UNIVERSITÀ DEGLI STUDI DI MILANO
FACOLTÀ DI SCIENZE MATEMATICHE, FISICHE E NATURALI

A proposal to integrate the analysis of trend concentration of contamination in wells in groundwater vulnerability assessment

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EC “Groundwater Quality Related” Directives

- **Article 10 of the Nitrates Directive (Directive 91/676/EEC) requires that Member States identify areas where groundwater is or will be potentially affected by nitrate contamination;**

- **Directive 2000/60/EC (Italian Law D.Lgs. 152/2006) requires the identification of significant and sustained upward trends in the concentration of contaminants in groundwater;**

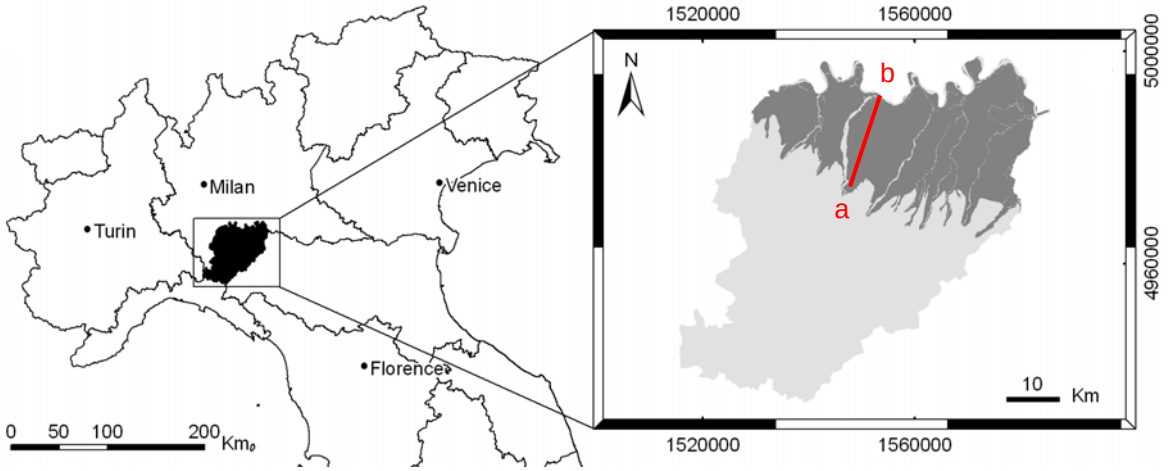
- **Groundwater Directive 2006/118/EC (Italian Law D.Lgs. 30/2009) has the objective of preventing or reducing nitrate contamination, implying the obligation to prevent further deterioration of groundwater quality.**

THUS, THE NECESSITY TO:

- **identify most vulnerable areas where concentrations are susceptible to exceed a pre-established threshold and where concentrations show an upward trend;**

- **understand the cause-effect relationship between concentrations, trends and variation of the predictor factors responsible for both of them.**

Study Area and Hydrogeological Setting



Province of Piacenza, Italy

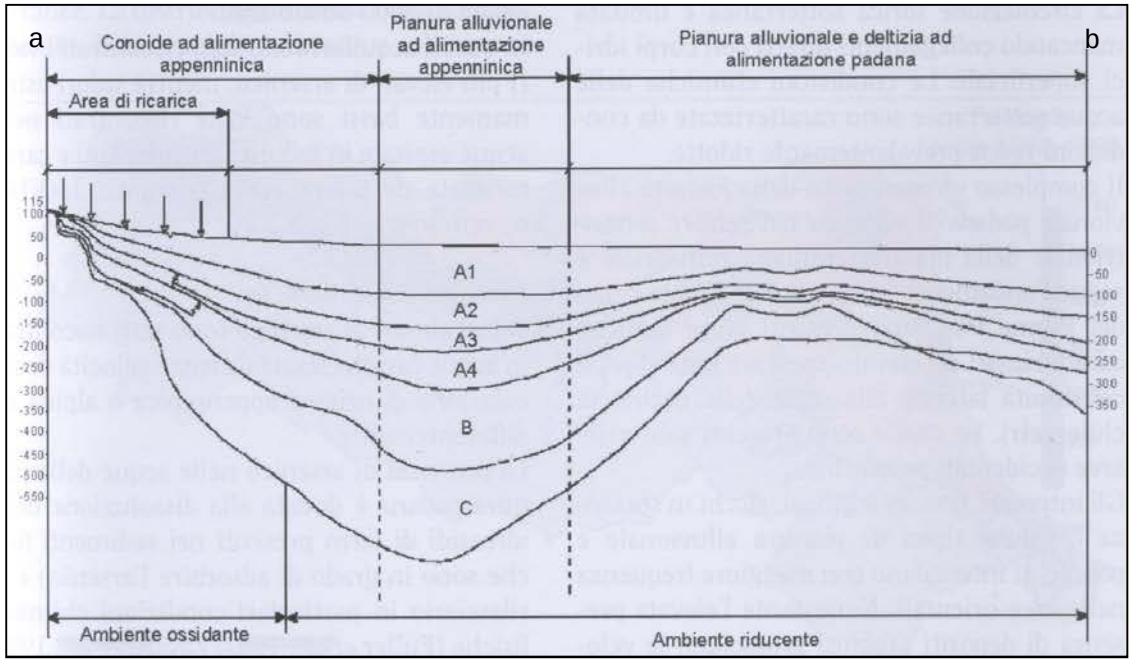
Three main aquifer units: A, B and C

The shallow unconfined-semiconfined aquifer considered in this study can be identified with two A sub-units (A0 and A1) in the alluvial plain and with the mixed aquifers in the recharge zone

The aquifer A is constituted mainly of gravel and sand with lenses of clay which thicknesses are highly variable

Hydraulic Conductivity ranges from 10^{-3} to 10^{-5} m/s

Porosity ranges from 15 to 25%



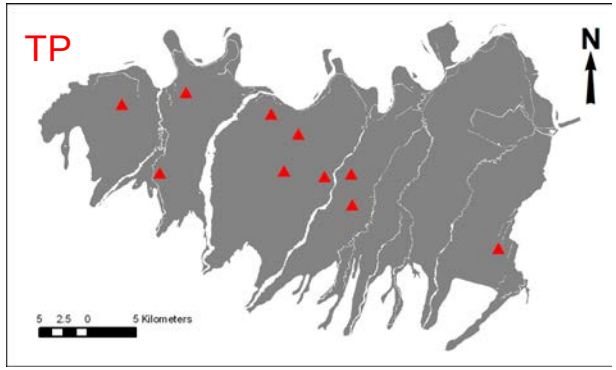
Methodology: Weights of Evidence

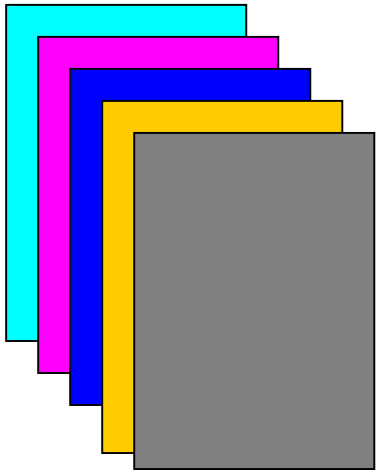
Prior probability → **Evidential themes** → **Post probability**

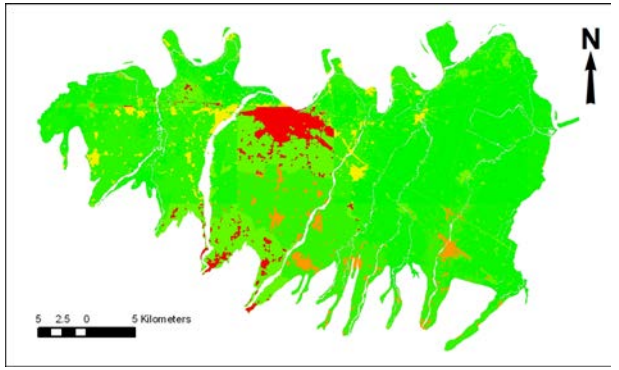
Based on Training Points: contaminant concentration data from a groundwater monitoring net

Natural and anthropogenic factors influencing groundwater vulnerability (from the conceptual model)

Dependant on the spatial association between training points and evidential themes







$$P_{prior} = \frac{N_{pix}(\text{TP})}{N_{pix}(Area)}$$

$$\log_e O\{T \mid V_i\} = \log_e O\{T\} + W^+$$

$$\log_e O\{T \mid V_i^{\wedge}\} = \log_e O\{T\} + W^-$$

$$\log_e O\{T \mid V_1 \cap V_2 \cap .....V_n\} = \log_e O\{T\} + \sum_{i=1}^{n} W$$

P_{post}

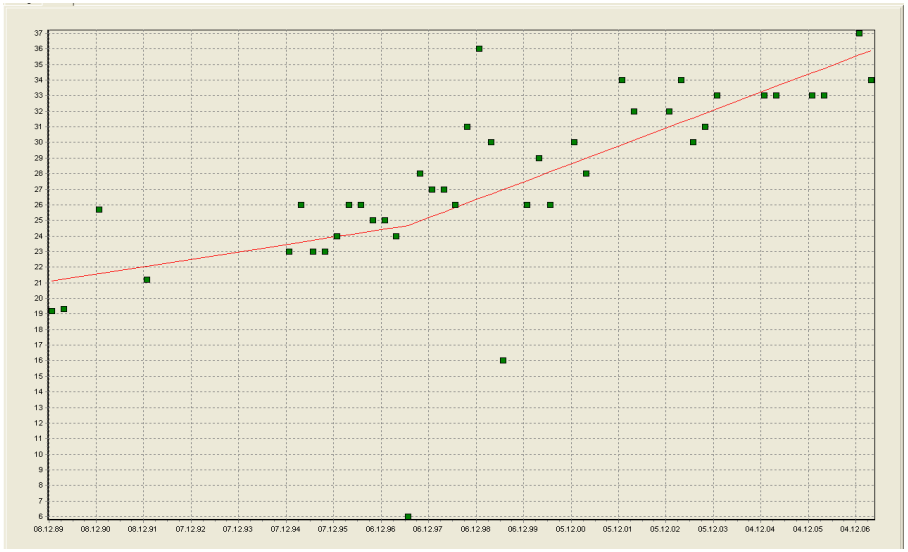
Weights of Evidences (WofE)

- Continuous explanatory variables are generalized as two or more classes to identify areas having relative high degree of spatial association with the location of occurrences (TPs);
- weights of each class are not arbitrarily assigned but calculated from existing correlation between the response variable (occurrences) and the predictive factors in the study area;
- the most appropriated explanatory variables may be objectively selected reducing the influence of subjective opinions;
- calibration and validation procedures such as the construction of success and prediction curves can be used to check respectively the robustness of the model assumptions and the predictive power of the results;

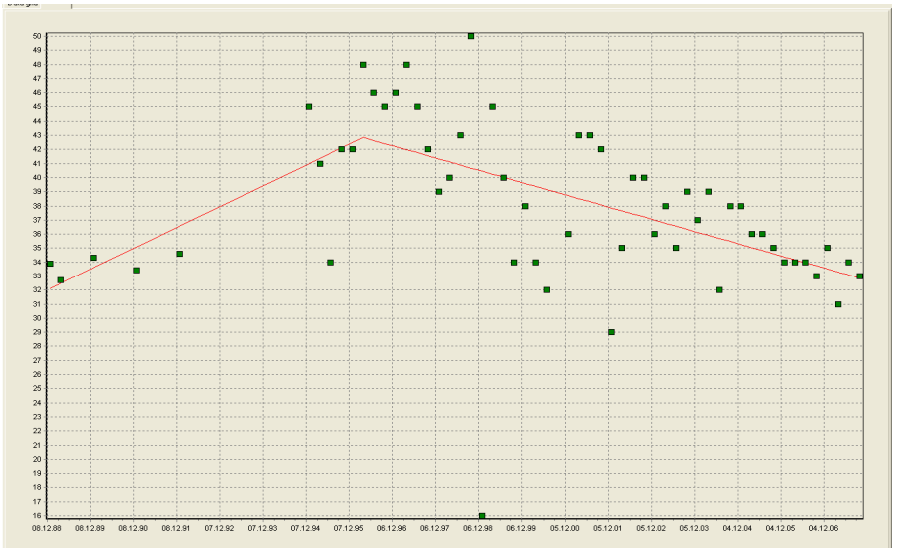
Trend Analysis (nitrate in groundwater)

Concentration trends in monitoring wells were evaluated using the **GW-Stat software***

Increasing upward trend



Upward-downward trend



* J. Grath, A. Scheidleder, S. Uhlig, K. Weber, M. Kralik, T. Keimel, D. Gruber (2001): "The EU Water Framework Directive: Statistical aspects of the identification of groundwater pollution trends, and aggregation of monitoring results". Final Report. Austrian Federal Ministry of Agriculture and Forestry, Environment and Water Management (Ref.: 41.046/01-IV1/00 and GZ 16 2500/2-I/6/00), European Commission (Grant Agreement Ref.: Subv 99/130794), in kind contributions by project partners. Vienna.

Ranking of Monitoring Wells

Class	Trend	Inversion
1	Increasing upward	
2	Upward	
3	Decreasing upward	
4	Downward-upward	More than 5 years ago
5	Downward-upward	Less than 5 years ago
6	Downward-constant	
7	Upward-constant	
8	Upward-downward	Less than 5 years ago
9	Upward-downward	More than 5 years ago
10	Downward	

Weighting formula

$$w = \frac{\left(n - r_j + 1\right)}{\sum_{j=1}^{n}\left(n - r_j + 1\right)}$$

Where:

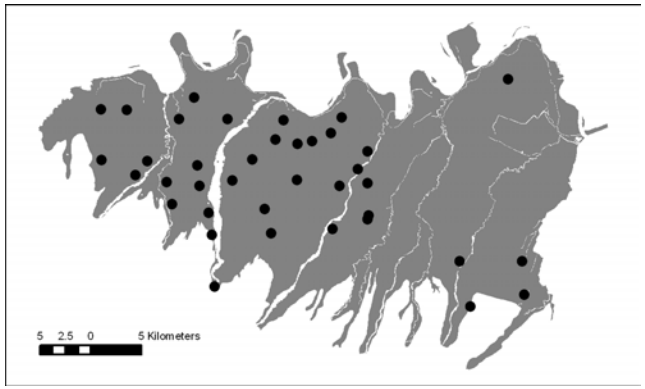
n is the number of classes

rj is the rank of the class j

Well_ID	cl. trend	weight trend
PC03-02-a1	7	0,0727
PC07-00-a1	4	0,1273
PC28-00-a1	3	0,1455
PC33-01-a1	1	0,1818
PC48-00-a1	5	0,1091
PC56-09-a1	9	0,0364
PC56-11-a1	4	0,1273
PC80-00-a1	7	0,0727
PC09-01-a2	7	0,0727
PC11-02-a2	7	0,0727
PC12-01-a2	7	0,0727
PC13-00-a2	7	0,0727
PC19-00-a2	7	0,0727

Response Variable and Training Points

The response variable has to be expressed as binary

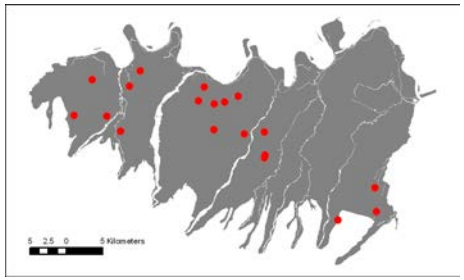


Regional monitoring-well network for the shallow aquifer (38)

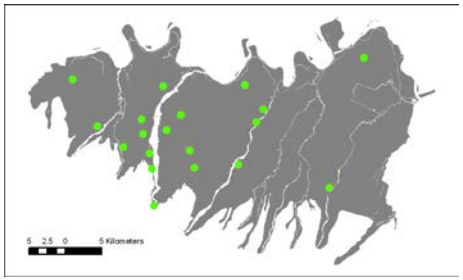
Threshold value →

Median value of rank

“Critical” wells (19)

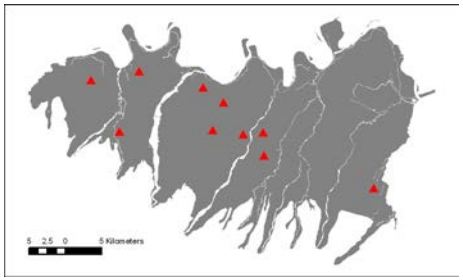


“non critical” wells (19)

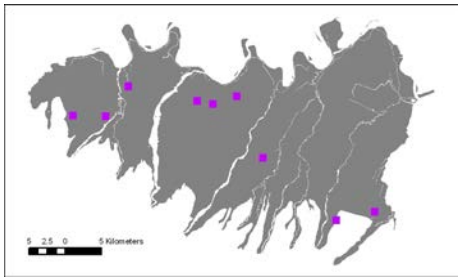


N

Training subset (10)



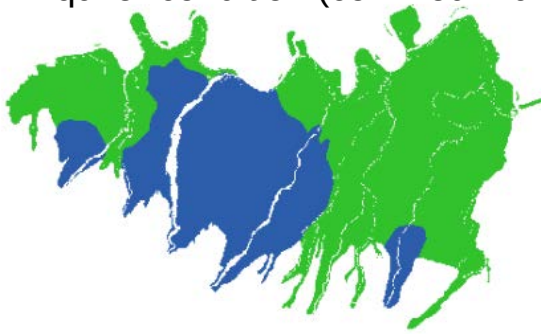
Success subset (9)



Evidential Themes

N

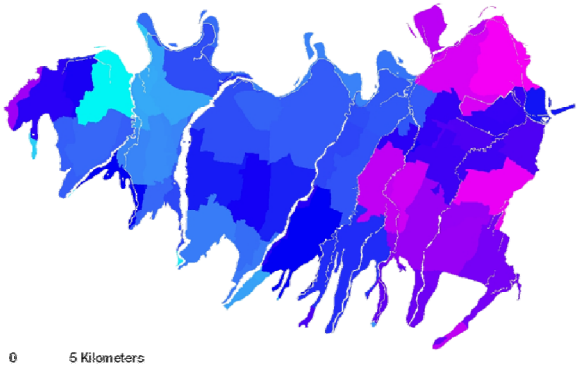
Aquifer condition (confined – unconfined)



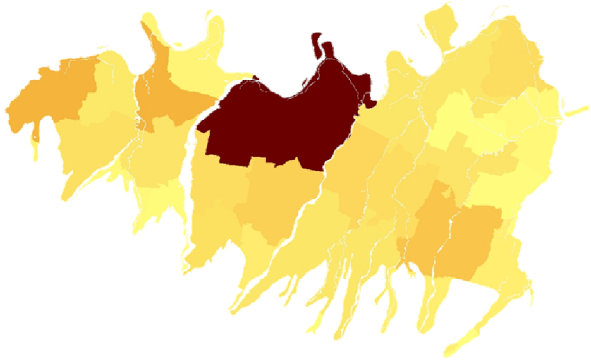
Effective infiltration

Groundwater depth

Variation of livestock manure nitrogen loading

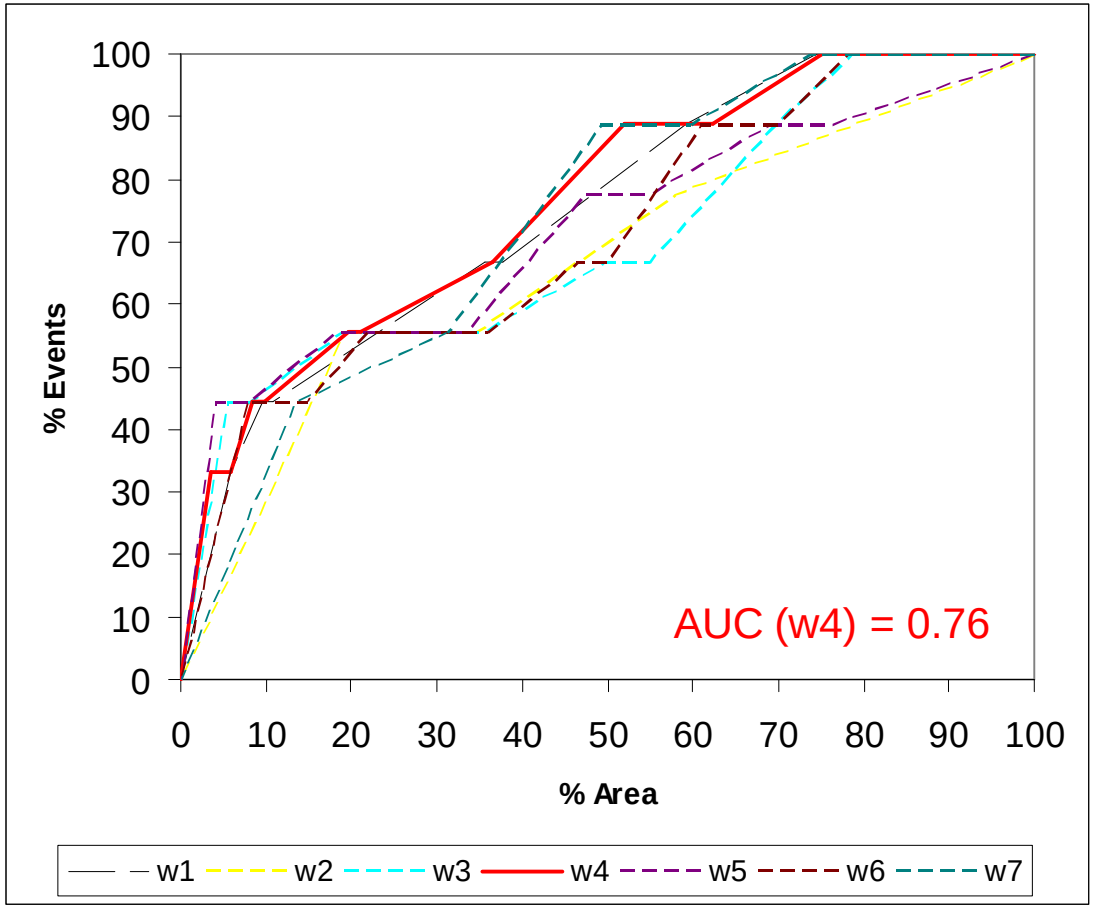


Variation of population density



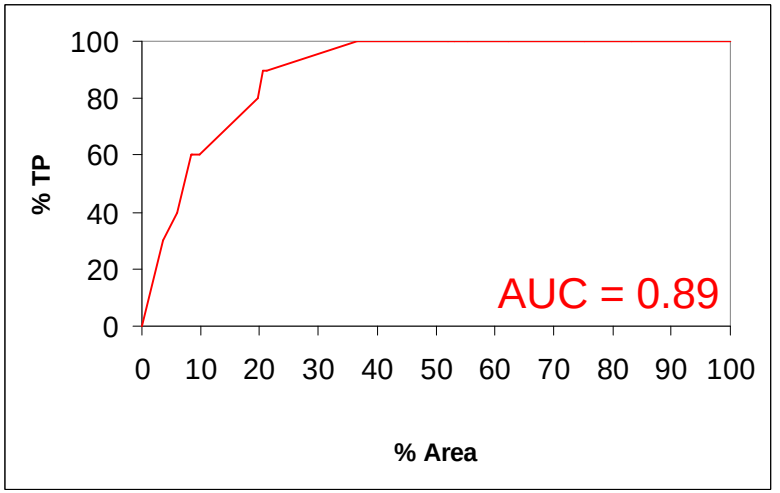
Success and Prediction Curves

Prediction curves for all models

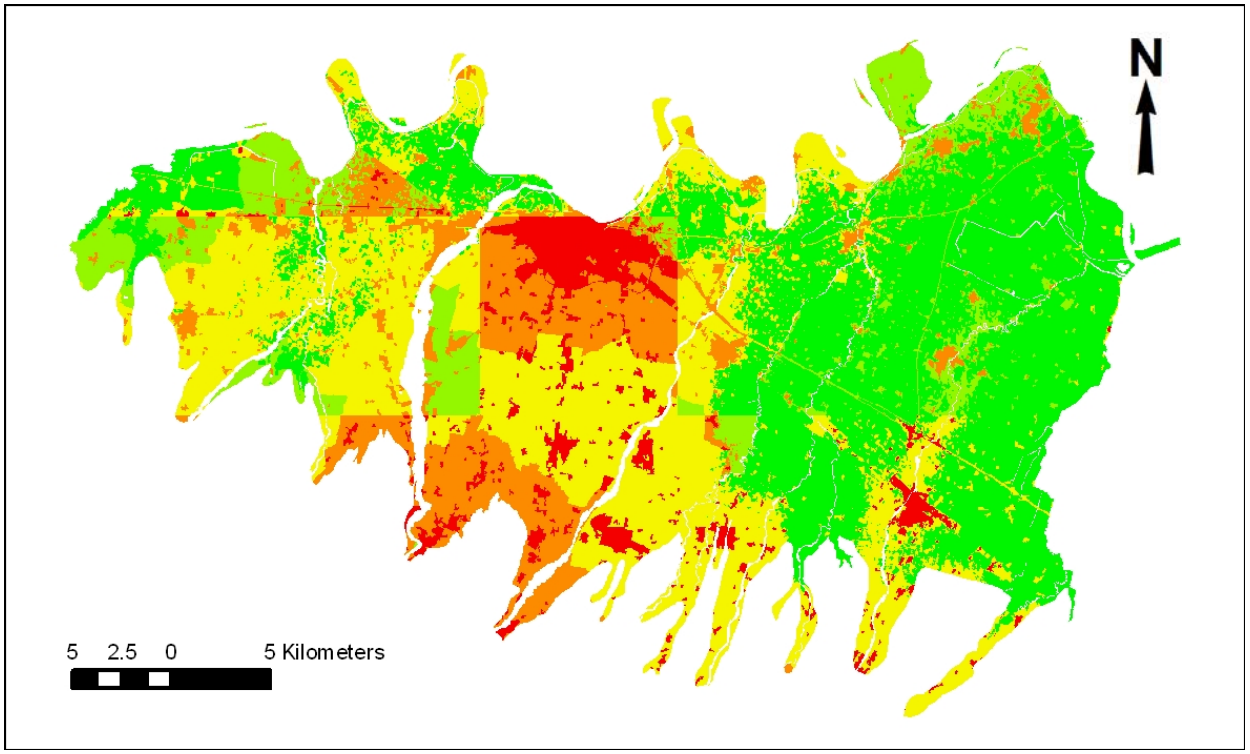


Simulations using different combination of evidential themes were performed. Prediction curves were used to select the “best model”

Success curve for the model w4



Vulnerability Map



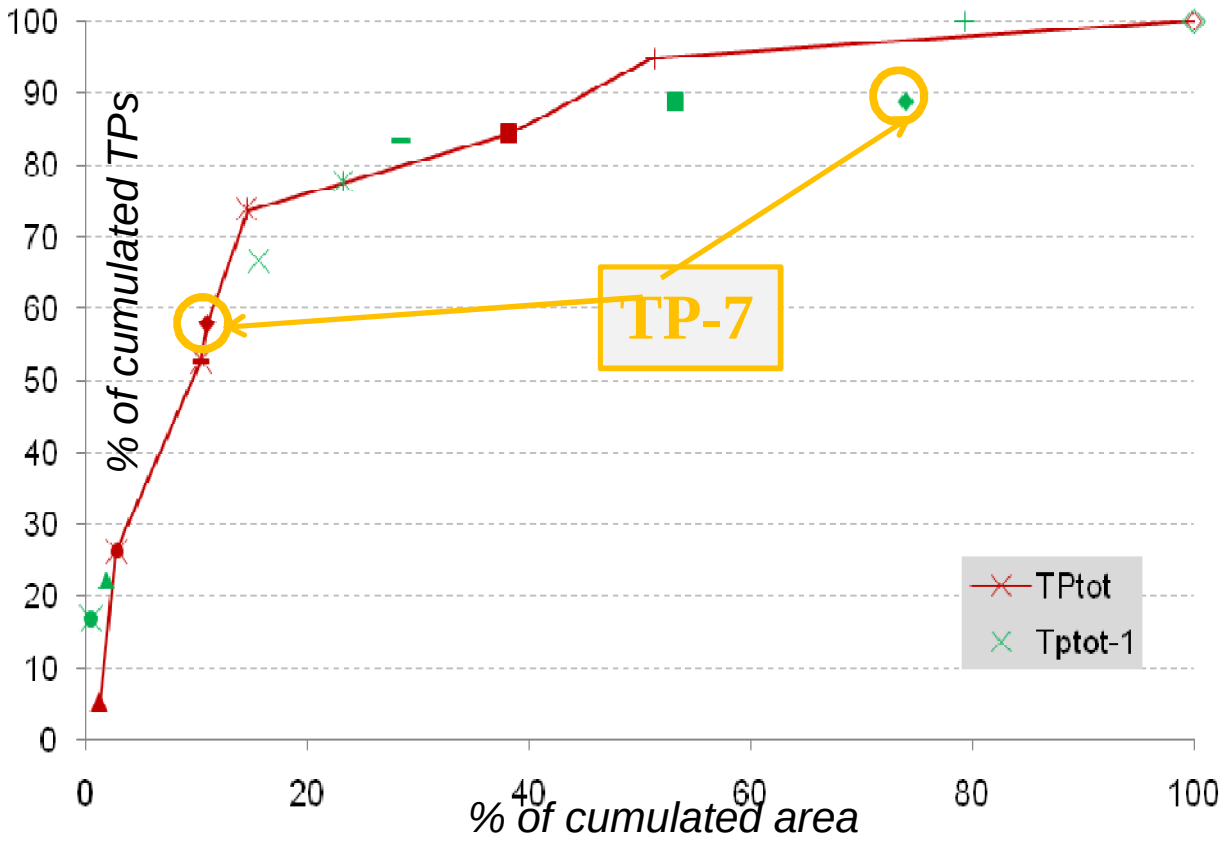
Vulnerability map obtained by reclassifying the posterior probability map into five classes using the geometrical interval method

Vulnerability class

1 2 3 4 5

Vulnerability increases from 1 to 5 (each class contains approximately the same number of different post probability values, not the same number of pixels)

Sensitivity analysis



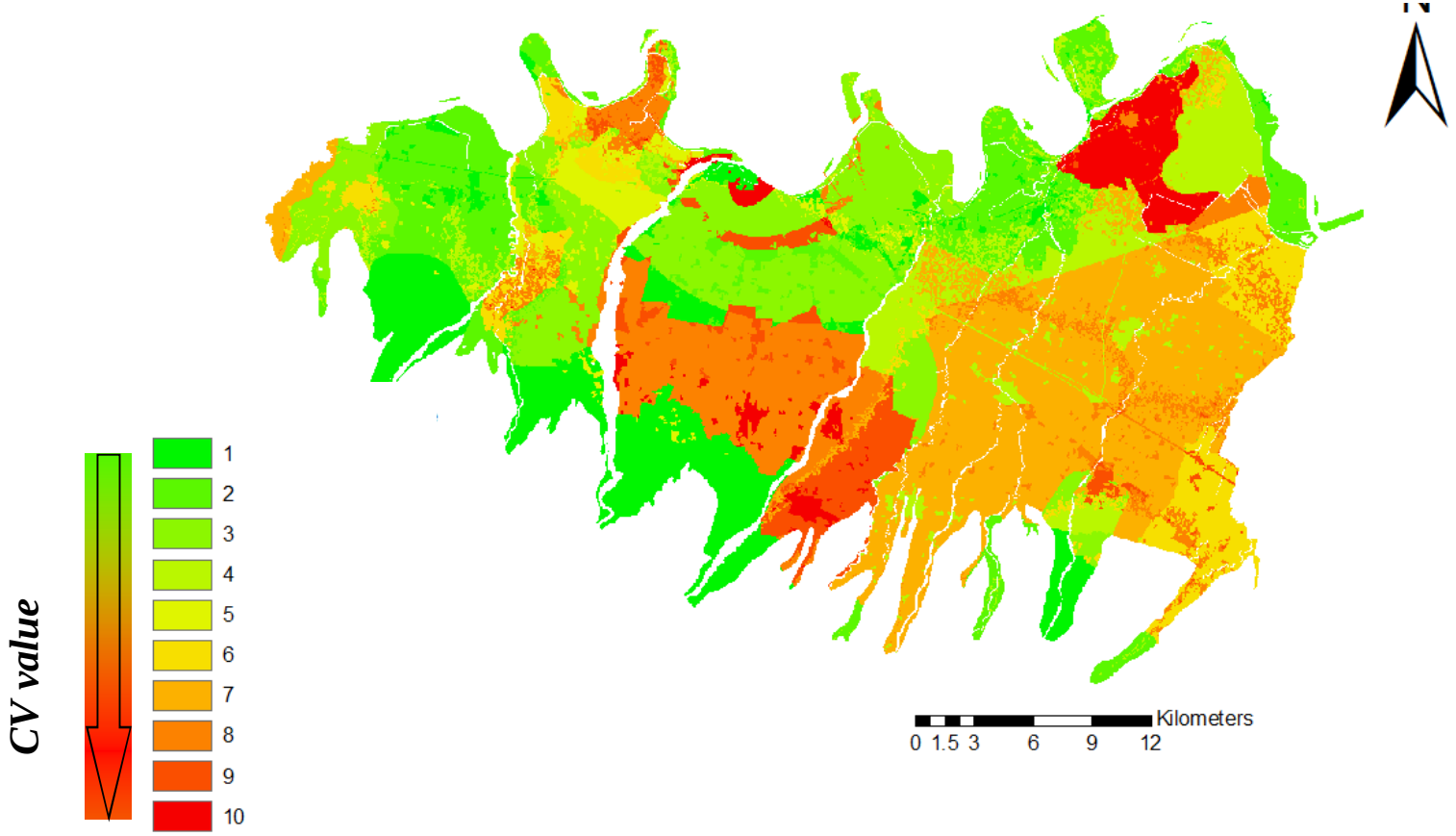
10 different analyses using 9 of the ten TPs

n_TP	%Atot	%TPtot	%Atot-1	%TP-1
6	1.259	5.263	1.850	22.222
3	2.767	26.316	0.577	16.667
9	2.767	26.316	0.577	16.667
2	10.375	52.632	15.538	66.667
8	10.375	52.632	28.381	83.333
7	10.988	57.895	74.008	88.889
1	14.540	73.684	23.123	77.778
10	38.085	84.211	53.126	88.889
4	51.235	94.737	79.325	100.000
5	100.000	100.000	100.000	100.000

Posterior probability calculated in the pixel of the not included TPs has been plotted on the success curve

Sensitivity analysis

Map representing classes of coefficient of variation (CV) of posterior probability obtained from results of the ten simulations performed for the sensitivity analysis



Conclusions

- **The identification of areas where groundwater is characterized by upward concentration trend of contaminants is required by EC laws;**

- **even when specific vulnerability maps correctly represent the present status of groundwater contamination, they could not be able to identify areas characterized by upward trend and therefore could not be a useful tool for preventing further deterioration of groundwater quality;**

- **results of this approach can be easily integrated by a WofE model which uses recent concentration data to produce a vulnerability map which considers both trends and present contamination in groundwater;**

- **the integration of the time variable in groundwater vulnerability assessment is a useful tool to support land-use planners and groundwater management.**