Estimation of the areas of air quality limit value exceedances on national and local scales. A geostatistical approach.[1]

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Abstract:
Each year Member States have to report to the European Commission on the exceedances of air quality limit values which occurred on their territory. Quantitative information is required about the areas and population exposed to such exceedances.
A probabilistic methodology for defining exceedance zones has been developed, based on preliminary air quality mapping. Atmospheric concentration fields estimated by kriging and the corresponding kriging variance are used to identify areas where the exceedance or non-exceedance can be considered as certain and areas where the situation with respect to the limit value is indeterminate. The methodology is applied on national and urban scales focusing on exceedances of PM_{10} daily limit value and NO_2 annual limit value. Results are discussed from operational perspectives.

Keywords: threshold exceedance, geostatistics, kriging, NO_2, PM_{10}

1. Introduction

In addition to reporting air quality measurement data above limit values, Member States have to provide estimates of the surface and population exposed to the observed exceedances. This study aims at developing a methodology that can be easily implemented both at national level for an overall evaluation of exceedance areas, and at local level for a more detailed assessment.

A two-stage methodology is proposed. It first involves estimating concentrations over the domain of interest and computing the estimation variance. A kriging based mapping approach can be used at that stage. Non-exceedance and exceedance zones are then determined from kriging results, considering the risk of misclassifying a point.

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The calculation steps are described in section 2. Section 3 provides application examples on national (PM_{10}) and urban (NO_2) scales. Improvement issues are discussed in the concluding part.

2. Materials and Methods

Let LV designate the considered limit value. LV = 40 µg/m^3 for NO_2 or PM_{10} annual mean concentrations; LV = 50 µg/m^3, not to be exceeded more than 35 times per year, for PM_{10} daily mean concentrations (Directive 2008/50/EC).

Let $Z(x)$ denote the concentration at location x that has to be compared to LV, $Z^*(x)$ its estimate from kriging and $\sigma_K(x)$ the kriging standard deviation. Let us take the estimation error $\varepsilon(x)$ into account, conventionally assumed to be a Gaussian process with zero mean and a standard deviation equal to $\sigma_K(x)$:

$$\varepsilon(x) = Z(x) - Z^*(x) = \sigma_K(x).T \qquad \text{with } T \sim \mathcal{N}(0,1) \qquad (1)$$

Evaluating whether Z(x) exceeds the limit value can be written as follows:

$$Z(x) > LV \Leftrightarrow Z^*(x) + \sigma_K(x) \cdot T > LV \Leftrightarrow T > \frac{LV - Z^*(x)}{\sigma_K(x)} \qquad (2)$$

In the proposed method, non-exceedance and exceedance areas are delimited from inequality (2), considering a non-detection probability threshold α, which is the risk of *x* belonging to a non-exceedance zone whereas Z(x) is above the limit value, and a false detection probability threshold β, which is the risk of *x* belonging to an exceedance zone whereas Z(x) is below the limit value.
If the priority is to keep the number of exceedance points wrongly included in the non-exceedance area as small as possible, then α should be set to a low value whereas a higher value may be allowed for β. Cori (2005) suggests that α be given the classical value of 5% while β could empirically be set to 1/3 to have a moderate risk of false detection. This leads to the following definitions:

- non-exceedance zone: {*x*} such as P[*Z(x)* > LV] < α

$$\Leftrightarrow P\left[T > \frac{LV - Z^*(x)}{\sigma_K(x)}\right] < \alpha \Leftrightarrow Z^*(x) < LV - q_{1-\alpha} * \sigma_K(x)$$

$$\Leftrightarrow Z^*(x) < LV - 1.65 * \sigma_K(x) \quad \text{for } \alpha\text{=5\%} \qquad (3)$$

- exceedance zone: {*x*} such as P[*Z(x)* ≤ LV] < β

$$\Leftrightarrow P\left[T \leq \frac{LV - Z^*(x)}{\sigma_K(x)}\right] < \beta \Leftrightarrow Z^*(x) > LV - q_\beta * \sigma_K(x)$$

$$\Leftrightarrow Z^*(x) > LV + 0.41 * \sigma_K(x) \quad \text{for } \beta\text{=34\%} \qquad (4)$$

$q_{1-\alpha}$ and q_β are the (1-α) and β-quantiles from the standard normal distribution.

The locations satisfying none of those conditions make the "uncertainty zone". In section 3 this formal approach is compared to a more empirical methodology previously developed for identifying exceedances of PM_{10} daily limit value and rapidly answering to urgent regulatory requests (Malherbe and Cárdenas, 2009; GT Zones sensible, 2010).

3. Results

National level. On French scale, daily PM_{10} and annual NO_2 concentrations are estimated on a 1 km x 1km grid by combining surface observations from background monitoring stations with outputs from the chemistry-transport model CHIMERE (resolution : about 10 km). For NO_2, which is mainly related to local emission sources, additional high resolution variables, precisely NO_x emission density and population density within a 2-km radius, are introduced in the kriging as external drift.

Figure 1 shows the example of one polluted day during a PM_{10} event (April 2009). Results are provided both for the methodology described in section 2 and the more empirical methodology in which only two states are defined (hypothesis (1) being unchanged):

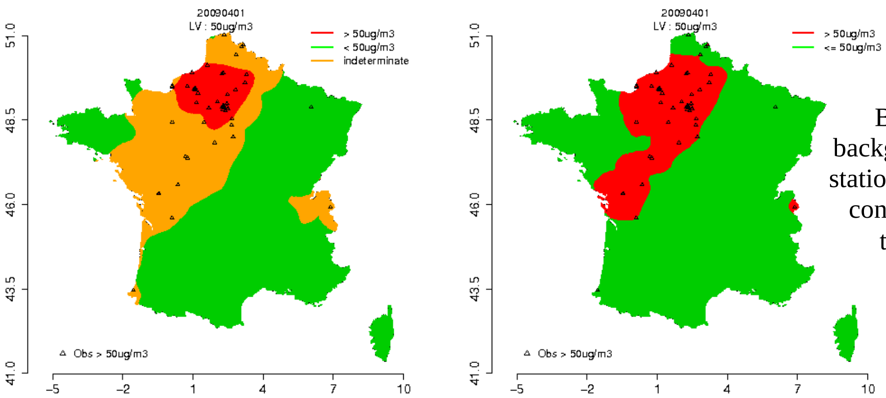
- exceedance: $\{x\}$ such as $P[Z(x) \le LV] < \eta$ with η: false detection probability threshold

$$\Leftrightarrow P\left[T \le \frac{LV - Z^*(x)}{\sigma_K(x)}\right] < \eta \Leftrightarrow Z^*(x) > LV - q_\eta * \sigma_K(x) \qquad (5)$$

q_η is empirically adjusted by comparing the annual numbers of exceedances estimated by cross-validation at the monitoring sites with the actual observed numbers. In this application q_η has been set to approximately 0.52, which amounts to defining a false-detection probability threshold of 70% and taking a cut-off value lower than LV.

- non-exceedance: $\{x\}$ making the complementary set, i.e. :

$$\{x\} \text{ such as } Z^*(x) \le LV - q_\eta * \sigma_K(x) \qquad (6)$$



Black triangles: background monitoring stations with daily mean concentration higher than 50 µg/m³.

Figure 1: PM_{10}. Exceedance of the daily threshold (50 µg/m³) on a highly polluted day. Left: newly formalized methodology. Right: empirical methodology.

Local level

Exceedance areas defined for NO_2 on national scale are very small since NO_2 exceedances mostly occur at traffic-related sites. On local scale, detailed concentration maps accounting for both background and roadside pollution can be established from passive sampling surveys, using high resolution auxiliary variables and additional information about traffic emissions and distance to the roads (Malherbe et al., 2008).
Results obtained for the French city of Montpellier are displayed in Figure 2. During year 2007 an extensive sampling campaign was carried out in this city by the local agency Air Languedoc-Roussillon. The sampling dataset includes eight 14-day periods of measurement at background and traffic sites.

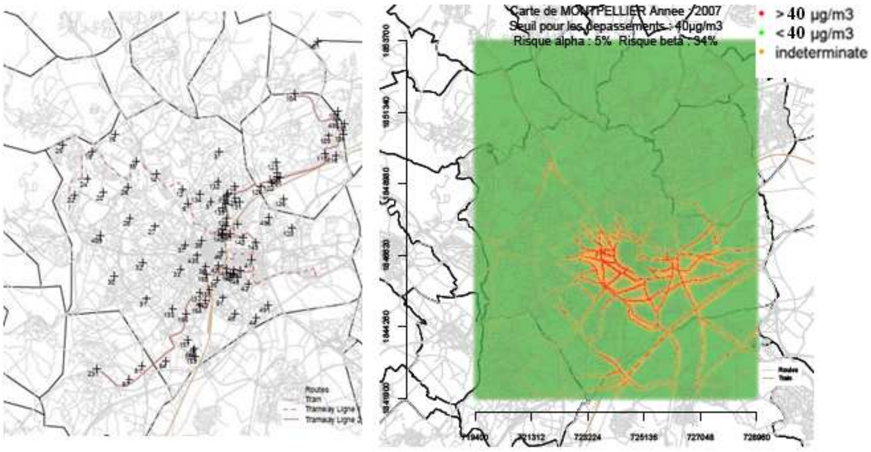


Figure 2: NO_2. Left: sampling points in Montpellier - year 2007 (source of the data: Air Languedoc Roussillon). Right: exceedance of the annual limit value (40 µg/m^3).

4. Concluding remarks

Annual reporting to the European Commission but also the working out of local air quality plans require the delimitation of areas where atmospheric concentrations do not comply with environmental objectives. A first approach was developed with a view to rapidly producing realistic exceedance maps for PM_{10}. The identified areas are consistent with observed exceedances but might somewhat be overestimated, especially where or when kriging variance is high. The notion of exceedance and non-exceedance was then formalized making some conventional assumptions due to operational constraints. The advantage of this second approach is that it distinguishes the non-detection and false detection probability thresholds which can be adjusted according to the objectives of the study. However, a remaining issue is the way of addressing the uncertainty area. In the end authorities and decision makers will rather have a single figure (spatial extent of the exceedance) than an interval of values. Among envisaged solutions are the refining of the uncertainty area and its inclusion in the exceedance area.

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