Geostatistical analysis of groundwater nitrates distribution in the Plain d'Alsace

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Abstract: The groundwater of the Plaine d'Alsace (France) is one of the largest water reservoir in Europe. It is highly vulnerable to pollutants coming from anthropic activities (industrial and agricultural). The monitoring carried on by the local agencies on the groundwater pollution concurred to form a very large public database on water quality. In this study the nitrate concentration has been examined in detail for two years, namely 1997 and 2003, for which dense sampling was available, and the evolution of the distribution of the pollutant has been highlighted.

Keywords: groundwater, nitrates, geostatistics, estimations

1. Introduction

The cartographic representation of a pollutant distribution in a large area is a key tool in the safeguard of the hydraulic resources. From the monitoring data, a correct description of the pollution can be reached taking account of the regional character of the relevant variables (G. Matheron, 1972), in the geostatistical framework (de Fouquet, 2006). The groundwater of the Plaine d'Alsace in the North East of France is highly vulnerable to pollutants, due to the intense anthropic activities (agricultural, industrial, etc.) on the whole area (BRGM, 2006). The use of the hydraulic resource for domestic and industrial purposes makes its safeguard essential for the sustainable development of the region. The present study examines the distribution of nitrates and its evolution for the years 1997 and 2003.

Quantitative and qualitative information about the groundwater were deduced form ADES groundwater national portal. D'Agostino et al. (1998) analyzed the distribution of nitrates in the groundwater of Lucca plain (Italy) with reference to three different periods of the same year. In this study the concentration of nitrates measured in the 1997 and 2003 were analysed with reference to the same time interval, namely August and September of each year. A multivariate approach allowed the representation of the evolution of nitrates concentration in the reference time interval.

2. Data Analysis

Figure 1 shows the nitrates concentration monitoring points for 1997 and 2003 data sets (i.e. 696 and 601 monitoring points respectively for 1997 and 2003). Full details on data sets can be found in Spacagna (2009). In order to perform a multivariate variographic analysis, 574 monitoring points belonging to both data sets were identified. The considered measures are related to a seven weeks time interval, during which stationary hydraulic regime for groundwater was assessed. In Table 1 the main statistical parameters of the two data sets are summarized. The histograms highlight the frequencies of concentrations over the threshold value (red for 1997 and blue for 2003 in Figure 1). The highest concentrations of nitrates are mostly located along the western border of the geographical area, between the Vosges and the Plain of Alsace, characterized by geological discontinuities, relatively small thickness of the groundwater and intensive agricultural activities.

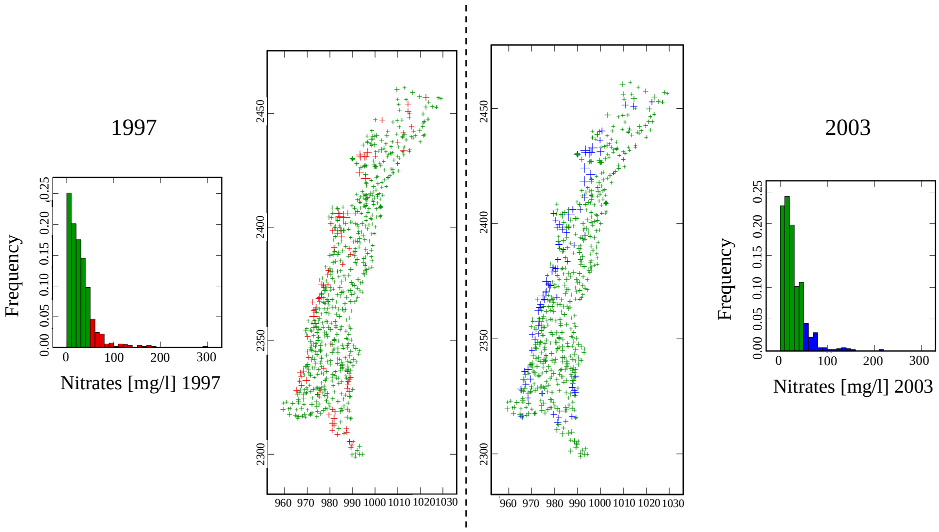

Figure 1: Monitoring points localisation a)1997; b) 2003 and nitrates concentration histograms

The good correlation (ρ = 0.86) between data of 1997 and 2003 sets is shown by Figure 2, where the nitrate concentrations are grouped in 30 classes ranging from 0 to 300 mg/l. The values greater than 100 mg/l or between 50 and 100 mg/l are mainly located under the bisector line, as well as the empirical regression of 2003-concentrations on 1997-concentrations. This suggests a decrease in the average concentration from 1997 to 2003.

Directional variographic analysis on different observation scale highlighted a geometrical anisotropy of the concentration at great distances, with a greater continuity along the N15° direction, according to the main flow direction of the Rhin river, whereas no anisotropy was detected at small distances (up to 5 km). The experimental variogram was then calculated with reference to the directions 15°, 60°, 105° and 150° setting a 4 km step. The simple variograms for 1997 data (γ_{97}) and 2003 data (γ_{03}) and the cross-variogram ($\gamma_{97,03}$) are fitted by means of a co-regionalisation linear model, considering the phenomenon as a sum or superposition of independent processes occurring at different spatial scales. The parameters of the theoretical variogram models are reported in Table 2.

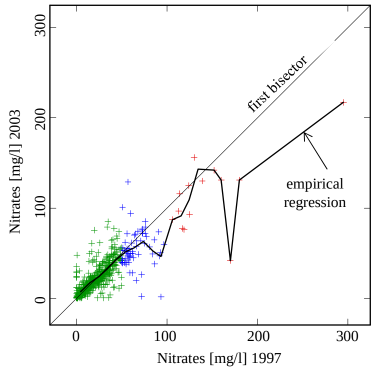

Figure 2: Correlation between the concentration of nitrates in 1997 and 2003

	1997		2003	
	complete set	common data	complete set	common data
points	696	574	601	574
minimum [mg/l]	0.17	0.17	0,50	0.50
maximum [mg/l]	295	217	217	217
average [mg/l]	28.06	27.28	27.36	27.30
std. dev. [mg/l]	23.00	24.60	24.67	24.39
variation coeff.	0.98	0.90	0.90	0.89
kurtosis	17.83	19.34	9.93	9.94
skewness	3.11	3.20	2.39	2.35

Table 1: 1997 and 2003 nitrates concentration data set.

	model	**sill**	**Range**
γ_{97}	nugget effect	166	-
	isotropic spherical	360	5 km
	anisotropic spherical	280	N15: 65 km / N105 15 km
γ_{03}	nugget effect	255	-
	isotropic spherical	140	5 km
	anisotropic spherical	248	N15: 65 km / N105: 15 km
$\gamma_{97,03}$	nugget effect	162	-
	isotropic spherical	220	5 km
	anisotropic spherical	242	N15: 65 km / N105: 15 km

Table 2: Simple and cross variograms model parameters

3. Estimation

In order to estimate the evolution of nitrates concentrations during the selected time interval, the difference D between 1997 and 2003 concentrations at the same measure points is introduced. The simple and cross variograms (namely γ_D and $\gamma_{97,D}$) of the difference D and the 1997 concentration are derived from the concentration bivariate model :

$$\gamma_D(h) = \gamma_{97}(h) + \gamma_{03}(h) - 2\,\gamma_{97,03}(h) \text{ and } \gamma_{97,D}(h) = \gamma_{97,03}(h) - \gamma_{97}(h);$$

the models parameters are summarised in Table 3. As the cokriging ensure the consistency between the estimations of different variables, it is equivalent to cokrige the two concentrations and to calculate their difference or directly to cokrige the difference from the two concentrations data (Rivoirard, 2003).

Figure 3a shows the nitrate concentration in 1997 estimated by means of cokriging. Figure 3b represents the cokriging of D with 1997, with evidenced the isofrequency classes of variation, whereas in Figure 3c the standard deviation of the estimation error of cokriging is presented.

	model	sill	Range
γ_D	nugget effect	97	-
	isotropic spherical	60	5 km
	anisotropic spherical	44	N15: 65 km / N105: 15 km
$\gamma_{97,D}$	nugget effect	-4	-
	isotropic spherical	-140	5 km
	anisotropic spherical	-38	N15: 65 km / N105: 15 km

Table 3: Simple and cross variograms model parameters

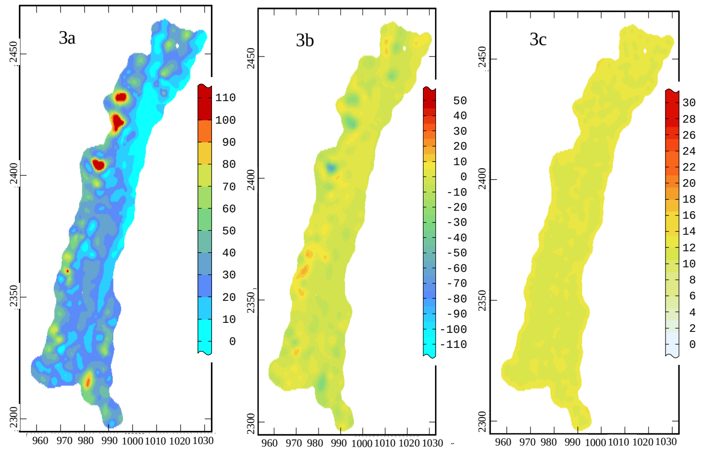

Figure 3. Estimation of nitrates concentration and its evolution between 1997 and 2003: a) 1997cokriging; b) Cokriging of the difference 2003-1997; c) standard deviation of estimation errors of the cokriged difference

4. Concluding remarks

The spatial structure of the nitrates concentrations was investigated by means of multivariate variography, highlighting the anisotropy closely related to the prevailing direction of groundwater flow (APRONA, 1999). Based on the correlation between the data collected at the same monitoring points and on the study of the difference of nitrates concentrations, a reduction of the highest concentrations of nitrate between 1997 and 2003 data was observed.

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