GEOSTATISTICAL ANALYSIS OF PCDD AND PCDF DEPOSITION FROM INCINERATION USING STACK EMISSIONS AND SOIL DATA

Adriaens P[1], Goovaerts P[2], Swan S[3]

[1]Department of Civil and Environmental Engineering, University of Michigan College of Engineering, 2340 G.G. Brown Building, Ann Arbor, MI 48109; [2]PGeostat, 710 Ridgemont Lane, Ann Arbor, MI 48103; [3]Center for Statistical Consultation and Research, Horace Rackham School of Graduate Studies, Ann Arbor, Michigan 48109

Keywords: geostatistics, TEQs, deposition model, stochastic simulation, uncertainty

Introduction

Deposition of pollutants around punctual sources of contamination, such as incinerator, can display complex spatial patterns depending on prevailing weather conditions, the local topography and the characteristics of the source. Deterministic dispersion models often fail to capture the complexity observed in the field, resulting in uncertain predictions that might hamper subsequent decision-making, such as delineation of areas targeted for additional sampling or remediation. Geostatistics[1,2] provides a set of methods for incorporating the spatial coordinates of field data in the mapping of pollutant levels and the assessment of the attached uncertainty. Lorber *et al.*[3] (1999) used geostatistical interpolation (i.e. kriging) to map the soil TEQ concentrations around a municipal soil waste incinerator. Their analysis had two major weaknesses: 1) important information, such as proximity to the incinerator and the predominant wind direction, was ignored in the interpolation procedure, and 2) the reliability of the estimated TEQ concentrations was not reported. This paper describes a geostatistical methodology to combine field data with the predictions of dispersion model. The approach generates a set of equally-probable maps of the spatial distribution of pollutants which can be post-processed to compute the probability that target thresholds are exceeded locally or on average over polygons of various size (i.e. census units). The methodology is illustrated using TEQ field data and a dispersion model created for the incinerator in Midland, Michigan.

Materials and Methods

Air concentrations values, as well as total deposition flux values (both dry and wet), were predicted for the period 1987-1991 at the nodes of a 500×500 receptor grid (spacing = 50 m) using EPA Industrial Source Complex (ICS3) dispersion model[4]. The input information consists of hourly meteorological data, including flow vector, wind speed, ambient temperature, stability class, rural and urban mixing heights, parameters for calculation of dry deposition (friction velocity, Monin-Obukhov length, and surface roughness length) and wet deposition (precipitation code and rate). Major differences were observed between the spatial patterns of dry and wet depositions; while higher dry deposition and air concentrations are observed on the North-eastern side of the plant (i.e. downwind), important wet deposition is predicted on the South-western side of the plant. It is also noteworthy that predicted values for wet deposition are two orders of magnitude larger than for dry deposition.

Up to 265 georeferenced soil TEQ concentrations were measured over various sampling campaigns between 1983 and 1998. The representativity of several of these campaigns is questionable given the strong clustering of some sample sets or their location along main roads. Therefore, in the present study we analyzed a subset of 53 samples used in a previous spatial characterization of the site by the crude method of Thiessen polygons, see Figure 1. To avoid giving too much importance to sampled values close to each other, data were declustered using cells of size 150×150 ft. In other words, all non-empty cells were equally weighted and this weight was distributed among the observations found within that cell. This cell-declustering[1] yields statistics that are more representative of the study area. The TEQ concentrations range between 0.60 ppt and 450 ppt, with a mean value of 73.66ppt.

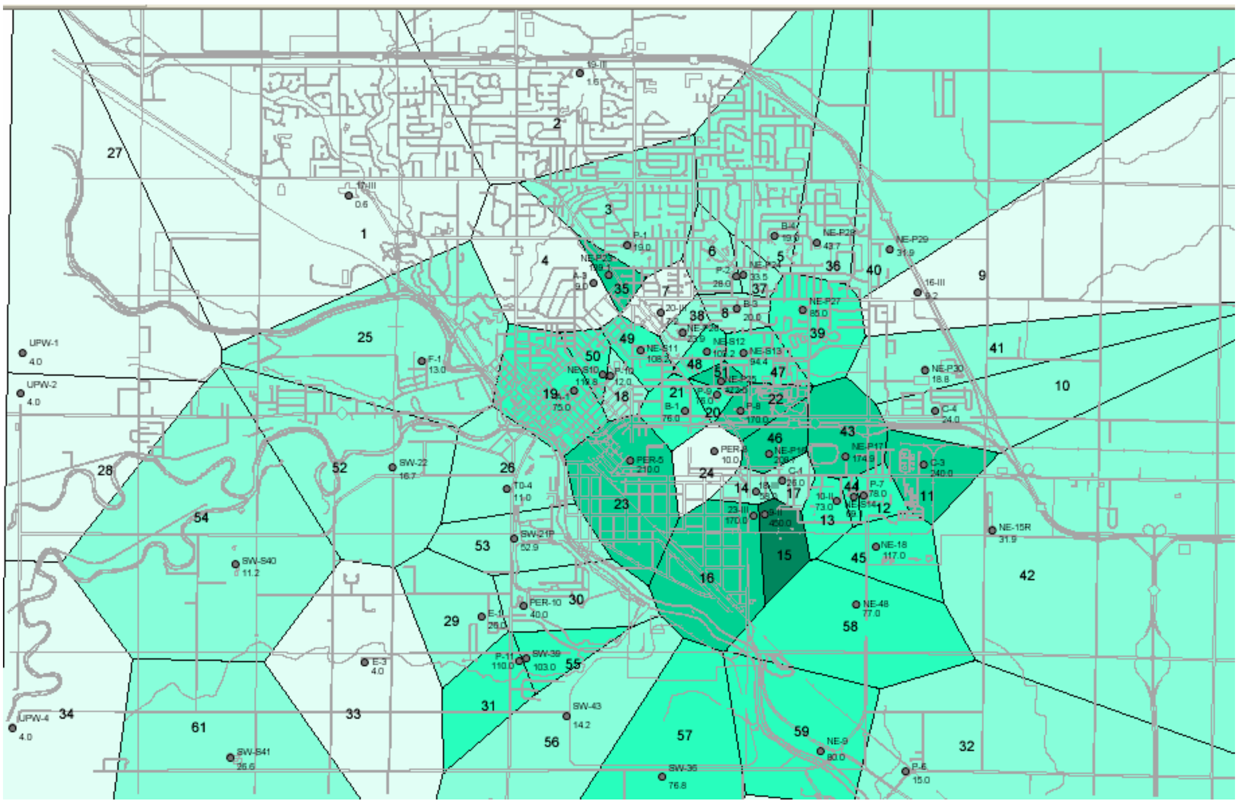

Figure 1. Data subset of 53 samples used for the preliminary spatial mapping of dioxin concentrations (Ref. Exponent).

The following geostatistical methodology was implemented:

1. The TEQ concentrations are normal score transformed to correct for the strongly positively skewed sample histogram.
2. The transformed data are regressed against the air concentration and deposition (wet and dry) values predicted using the numerical dispersion model. This regression model, which explains 45.3% of the total variance in TEQ data, is used to predict the TEQ concentration and standard error at the nodes of the 500×500 receptor grid.
3. The spatial variability of regression residuals is modeled using the semivariogram.
4. Sequential Gaussian simulation[1] is used to simulate the spatial distribution of TEQ values conditionally to the TEQ data, the trend model inferred from the calibration of the deposition data (step 2) and the pattern of correlation modeled in step 3. One hundred realizations were generated using a 500×500 simulation grid with a spacing of 50 m.
5. Point simulated values are aggregated within each census block to yield a simulated block value (upscaling). This aggregation is repeated for each realization, yielding a set of 100 simulated values for each census block. The following five statistics are computed from the simulation results:
    - Simulated TEQ value for the block (average over 100 realizations)
    - Average (over 100 realizations) WITHIN-BLOCK variance of simulated point TEQ values

- Average (over 100 realizations) proportion of simulated point TEQ values WITHIN the BLOCK that exceeds the threshold of 90 ppt.
- Variance of the distribution of 100 simulated block values
- Proportion of the 100 simulated block values that exceeds the threshold of 90 ppt.

Discussion

Field data showed a good correlation with the deposition model (R^2 = 45%), the most significant effect being observed for dry deposition. The regression residuals are spatially correlated with a range of 3,000 feet, which indicates the presence of spatially structured variability that cannot be explained by atmospheric deposition. Geostatistics allows one to capitalize on this correlation to interpolate spatially the TEQ concentrations. The main benefit of the proposed stochastic simulation approach is the availability of a model of uncertainty that is scalable. In particular, the uncertainty modeled at the scale of the data (i.e. soil cores) can be up-scaled to the level of the decision units, which are census blocks in this study. Information critical for decision making, such as the probability of exceeding a negotiated TEQ threshold for census block averages or a measure of the spatial heterogeneity within these blocks, can be easily retrieved from the set of simulated maps. These statistics provided guidance for the collection of new human and soil data in the study area. The incorporation of newly collected data into the regression and simulation procedures is straightforward, leading to updated models of the spatial distribution of TEQ values. These models would also benefit from additional information regarding past incinerator activities, as well as the cleaning of databases to ensure consistency among studies.

References

1. Goovaerts, P. *Geostatistics for Natural Resources Evaluation*. New York, Oxford University Press, 1997.
2. Chiles JP, Delfiner P. *Geostatistics: Modeling Spatial Uncertainty*. New York, JW Wiley and Sons, 1999.
3. Lorber, M, Pinsky, P, Gehring, P, Braverman, C, Winters, D, Sovocool, W. *Chemosphere* 1998, 2173-2197.
4. US EPA. *User's Guide for the Industrial Source Complex (ISC3) Dispersion Models*. EPA-454/B-95-003a. Research Triangle, NC, 1995.