.5
		>100	0.4

The Weight 1 was assigned for the first criterion, which is the type of aquifer, since it is a free without cover. For the second criterion, residual soil were affected by the value 0.4 followed by Alluvial silts 0.5. The weight value 0.6 wa contributed to the clays, the sands and gravel, sandstone and tuffs were affected by the weight value 0.7. While the weight 0.8 corresponds to the Gravel, chalky and limestones formations (**Table 1**). The maps below (**Figures 9-11**) show the results obtained based on the reclassification.

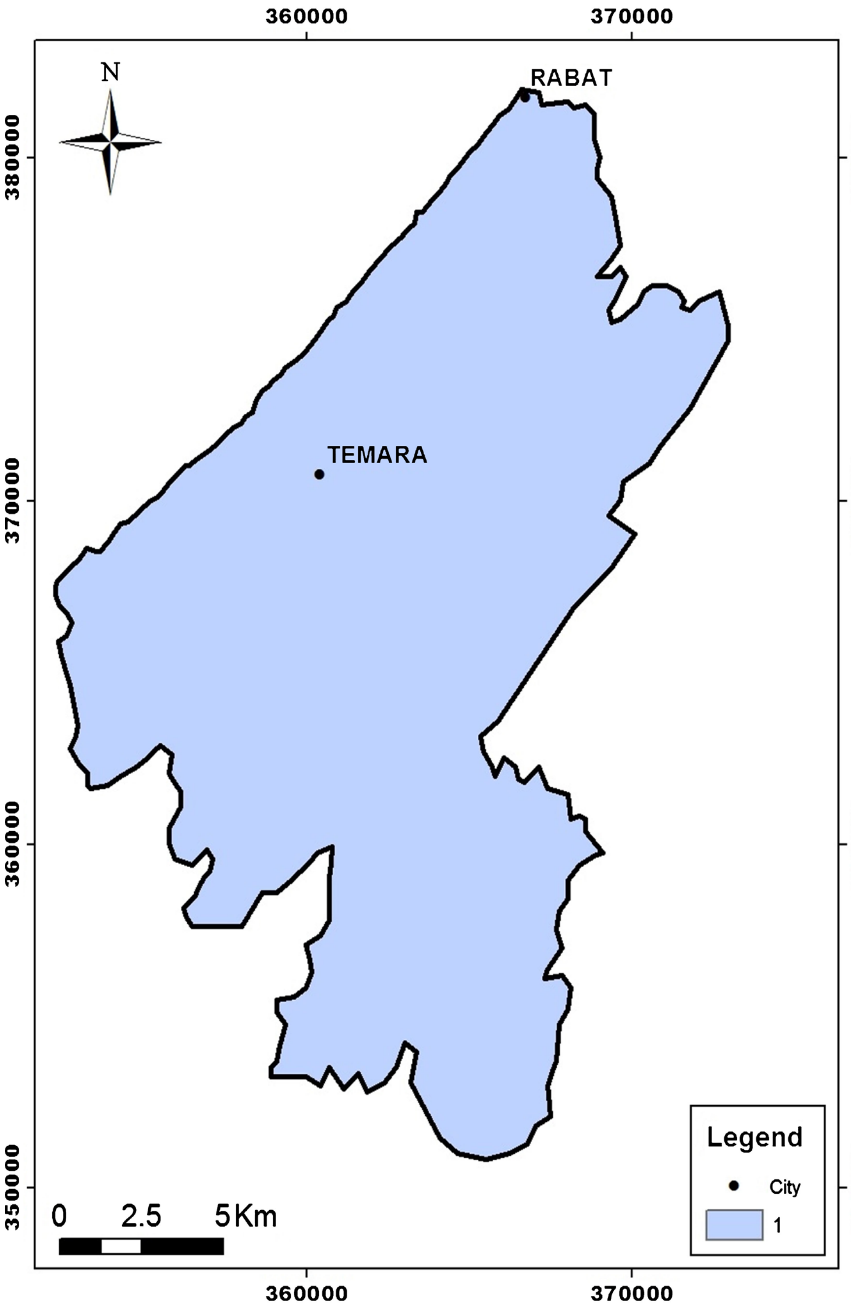

Figure 9. Reclassified Aquifer Type Map.

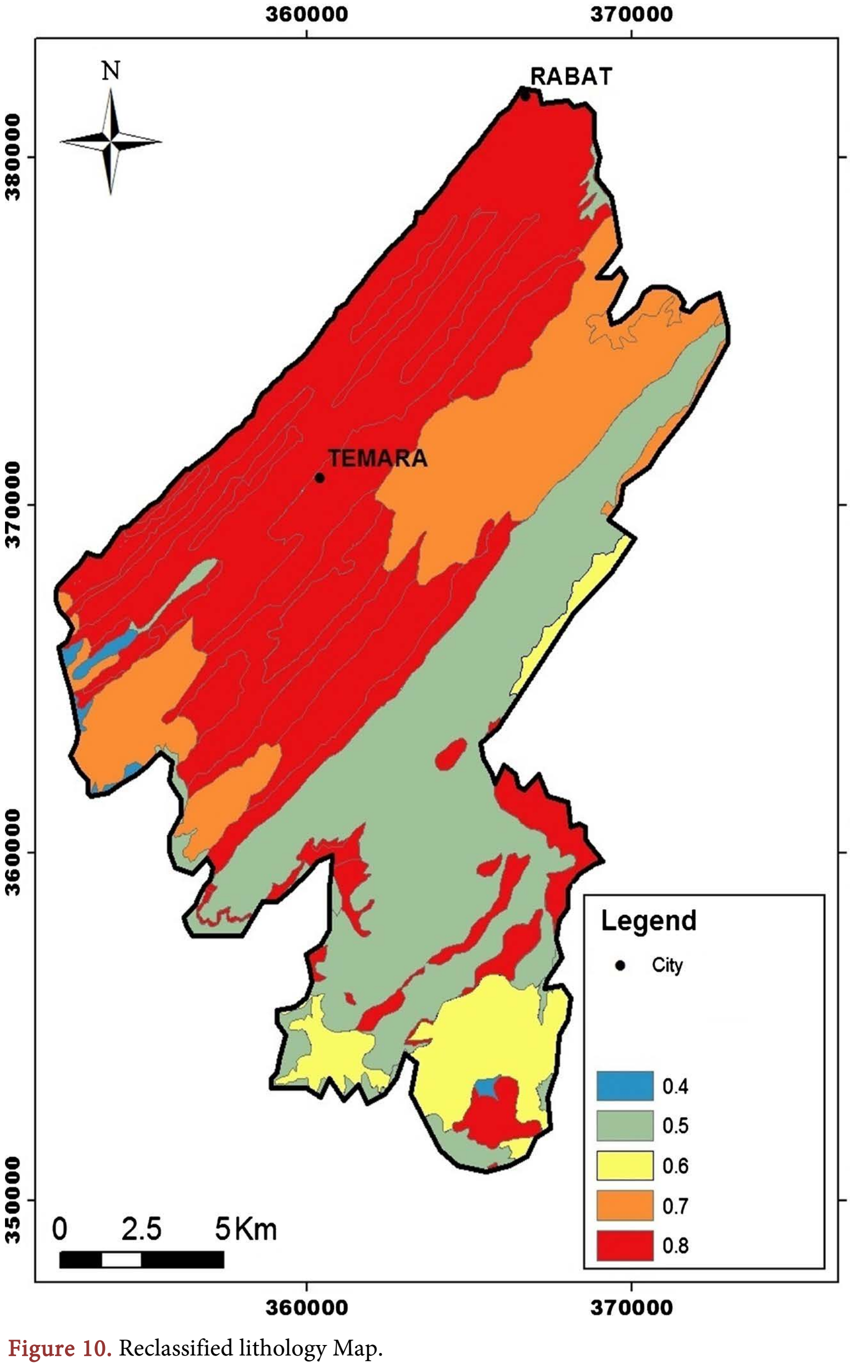

Figure 10. Reclassified lithology Map.

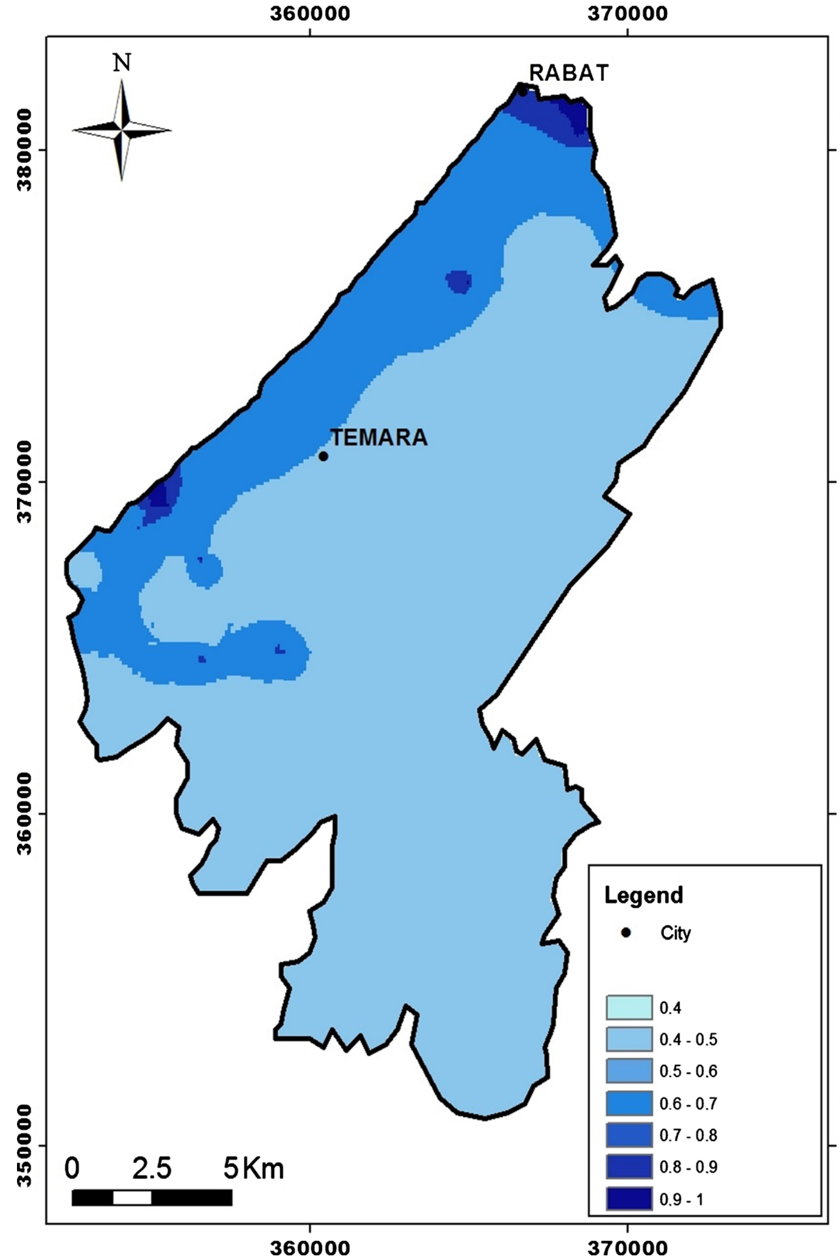

Figure 11. Reclassified Depth Map.

The earned vulnerability index (GI) ranges from 0.16 to 0.8. Classes developed from the index (GI) identified five vulnerable classes (**Figure 12**): GI - 0.16 (Very slight vulnerability); 0.16 - GI - 0.3 (Slight vulnerability); 0.3 – GI - 0.5 (Moderate vulnerability); 0.5 - GI - 0.7 (High vulnerability); 0.7 - GI - 0.8 (Very high vulnerability).

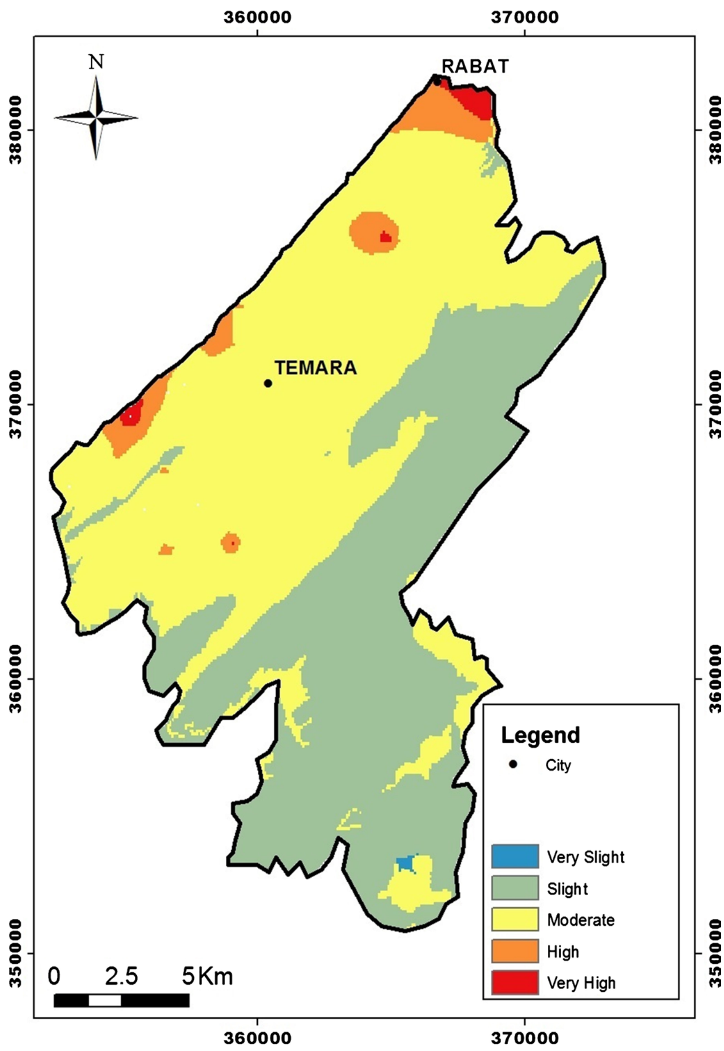

Figure 12. Skhirat-Temara Water Pollution Vulnerability Map.

The Very slight vulnerability class occupies a small area at the southern level of the study area. The Slight vulnerability class covers the entire southern part, the Moderate class covers the entire northern part. The High and Very high vulnerability classes are found in the north and northwest end. The variability of vulnerability to pollution noted is mainly related to the depth of no more than 20 m in the east, south and west of the groundwater, the direction of flow from the southeast to the northeast favors the overshoot of pollutants to the coast which increases the degree of vulnerability in this area. There are also disturbances at local levels related to overexploitation of the water table as well as lithology of the aquifer that usually forms sizzling limestone formations of the plio-quaternary with a marl substrate that forms an important cover of the groundwater. Thus, the very high vulnerabilities to pollution noticed at the level of the final map are present in the north (the cities of Rabat and Salé) especially at the mouth of the Oued Bouregreg, in the south-west (the city of Temara) and at the level of the STEP of Ain Atiq.

7. Conclusion

Many programs and models for the management and monitoring of groundwater using new technologies such as geographic information systems have been developed with the aim of preserving the hydrogeological heritage. However, the latter require a large database to be able to develop thematic maps corresponding to the parameters of each model.

Our study focuses on the application of the GOD-Foster method which requires three criteria to study the vulnerability to pollution of groundwater. These criteria are generated from data from the Chaouia Hydraulic Basin Agency (ABHC) of 85 wells.

Mapping the inherent vulnerability to pollution of the Skhirat-Temara groundwater determined by the GOD-Foster method reveals high-vulnerability areas in the northwest near the mouth of Oued Bouregreg where wastewater discharges from the city of Rabat, salt and drinking water treatment plant gathers (Ain Atiq STEP). That said, the GOD-Foster method, although it only takes into account three criteria, namely; the type of aquifer, lithology and depth, it helps to delineate areas at risk, so it remains a considerable tool for decision-making and integrated management of groundwater resources.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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