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Marine and Freshwater Research

Supplementary Material

Assessing coastal aquifer vulnerability to seawater intrusion: adaptation of the DCG method and application to the Dradère–Souière coastal aquifer in northern Morocco

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In this paper a vulnerability index Iv is proposed to express:

$$\text{DCG} - \text{Index} = \alpha \frac{1}{D} + \beta C + \gamma \frac{1}{G} \qquad \text{(S1)}$$

The difficulty in using this index lies in the choice of the weights α, β, and γ, because one does not have a priori values of Iv to be able to use multiple linear regression techniques. Indeed, the field data allow us to measure and calculate D, C and G. However, the determination of α, β and γ requires knowledge of the Iv index which is not known a priori. For this purpose, sensitivity tests followed by multiple linear regression analyses were performed on control wells, as follows:

1. Evaluation of Iv for control wells

To determine an approximate value of Iv for some so-called "control" wells, a four-step process was used:

Step 1. Selection of control wells

From the analysis of the data collected on the coastal plain of Dradère – Souière, 9 control wells were selected representing significant variations of the different parameters (Distance from saltwater D, aquifer hydraulic Conductivity C and hydraulic Gradient G). In addition to these control wells, a Reference Well (R.W) was considered, which is a fictitious well, with D = 1, C = 1 and G = 1.

Step 2. Qualitative classification of the vulnerability of control wells

Based on the analysis of the Distance from saltwater (D), the aquifer hydraulic Conductivity C, and the hydraulic Gradient (G), along with geological and hydrogeological data specific to the study area, the control wells were qualitatively ordered based on increasing vulnerability. This ranking was facilitated by determining the sign of the change in the vulnerability index (Iv) for two consecutive wells with the unknown weights ($Iv_{i+1} - Iv_i$). The results obtained give the ranking according to the order given in Table S1 (well number 1 is the least vulnerable).

Table S1. Control well data and vulnerability classification

Number of control wells	X	Y	D (km)	C (m h^{-1})	G (%)	IV average
1	442000	477950	21.99	0.22	1.8	0.2789
2	430043	481906	9.45	0.31	1.5	0.3415
3	437000	471200	19.71	0.27	0.8	0.4197
4	435370	467450	19.53	0.42	0.8	0.4997
5	429600	476900	10.81	1.14	0.8	0.7284
6	432200	469175	15.95	1.17	0.8	0.8129
R.W (7)			1	1	1	1
8	417550	467300	3.21	2.80	0.8	1.5339
9	423419	486629	1.55	2.47	0.5	1.8478
10	420625	482400	0.49	2.07	0.4	2.2156

Step 3. Analysis of the effect of the variation of the different parameters

Based on the obtained ranking (Table S1), an initial analysis was performed to assess the effect of the variation in the different parameters (D, C and G) on vulnerability. It can be seen that the three parameters D, C and G have more or less the same influence on the Iv-DCG index. To determine the range of Iv variation (Eqn S2), thenormalized index (Iv ÷ Ivmax) were considered with respect to the maximum index (Iv-max, Eqn S3). The normalized index Iv therefore varies between 0 and 1. With this normalization, the normalized weights α, β and γ can then be considered to vary in the interval [0,1] and α + β + γ = 1.

$$Iv = \alpha\ 1/D + \beta\ C + \gamma\ 1/G \qquad (S2)$$

$$Iv\text{-}max = \alpha + \beta + \gamma \qquad (S3)$$

A series of simulations were then run for different values of α, β and γ in the interval [0,1] with a step size of 0.1 for each weight. The choice of 0.1 is made from the qualitative ranking, as a step size of 0.01 would mean that the effect of the parameter in question is negligible compared to the others. For each combination and using the calculated Iv index, control wells were ranked and outliers (not the same ranking obtained in Table S1) were eliminated. The selected combinations were graphically compared and found to give the same qualitative ranking (see Figures S1–S3).

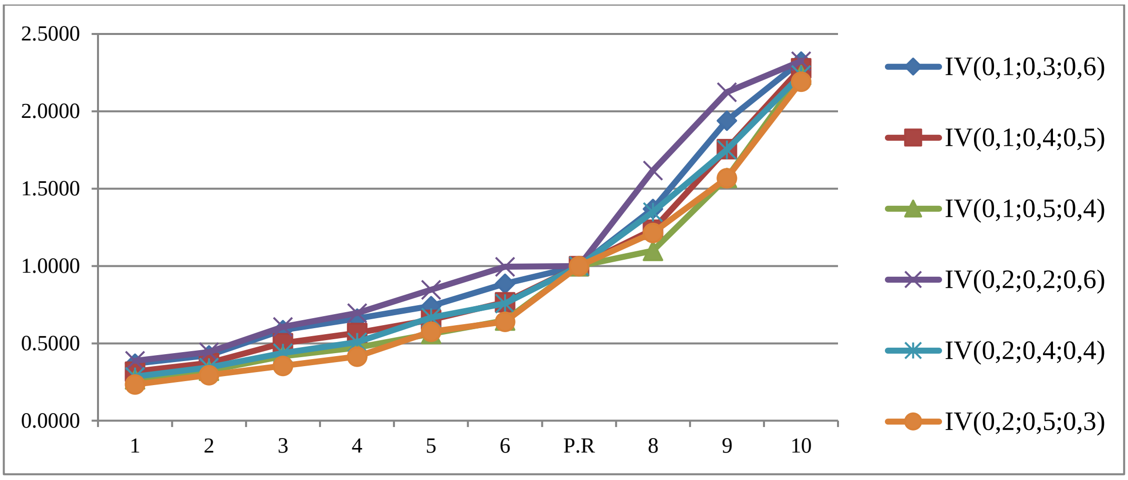

Fig. S1. Curves representing Iv for different combinations of weighting coefficients in the interval [0-1] and with a step of 0.1

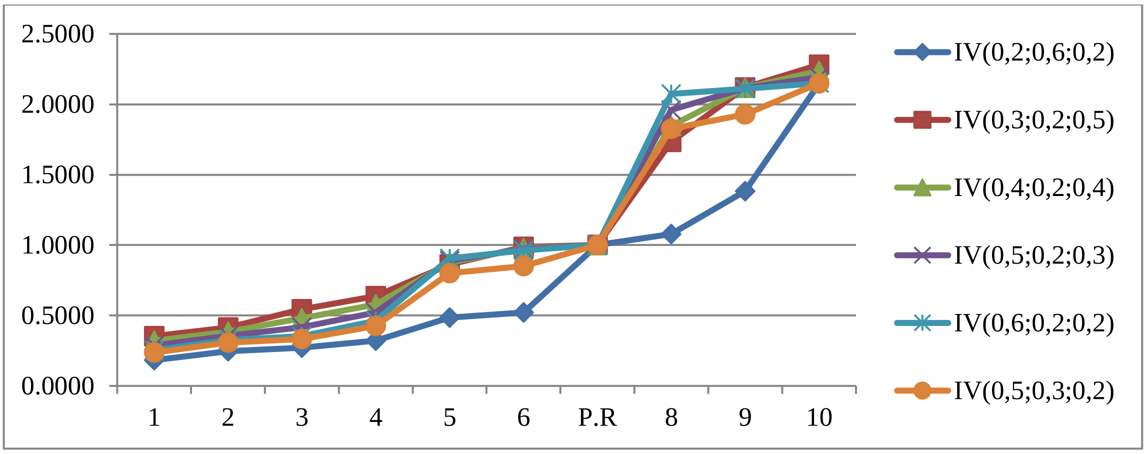

Fig. S2. Curves representing Iv for different combinations of weighting coefficients in the interval [0-1] and with a step of 0.1

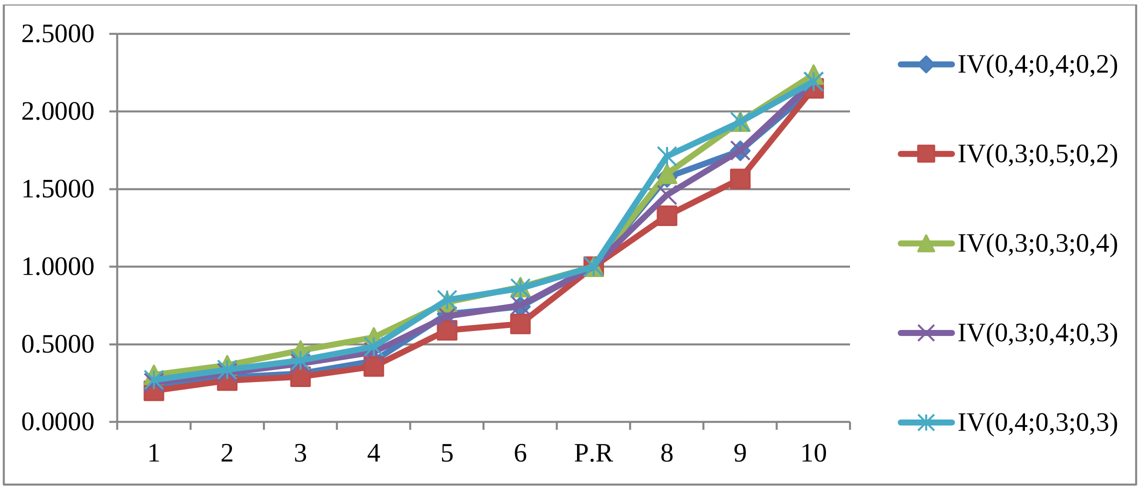

Fig. S3. Curves representing Iv for different combinations of weighting coefficients in the interval [0-1] and with a step of 0.1

Step 4. Estimation of the Iv index for control wells

In order to have an approximate value of Iv with a minimum error of the results obtained by the selected combinations, a mean value of Iv was considered, which is the average of these results, resulting in approximate values of Iv for the control wells. These results are provided in Table 1. Figure S4 gives a graphical representation of "average Iv" for different selected combinations.

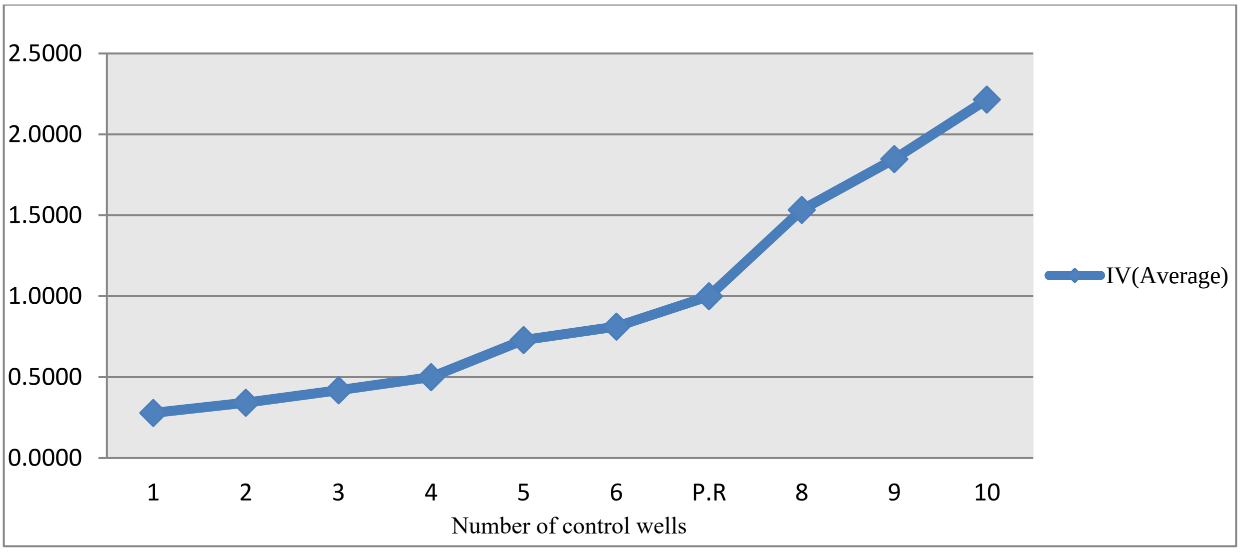

Fig. S4. Representation of average Iv for different retained combinations

2. Evaluation of weighting coefficients (α, β and γ)

Using the Iv values obtained for the different control wells, multiple linear regression was performed to determine the values of α, β and γ (Table S2). Among the outputs, the results appearing in Table S2 were noted. The best linear combination (in the sense of the least squares criterion) estimating the vulnerability index as a function of the three parameters is therefore approximately:

$$\text{DCG} - \text{Index} = 0.36\,\frac{1}{D} + 0.31C + 0.33\,\frac{1}{G} \qquad \text{(S4)}$$

The model obtained describes a highly significant relation between the vulnerability index (Iv) and the three parameters (D, C and G). It shows that the importance of these three parameters on the vulnerability index (Iv) is relatively similar (Table S2), with weighting coefficients α of 0.36, β of 0.31 and γ of 0.33.

Table S2. Results of the multiple linear regressions between the vulnerability index and the three parameters (C, D and G).

Parameters	**Coefficients**	**Regression statistics**	
D	0.36	Coefficient of multiple determination	1
C	0.31		
G	0.33	Erreur-type	1.29319E-16