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COMPARATIVE ASSESSMENT OF VULNERABILITY BY DRASTIC AND TCR METHODS: APPLICATION TO THE R'MEL AQUIFER, MOROCCO

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To assess vulnerability to groundwater pollution there are several methods. Therefore, for a given application, the choice of the most appropriate method is not always straightforward. The aim of this work is to carry out a comparative study between standard DRASTIC methods and TCR methods, with an application to the R'Mel aquifer (Morocco). The DRASTIC method, widely used since 1987, assesses vulnerability based on seven parameters which are: depth of the water table, effective infiltration, aquifer environment, soil type, slope of the ground, impact of the unsaturated zone and hydraulic conductivity. The DRASTIC index is given by the weighted sum of these seven factors. The TCR method consists in determining an Iv index determined by three parameters involved in the transfer of the pollutant: transit time (T) of a pollutant in the unsaturated zone, the degree of purification (C'p/Cp) and the degree of recharge (R'/R). The index is given by the weighted sum of these three parameters. The comparative study of the two maps, based on the statistical analysis of the vulnerability classes, revealed that this difference involves 56% of the mapped area. The dissimilarity between the two maps is marked by the dominance of the "high" vulnerability class for the map produced by the DRASTIC method and of the "extreme" class for that produced by the TCR method. To explain these results, a detailed analysis of the two methods is then necessary.

INTRODUCTION

The groundwater vulnerability maps are used to identify areas most exposed to potential pollution and where protective measures are necessary (Margat and Suais-Parascandola, 1987). They take into account the different physical factors determining the degree of exposure of these aquifers to pollution from the soil surface(Albinet and Margat, 1970). The concept of groundwater vulnerability is not an absolute property, but a complex indicator (Maxe and Johansson, 1998). However, there is no strict definition of groundwater vulnerability and no standard technique for its estimate (Vrba and Zaporozec, 1994). Therefore, various vulnerability assessment methods have been developed worldwide. This makesthechoice of an appropriate method for a given area very difficult.

In this work we consider a comparative study between two methods DRASTIC (Aller et al., 1987; Engel et al., 1996) and TCR (Amharref et al., 2001 and 2007; Bernoussi and Amharref, 2003) through an application to the R'Mel aquifer (Morocco). Both of these methods, weighting and indexing parameters were used to determine which method proves most secure from the standpoint of protection of water resources. To develop vulnerability maps by these two methods, we considered four classes of vulnerability, according the index values obtained: low, medium, high and extreme. The area occupied by the different classes in the two maps produced by the two methods is different (three classes and four classes for DRASTIC and TCR). This difference is particularly striking in areas of high and extreme vulnerability.

STUDY AREA AND DATA

The R'Mel aquifer is located in the North-West of Morocco; it is a part of the Bas-Loukoss Basin localized in the South of the city of Larache (Morocco). It covers an area of approximately 240 km^2. It is bounded to the West by the Atlantic Ocean, the Oued Loukoss to the East and by the Mio-Pliocene marl outcrops in the South. It is drained by three rivers (Oueds): Sakh-Sokh, Smid El Ma and El Kihel (Figure 1).

This area is classified in the area of sub-humid Mediterranean climate characterized by hot and dry summer and mild and wet winter. The annual average temperature varies between 11°C in winter and 25°C in summer and the average annual rainfall is 700 mm distributed between October and April (ORMVAL., 2004).

The results of the geophysical surveys and data extracted from the logs of boreholes have revealed two aquifers units consist essentially of dune sands and sandstones of Late Quaternary, and shelly sandstone Plio-Villafranchian. Both hydrogeological formations are usually separated by a layer of variable thickness and permeability, attributed to sandy clay or clay formations of villafranchien. This impermeable layer, when its thickness exceeds 30m, puts the lower water table of support degrees, therefore the aquifer is considered semi-captif in the area between the Oueds Sakh-Sokh Smid El Ma El Aouamra and Boucharen. Furthermore, the two units are closely and the aquifer is considered as free regime. The substratum of the R'Mel aquifer consists essentially of blue marl Mio-Pliocene [Messaoud, 1963].

MATERIALS AND METHODS

The development of both vulnerability maps, which requires analysis and overlay of factors and parameters recommended by the two methods, has been facilitated by the use of ArcGISsoftware. In

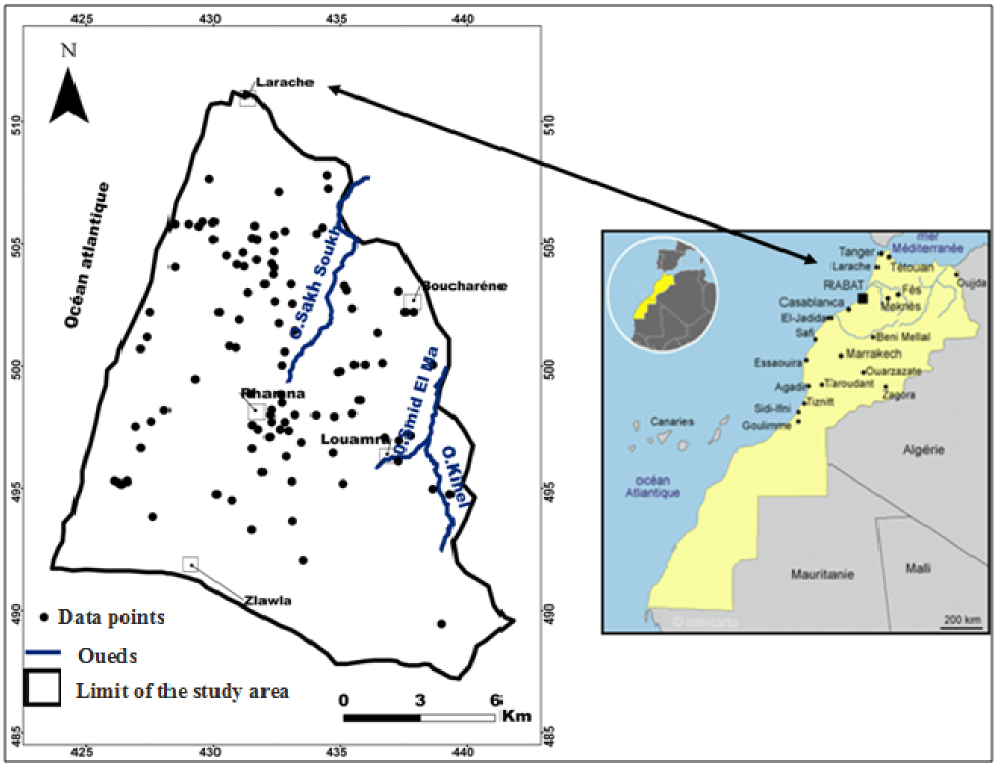

Figure 1: Location of R'Mel aquifer and distribution of data points.

order to explain the results, a detailed analysis of the two methods (DRASTIC and TCR) was required and their principles are recalled below.

Principle of the DRASTIC Method

The DRASTIC method, widely used around the world since 1987, evaluates the vertical vulnerability based on seven factors are: D: depth of the water table, R: effective infiltration; A: aquifer; S: soil type; T: slope of the land; I: impact of the unsaturated zone and C: hydraulic conductivity.

The DRASTIC indexis calculated by the sum of the product of the coasts and weight assigned to each factor using the Equation (1):

$$I_{DRASTIC} = DnxDp + RnxRp + AnxAp + SnxSp + TnxTp + InxIp + CnxCp \quad (1)$$

Where D, R, A, S,T, I, C, are the parameters mentioned above; n: rating assigned to each parameter; p: weighting factor assigned to each parameter.

Principle of the TCR method

The TCR method was designed based on a quantitative assessment of transfer mechanisms of a pollutant that is based on a conceptualization of the multilayer medium traversed (Amharref et al., 2001, 2007; Bernoussi and Amharref, 2003). The vulnerability index Iv is measured as the weighted sum of three parameters characterizing the transfer of a pollutant from the soil surface to the water table. This is the transit time, T, via the coverage area, the degree of purification C'p/Cp (the ratio of the pollutant concentration, C'p, reaching the water table and the initial pollutant concentration in the aquifer, Cp, and the recharge degree R'/R (ratio of the effective recharge, R', relative to the potential recharge, R).

The calculation of the vulnerability index requires the estimation of the three parameters T, C'p/Cp and R'/R and then the index Iv is estimated by Equation (2) below:

$$\mathrm{Iv} = \alpha \frac{1}{T} + \beta \frac{\mathrm{C'p}}{\mathrm{Cp}} + \gamma \frac{\mathrm{R'}}{R} \tag{2}$$

With α, β, and, γ: positive weight coefficients and their determination is done by sensitivity tests of control wells in the study area. T: The transit time and C'p/Cp the degree of purification. The transit time T is the sum of the transit time (Ti) of each sub-layer crossing from the ground surface to the water table, it is calculated by Equation (3):

$$T = \sum_{i=1}^{n} \mathrm{Ti} \tag{3}$$

Where:

$$\mathrm{Ti} = \frac{\mathrm{hi}}{\mathrm{Vi}}$$

Vi: average infiltration speed characterizing each type of rock crossed by the pollutant;

Hi: thickness of each sub-layers constituting the unsaturated zone;

N: the number of sub-layers which is always finite.

The parameter (Ti) depends on several factors and the difficulty of its estimation is the choice of speed to be considered, Vi. This average speed filtration (Vi) characterizing the different types of rocks representing our study area (Table 1) was estimated from previous studies(Rehse, 1977; Maxe and Johansson, 1998; Amharref et al.. 2007).

The ratio C'p/Cp, is the degree of reduction in the concentration of polluted water on arrival at the water table. It is approached with the purifying power of Md cover layer (Bernoussi and Amharref, 2003). Its calculation considers that :

C'p/Cp = 1-Md in the case of partial purification

C'p/Cp = 0 in the case of total purification

Md is the purifying power and depends on the thickness and nature of layers crossed in unsaturated condition (Rehse, 1977; Lallemand-Barres and Roux, 1989). It is calculated along the vertical path by the relation:

$$\mathrm{Md} = \sum_{i=1}^{n} \mathrm{hi} * \mathrm{Ii} \tag{4}$$

Where hi: thickness of each sub-layers constituting the unsaturated zone ; Ii: purifying Rehse index defined in terms of physical and hydrodynamic parameters for different types of materials in unsaturated condition. It is related to the permeability and the retention capacity of the constituent's material concerned; n: the number of sub-layers constituting the unsaturated zone.

Table 1. Index of purification and filtration rate of different materials (Rehse, 1977).

Matériaux	Material	purification index	filtration speed (m/j)
Humus, 5-10 % humus, 5-10 %argile	Humus, humus 5-10%, 5-10% clay	0,8	0,86
Argile, limon argileux, sable très argileux, argile limoneuse,	Clay, clay loam, clayey sand, silty clay,	0,5	0,003-0,025
Silt argileux à silt, limon fin	Clayey silt to silt, fine silt	0,4	0,16
Silt, sable silteux, sable peu silteux et peu argileux, sable limoneux	Silt, silty sand, litle silty clayey sand, silty sand	0,22-0,33	0,54-4,32
Sable fin à moyen	Fine to medium sand	0,17	8,23-10
Sable moyen à grossier	Medium to coarse sand	0,1	19,2
Sable grossier	coarse sand	0,07	27
Gravier silteux, riche en sable et en argile	Silty gravel, rich in sand and clay	0,13	0,72
Gravier peu silteux, beaucoup de sable	Little silty gravel, lots of sand	0,08	144
Gravier fin à moyen riche en sable	Fine to medium gravel rich in sand	0,04	201
Gravier moyen à grossier, peu de sable	Medium to coarse gravel, litle sand	0,03	480
Galets	pepple	0,02	4 320

Degree of recharge R'/R: the recharge degree R'/R, represents the degree of aquifer recharge and is the transfer factor of pollutants to the water via the unsaturated zone. Potential contamination of a water table is therefore linked to this degree of recharge [Amharref et al., 2001]. However, this parameter is not easy to estimate; in this study it was evaluated by the water balance (see III.3).

Sensitivity Tests: the determination of the weight coefficients α, β and γ is by sensitivity tests, followed by multiple linear regression analysis of the index Iv and the three parameters (1/T, C'p/Cp and R'/R). This analysis is performed on the control wells.These wells are chosen to reflect the important variations in the three parameters (transit time, degree of purification and recharge degree). The fictive wells (wells No. 1111: dummy wells with T = 1, C'p/Cp = 1 and R'/R = 1) is taken into account as reference wells and used to classify all wells.

RESULTS AND DISCUSSION

Application of the DRASTIC method

The combination of the seven thematic maps recommended by the DRASTIC method yielded a vulnerability index (ID) of between 105 and 185. The vulnerability map drawn, for 2003, was obtained by the classification of these values into four classes: low, medium, high and extreme (Figure 2). These classes were determined by a compromise between the classifications of McCormack, Civita and De Régibus, Engel et al., and Corniello et al. [Mc Cormack, 1986 ; Civita and De Régibus, 1995 ; Engel et al., 1996 ; Corniello et al., 1997].

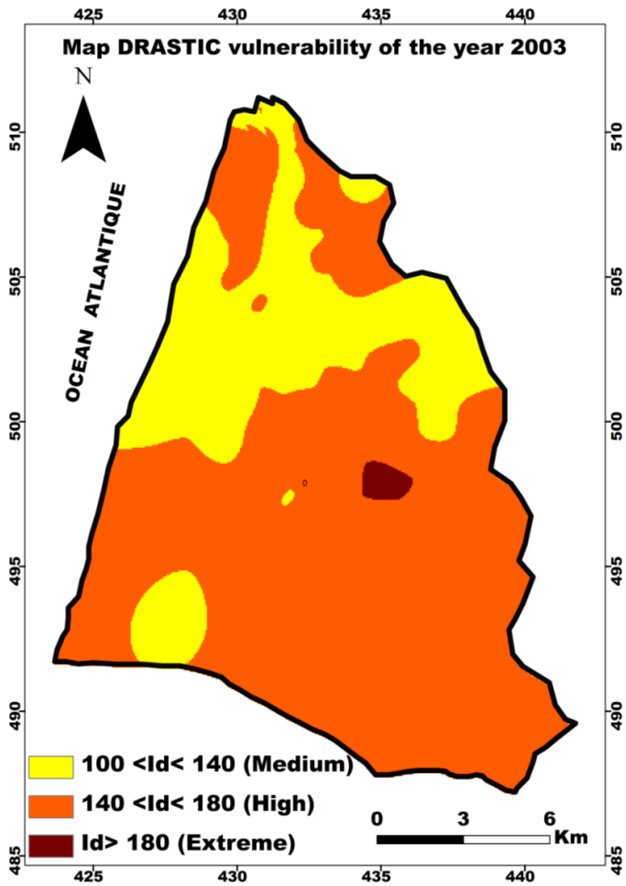

Figure 2: Map of inherent vulnerability of the web of R'Mel by DRASTIC method.

Application of the TCR method

Degree of recharge**: t**he groundwater recharge of R'Mel is mainly through the effective infiltration of rainfall and irrigation water returns. However, the return of irrigation water has not been considered in this part of study. Effective infiltration is determined by the water balance established by the method of Thornthwaite. To do this, we used climate data of 2003 at stations Larache, Laouamra and M'rissa. It should be noted that surface runoff has been neglected because of the sandy nature of the soil and low values of slopes of the R'Mel plain.

Transit and degree of purification Time**: t**hese two parameters were calculated using data provided by the Office of Agricultural Development Loukkos (ORMVAL), Agency Loukkos hydraulics Basin and the Water Department. These are the data from the records of drilling and wells, soil profiles and tracking data capturing groundwater piezometers of R'Mel. The interpolation of the calculated values in each data point, allowed us to get the map transit time and the degree of purification.

The weighting coefficients α, β and γ: for our study area, sensitivity testing of 15 wells selected controls (Table 2) gave normalized values for the coefficients α, β and γ which are respectively 0.4; 0.3 and 0.3 characterizing the aquifer of R'Mel; which seem to be different from those estimated for the Gharb aquifer (Amharref et al., 2007).

Table 2: Data and classification of control wells in 2003.

N° Wells	T 2003	1/T 2003	C'P/CP 2003	R'/R 2003	Iv medium 2003	Ranking
1687/3	379.9	0.0026	0	0.49	0.15	1
1396/3	7	0.1428	0	0.55	0.22	2
1535/3	3.12	0.3208	0	0.53	0.29	3
1534/3	2.39	0.4184	0	0.55	0.33	4
1685/3	1.84	0.5431	0	0.48	0.36	5
1414/3	1.66	0.6018	0.112	0.5	0.42	6
1661/3	1.14	0.8801	0	0.55	0.51	7
1365/3	1.29	0.7781	0.474	0.5	0.6	8
1111/1	**1**	**1**	**1**	**1**	**1**	**9**
342/3	0.56	1.7948	0.475	0.55	1.01	10
2643/3	0.55	1.8066	0.812	0.48	1.09	11
1413/3	0.41	2.4307	0.362	0.5	1.2	12
1580/3	0.35	2.8504	0.858	0.48	1.51	13
2735/3	0.29	3.4704	0.577	0.49	1.67	14
1581/3	0.18	5.6118	0.816	0.49	2.61	15
1401/3	0.12	8.23	0.83	0.48	3.58	16

The vulnerability maps obtained by the two methods show a variability in areas of different classes (Figure 2 and Figure 3). The class of high vulnerability dominant 72% map produced by the DRASTIC method to the detriment of other classes (low, medium and extreme) which represent 0%, 27% and 1%. While the class extreme vulnerability dominates 41% map produced by the TCR method, and other classes occupy respectively 0.3%, 33.7%, 25% of the rest of the map (Table 3).

Comparing the two vulnerability maps obtained by the two methods was made by surface analysis to spatially locate areas of similarity and dissimilarity. This class analysis is done by subtracting the two vulnerability maps obtained by assigning the values 1, 2, 3 and 4 respectively to the low, medium, high and extreme classes. The resulting map revealed that DRASTIC and TCR methods generated:

A similar index of 44% surface of the study area;

A different index of 56% of the surface of the study area. This difference is especially for high and extreme vulnerability classes.

The correlation of the results obtained by the two methods and the actual characteristics of the natural environment, emphasized:

A better concordance between the results obtained by TCR method and characteristics of the study area;

Undervaluation of the vulnerability index by the DRASTIC method for areas that should really be classified in areas of extreme and high vulnerability.

This disparity in results obtained by the DRASTIC and TCR methods can be explained by the difference in their concepts. Indeed, the two methods DRASTIC and TCR are methods of weighting and indexing parameters, but the first uses seven parameters while the second uses only three. The use of a large number of parameter (7) causesa high redundancy. The effect of the most important parameters (water table depth (D), lithology of the unsaturated zone (I), recharge (R)) was masked by other parameters such as permeability (C) and lithologyof aquifer (A).On the other hand, Both methods use weighting coefficients, but the weight of each parameter for DRASTIC method is selected for the first time to a definite special site are subsequently used universally. In the case of the TCR method

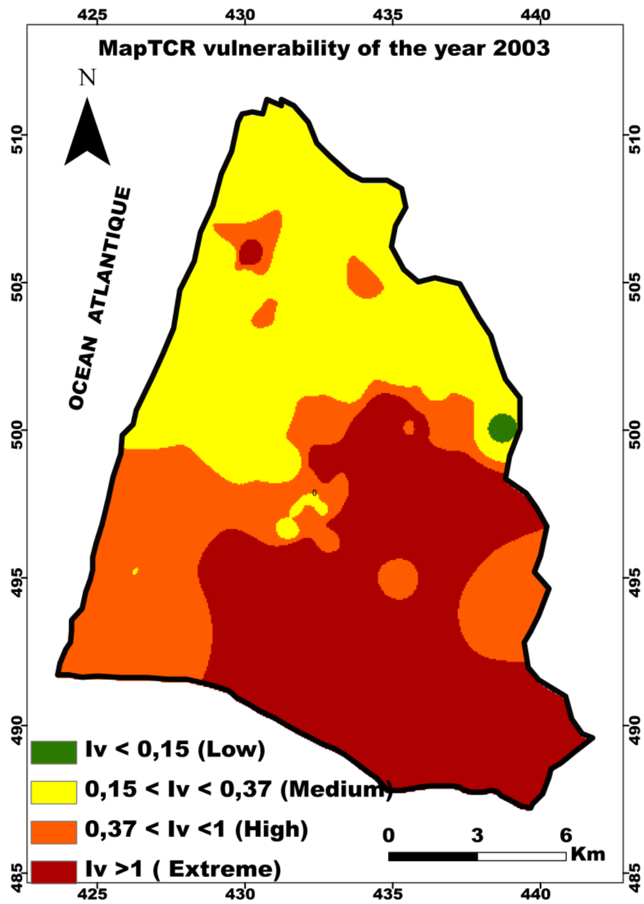

Figure 3. Map of inherent vulnerability of the web of R'Mel by the TCR method.

Table 3. Classes and degrees of vulnerability and percentage of areas of the two methods DRASTIC and TCR for 2003.

CLASS OF VULNERABILITY	DRASTIC INDEX	PERCENTAGE	TCR INDEX	PERCENTAGE
Low vulnerability	ID < 100	0%	Iv < 0,15	0,30%
Medium vulnerability	100 < ID < 140	27%	0,15 < Iv < 0,37	33,70%
High vulnerability	140 < ID < 180	72%	0,37 < Iv <1	25%
Extreme vulnerability	ID > 180	1%	Iv > 1	41%

the weighting coefficients are determined by the sensitivity tests that accurately indicate the specific factors for each study area (facts sensitivity tests for Gharb aquifer gave different results compared toour study area) (Amharref et al. 2007).

The DRASTIC method takes account of the saturated zone, while TCR considers only the water table cover. To assess the effect of the parameters "A" and "C", we applied the sensitivity analysis. This analysis showed that these two parameters affect the least variation in the vulnerability index. Therefore, this difference in the concept of these two methods does not explain the difference in results

(56%). Also, for the method DRASTIC intervals of each parameter were performed based on the conditions of a definite site. The limits of the standard classes do not often correspond to the reality of the study area and aggregation of the coast is not always identical to that defined by the DRASTIC method. For the recharge parameter, for example, the maximum score (9)is attributed to recharge values exceeding 250 mm/year. But in our study area ranges recharge is between 357 and 532 mm/year, which causes a reload map with a rating maximum over the entire surface of the water table of R'Mel. Application of the DRASTIC method without adapting classes to the particularities of territories may not give accurate results and thus not be representative of reality.

CONCLUSION

The mapping of the intrinsic vulnerability of the R'Mel aquifer, conducted by both methods DRASTIC and TCR, revealed that the water table has a very high overall vulnerability with respectivedominance of high and extreme vulnerability classes.The spatial analysis of vulnerability classes by surfaces showed a concordance of 44% of the results (identical index) by both methods (DRASTIC and TCR). While 56% of remaining surface have different indexes and it mainly concerns the classes of high and extreme vulnerability.

The detailed comparison based on hydrogeological data of each point of the data revealed that the TCR method proves the safest and best represents the characteristics of our study area. As against the DRASTIC method underestimated the high and extreme vulnerability of the study area. To confirm this result and validate the vulnerability maps produced by the two approaches, a confrontation of these maps with the results of pollutant analysis is required. This constitutes a work in perspective.

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