Pollutant diffusion model and G.I.S. integration procedure for evaluating atmospheric emissions in industrial areas

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Abstract

This work presents a methodology off-the-shelf to characterise, in industrial zones, high level ground pollutant concentrations areas in order to optimise the monitoring network system location and point out interesting pollutants, parameters and the others meteorological information, to evaluate the pollutants diffusion in atmosphere and their soil impacts, e.g. Kainuma[1]. This methodology has been obtained by integrating the pollutant transport model and the Geographic Information System. In particular, the chosen air quality model is the Rough Terrain Diffusion Model (E.P.A. model), able to estimate ground-level concentration in complex terrain near one or more co-located industrial sources.
1 Introduction

The problem of atmospheric pollution in industrial areas is very important in environmental protection matter. Particularly, the monitoring networks have to be able to check industrial emissions both in normal and in emergency situations. For this reason it’s useful to define criteria on which integrated monitoring networks project has to be based. This approach requires that different kinds of monitoring technologies (traditional instrumentation, SODAR, RASS and LIDAR, etc.) and methodologies (in situ, remote sensing and bio-monitoring measurements), must be taken into account together with a cost-analysis of the system.

In this context it is important to integrate predictive tools, such as air pollutant diffusion models, with territorial management system, like a G.I.S., in order to link emissions, pollutant concentrations and land use. Air pollutants diffusion depends on physical characteristics of local atmosphere, for instance wind fields, mixing height, stability class, air temperature, vertical potential temperature gradient and buoyancy. Plumes path and ground level concentration are affected by orography and, finally, environmental impacts depends on land use. Consequentially, the coupling of diffusion models and G.I.S. database and techniques is useful in design of monitoring networks and in assessment of environmental strategies.

The methodology has been applied to evaluate environmental impact of industrial sites in the area of S.Nicola di Melfi (Basilicata region, Southern Italy), in which the FIAT production plants is located and an integrated platform for incineration, called FENICE, is under construction. The area of S.Nicola of Melfi is located in the north of Basilicata region in the Ofanto river valley. Apennines limit the valley in South and West direction, with an average altitude of 600 metres, whereas in North direction there are low hills with an average altitude of 300 metres on sea level.

All information relative to the site characterisation has been georeferenced and translated in informative layers of a Geographical Information System, based on Arc/Info software produced by Environmental Systems Research Institute. A lot of industrial activities present in S.Nicola area had been installed after ‘84-'85, but the most important plant is FIAT-SATA factory and its support activities. These plants represent principal sources of pollutant emissions in atmosphere.
2 The pollutants diffusion model: RTDM

Among different kinds of models implemented to study pollutant diffusion, we use Rough Terrain Diffusion Model (RTDM), developed by Environmental Protection Agency. RTDM is a sequential Gaussian plume model to estimate ground-level concentration in rough (or flat) terrain near of one or more co-located point source, e.g. ERT[2]. It is specifically designed for application involving chemically stable atmospheric pollutants and is best suited for evaluation of buoyant plume behaviour within about 15 kilometres from the source.

RTDM has special algorithms to deal with plume behaviour in complex terrain and is especially suited for rough terrain applications. Various features of the model make it useful for real and/or research-sensitivity applications and the ability to read hourly emissions data makes it useful for site-specific model evaluation studies, e.g. Egan[3]. Some of these features are listed below:

- Wind speed;
- Plume path adjustment as a function of Pasquill-Turner stability class;
- Calculation of a dividing streamline height in stable conditions;
- A choice of dispersion parameters;
- Buoyancy-induced dispersion;
- Stack-Tip downwash;
- Partial plume penetration of a mixing lid;
- An option to set the height of mixing lid to 10,000 metres in stable conditions;
- Use of hourly stack emission data;
- Maxim of 400 receptors and 35 co-located sources;
- Sector-averaged or centreline concentrations calculated;

Use of RTDM requires the presence of the following input files:

- Hourly meteorological data;
- Optionally, hourly emissions data;
- Model options and characteristics of source, receptor, and terrain information.

The output of model contains computed ground-level concentrations, a list of program options selected, a list of key program parameters and their initialised values, a description of the source and receptor characteristics, and a description of the terrain surrounding the source.

The fundamental formula used in the model to estimate ground-level pollutant concentrations from a point source, as shown in eqn. (1), is the
bi-variate Gaussian plume equation, e.g. Pasquill[4]. The general form of the equation is:

\[ C(x,y,0) = \frac{Q}{\pi u \sigma_y \sigma_z} \exp\left\{ -\frac{y^2}{2 \sigma_y^2} \right\} \exp\left\{ -\frac{H^2}{2 \sigma_z^2} \right\} \] (1)

where:

- \((x,y,0)\) are the (downwind, crosswind and vertical) coordinates of a receptor point in a Cartesian coordinate system, with the origin at the source location;
- \(C(x,y,0)\) is the pollutant concentration at receptor location \((x,y,0)\) [mass/length\(^3\)];
- \(H\) is the effective height (stack height plus plume rise) of emission; that is the centreline height of the plume [length];
- \(Q\) is the source strength [mass/time];
- \(\sigma_y, \sigma_z\) are the dispersion coefficients that are measures of cross-wind and vertical plume spread, respectively, e.g. Hanna[5]. These two parameters are function of downwind distance and atmospheric stability [length];
- \(u\) is the average dilution wind speed [length/time].

3 RTDM and G.I.S. integration procedure

The relationships between the EPA-RTDM model and the Geographical Information System are shown in Figure 1.

The first step of integrated procedure deals with set-up the RTDM orographical data input. It allows one to provide the topographical description of interest area and the \((x,y,z)\) coordinates of RTDM receptors, e.g. ESRI[6]. This information is based on Digital Terrain Model (DTM) of the Northern Basilicata elaborated by Arc/Info software G.I.S.. Therefore this kind of data are more reliable than the ones obtained by a traditional cartography, typically used in performing RTDM data input.

In particular, the analysed area extends for 15 kilometres around FIAT-SATA plant and FENICE incinerator. In our case, RTDM considers FENICE stack the centre of a circular study zone with radius of 15 kilometres. The orography of the site and receptors location is obtained by means of G.I.S., intersecting 36 radius (at 10\(^\circ\) intervals) with digital contour lines (see the grey G.I.S. box on the left of Figure 1). This terrain data consists of downwind distances to successive contour heights (at a constant height intervals of 20 metres), starting below stack-top elevation.
Figure 1: Scheme of integration procedure of GIS-RTDM.

- In situ measurements and/or statistical examination
- Hourly meteorological input
- Hourly emission input
- Emission rate of pollut.
- Stack gas exit velocity
- Stack gas temperature
- Constants emission parameters
- Stacks characteristics
- RTDM parameters
- Ovography
- Receptors location
- DTM digital terrain model
- GIS
- RTDM
- Landuse map
- Impact map
- Pollutant isoconcent. map
- Overlap
- GIS
and ending at highest point within the distance from the source under consideration (15 km). In that way, G.I.S. carries out a coverage of georeferenced points, describing longitudinal profiles of terrain and receptors localisation (Figure 2) and produces 36 files, one for each direction, which contain:

- \((x,y)\) Gauss-Boaga coordinates of the intersection points in fixed direction;
- \((z)\) height on sea level of the intersection points in fixed direction;
- relative distance between two successive intersection points.

After running, RTDM generates an output file assigning a value of ground concentration for each receptor previously located.

In the second grey G.I.S. box, on the right of Figure 1, the successive step of our integration methodology is shown: starting from punctual concentration values, produced by the diffusion model, we have implemented G.I.S. and RTDM interface to realise georeferenced pollutant isoconcentration layer, based on an interpolating technique, e.g. Lott[7]. In Figure 3 an example of NOx isoconcentration layer overlapped to contour line coverage is shown.

4 Results and Conclusions

The predisposition of impact maps, carried out by overlapping pollutant isoconcentration level layer and land use layer, e.g. Briggs[8], is an effective result for monitoring networks design. The Figure 4 represents an impact map of test site. Concerning land use, the examined area is characterised by a prevailing agricultural activities: grain is the most spread cultivation (60% of cultivated soil), whereas as irrigated cultivation, there are sugar beet, tomato, vineyard and other kinds of orchards. Most sophisticated measurement instruments of integrated monitoring network have to be placed in the maximum ground level concentration points. Figure 4 emphasises that higher NOx concentration occurs neither on urban areas (Melfi and Lavello municipalities) nor on vintage cultivation. Impact maps can be compared to soil concentrations maps obtained by field survey. Moreover these products allow one to validate the model, to optimise the spatial distribution of measurement instrument and to suggest interventions for local environmental planning. Moreover, this GIS-RTDM integration procedure could be used by Public Administrations for evaluating environmental impact of new plants in pre-existent industrial areas.
Figure 2: Receptors localization
Figure 3: Overlapping between isoconcentrations map and contour lines map
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Figure 4: Impact map (NOx)
References


