Romanian Reports in Physics, Vol. 62, No. 2, P. 383–395, 2010

ENVIRONMENTAL PHYSICS

DESIGN OF THE AIR QUALITY MONITORING NETWORK FOR BUCHAREST CITY

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(Received July 14, 2009)

Abstract. This paper summarizes the methodology and concept used to design the air quality monitoring network in Bucharest City carried out during 2002 and 2003 in the framework of the EU PHARE Project "Local Pilot Investment Project in the EPA (Environment Protection Agency)-Bucharest for Air Quality Monitoring". Although, similar methodologies were widely used in the majority of European metropolitan areas with the purpose of improving the air quality networks, some original approaches have been applied for the Bucharest city. The procedures underlying this methodology are principally based on combining the dispersion modelling activities with the results of two measurement campaigns using passive sampling technique. Previously, the preliminary assessment of the Air Quality (AQ) in the city of Bucharest mainly performed by modelling indicated in 2002 possible positions of the future AQ monitoring sites. The results of the measurement campaigns and the additional modelling activities during the project, largely confirmed the appropriateness of the initial proposal for the 6 fixed monitoring AQ stations. The good response of model compared to measurements encourages the development of modelling activities in the future for improving the actual proposed air quality network configuration.

Key words: monitoring network, passive sampling, dispersion modelling.

1. INTRODUCTION

According to the Air Quality Framework Directive of the European Union, Article 6 air quality monitoring and assessment is mandatory in an agglomeration (metropolitan areas over 200 000 inhabitants) like the City of Bucharest. The detailed pollutant-specific assessment requirements for agglomerations are defined in three Daughter Directives. These directives ([1, 2, 3]) contain criteria for reference measurement methods, sampling techniques as well as the minimum number of fixed monitoring stations.

The position of all measurement sites should be exactly identified and evaluated. Sites should be characterised according to classifications given by the Exchange of Information and specified by the European Air Quality Monitoring and Information Network (EUROAIRNET) [4]. The station classes and the locations are relevant to differing degrees for exposure of populations, materials and ecosystems (Table1).

Table 1

Stations classification according to EUROAIRNET

Station classes	Relevant for exposure of		
	Population	Materials	Ecosystems
Traffic stations	x	(x)	
Industrial stations	x	x	x
Background stations			
-Urban background stations	x	x	(x)
-Background stations	x	x	x
-Suburban background stations	x	x	x
-Regional background stations	x	(x)	x
Remote stations			x

The minimum number of measurement stations per agglomeration depends on its population and on the pollution level. Therefore, the pollutant levels need to be assessed according to criteria defined in the Daughter Directives [5]. This assessment should be based on concentrations measured over a period of five consecutive years. If there is little information on air quality levels available a so-called Preliminary Assessment needs to be conducted according to Article 5 of the Framework Directive [5]. During this preliminary assessment, also other techniques – like indicative measurements and modelling – may be applied to obtain the required information. Indicative measurements are a very common method used in the urban agglomerations for different purposes:

- to optimise the design of the monitoring networks,
- to assess the exposure of the population to pollution levels,
- as support to traffic management.

Such indicative measurement campaignes have been carried out in Paris (1989–1990), Madrid (1990–1991) and Brussel (1993–1994) ([13, 14]).

The design of the monitoring network in Bucharest city was a complex task performed in a relative short period of time but covering large and complex tasks from performing of indicative measurement campaignes to emission inventories and modelling.

Two components underlay the preliminary assessment we have performed: the air quality modelling and the indicative measurements based on a passive sampling method.

Air Quality (AQ) modelling plays an important role in preliminary assessment. It can provide an indicative checking of compliance/non-compliance against air quality standards as well as an assessment in relation to lower and upper thresholds defined in the directives. It also allows a better design of monitoring networks.

For the Bucharest City (the city and environmental database were described in Section 2) the AQ modelling for the preliminary assessment has been carried out within another international project, which was lead, by a Danish–Norwegian Consultant team [7]. This preliminary assessment included the pollutants covered by the first Daughter Directive: nitrogen oxides, sulphur dioxide, particulate matter and lead.

The present work summarizes the activities related to the two major tasks performed for selecting the locations of the future air quality monitoring stations: the indicative measurement campaign and the AQ modelling.

It presents the methodology of locating the passive samplers over the entire metropolitan area in order to extract a better image of air pollution spatial distribution. This should be also suplemented with the AQ modelling performed previously during the preliminary assessment and also with some other modelling scenarios able to recommend the future positions of monitoring stations.

2. DATA AND METHODS

2.1. CITY OF BUCHAREST AND THE ENVIRONMENTAL DATABASE

Bucharest is located in the southern part of Romania, on a flat region, crossed from northwest to southeast by the river of Dambovita. It is a very industrialized city although in the past decade several important factories shut down. The local Environmental Protection Agency (EPA) is responsible for preparing the emission inventory for the air pollutants in Bucharest. In the preliminary air quality assessment the reference year of study was 2001 as such, the emission data were taken from the emission inventory performed for this year by EPA-Bucharest, Institute of Environment Research and Engineering and Consultants during the Danish Project [6]. The emission inventory includes:

- a number of 430 point sources (stacks) identified in the Bucharest agglomeration;
- area sources generated by the distribution of area emission sources due to residential heating for 1 km × 1 km grid cells;
- area sources generated by the distribution of traffic emissions for 1 km × 1 km grid cells.

The necessary meteorological database for air pollution modelling for the year 2001 was provided by the National Institute of Meteorology and Hydrology, Bucharest.

2.2. THE OML (OPERATIONELLE METEOROLOGISKE LUFTKVALITETS-MODELLER) DISPERSION MODEL

AQ modelling has been performed using OML ([8–11]) for the simulation of the urban background concentrations.

OML is a local scale Gaussian dispersion model designed to estimate pollution levels up to a distance of 20 km from a source. The model is making use of the boundary layer parameters to simulate atmospheric dispersion instead of relying on Pasquill stability classification.

The model requires information on emission and meteorology on an hourly basis as well as input data about the receptors and the source, building, terrain topography and regional background concentrations. Meteorological parameters are provided by the OML pre-processor which is a separate software package Tipically, hourly data from surface meteorological stations, such us wind speed, wind direction, cloud cover, temperature, relative humidity, presence of precipitations, are required. In order to compute the mixing height two daily profile data from radiosoundings are also necessary.

The model computes time-series of concentrations at user-specified receptor points; also, statistics are extracted and presented graphically to the user.

3. AQ MODELLING

3.1. AQ MODELLING IN THE PRELIMINARY ASSESSMENT

During the preliminary assessment in the Danish project the dispersion model OML was applied considering separately the following source groups:

- Residential heating in Bucharest distributed as area sources;
- The point sources, major and minor ones;
- Major point sources: the 5 thermal power plants;
- Traffic sources distributed in 2×2 kilometres square grids.

The reason of this proposed algorithm of desagregating different types of sources is that each concentration field obtained with the above separated terms is indicative for a proposal of a certain type of monitoring station, *e.g.*:

- The concentration distribution from the point source impact (both major and minor) indicates the location of the future background station – low-level concentration areas and away from traffic roads. High concentration distribution of these sources might be indicative for the future industrial stations;
- The concentration distribution from the heating source (as area sources) impact indicates the position of the future background station in the way that the area of moderate pollution should be eligible for an urban background station;
- The concentration distribution from traffic source is indicative for the position of a traffic station.

As example, the long-term concentration pattern for NO_2 as emitted by the residential sources is exhibited in Fig. 1.

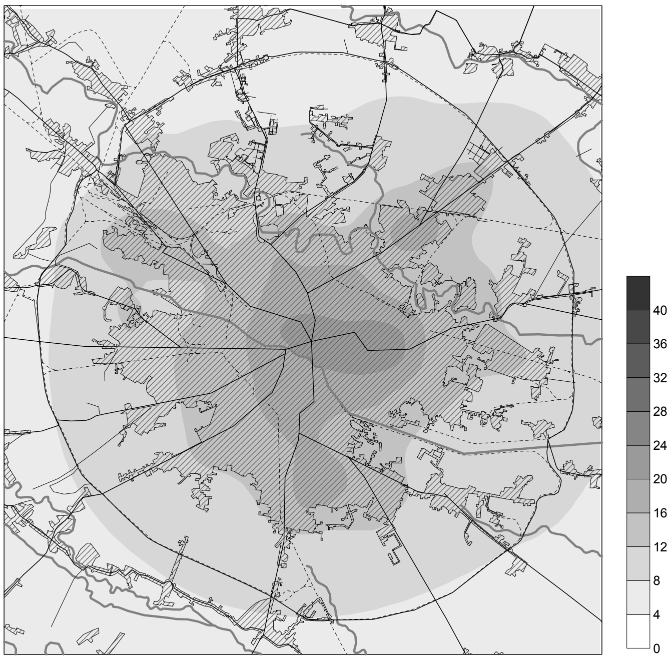

Fig. 1 – Spatial distribution of the NO_2 annual average concentration from residential heating in the agglomeration of Bucharest. The values are expressed in $\mu g/m^3$.

3.2. AQ MODELLING FOR MEASUREMENT CAMPAIGNS

To supplement the results of passive sampling during the indicative measurement campaign (summer campaign August-September 2002 and winter campaign November–December 2002), air quality modelling was applied to estimate pollutant concentrations during both measurement campaigns. For this purpose the OML Multi model was applied for the periods of measurement campaigns. The necessary meteorological data correspondig to the investigated periods in 2002 were provided by the National Institute of Meteorology and Hydrology and the emission data were taken from the emission inventory performed in 2001 by EPA-Bucharest, ICIM (Research Institute for Environmental Engineering) and Consultants during the Danish Project. In order to update the database the emissions of the 5 thermal power plants were updated for the periods of the measurement campaigns.

OML was run for the measurement campaign periods, providing the average modelled concentration for these time intervals. The model was run for the pollutants: nitrogen dioxide, sulphur dioxide and ozone, taking into account a photochemistry scheme of NO-NO_2-O_3. The averaged modelled values have been calculated in the receptors corresponding to the locations of passive samplers.

4. INDICATIVE MEASUREMENT CAMPAIGNS

In order to check the appropriateness of the initial proposed sites for the monitoring stations, The Federal Environment Agency of Austria in collaboration with the Pro-Air Consortium members conducted two indicative measurement campaigns-one during summer and the other one during winter period (13 days each – summer August 27th to September 10th 2002 and winter November 26th to December 10th 2002) – using the diffusive sampling method [11, 12].

4.1. CONCEPTUAL DESIGN OF THE MEASUREMENT CAMPAIGNS

In general, the methodology applied for settling the passive sampling sites is based on the provisions of the Guidance Report on Preliminary Assessment under the EC Air Quality Directives [5].

A grid monitoring approach was chosen to assess the spatial distribution of key air pollutants in the agglomeration of Bucharest. A grid layer of 2 km × 2 km was put over the City of Bucharest with focus on densely populated residential areas. The sampling concept was developed to obtain information on the average concentration level in each grid (to obtain information which is representative for the general exposure of the population). These sites were supplemented by sites in the vicinity of strong emission sources, like thermal power plants and industrial sources, in order to get information on hot-spot peak concentrations, as requested by the corresponding EC directives. The spatial distribution of the passive sampler locations is presented in Fig. 2.

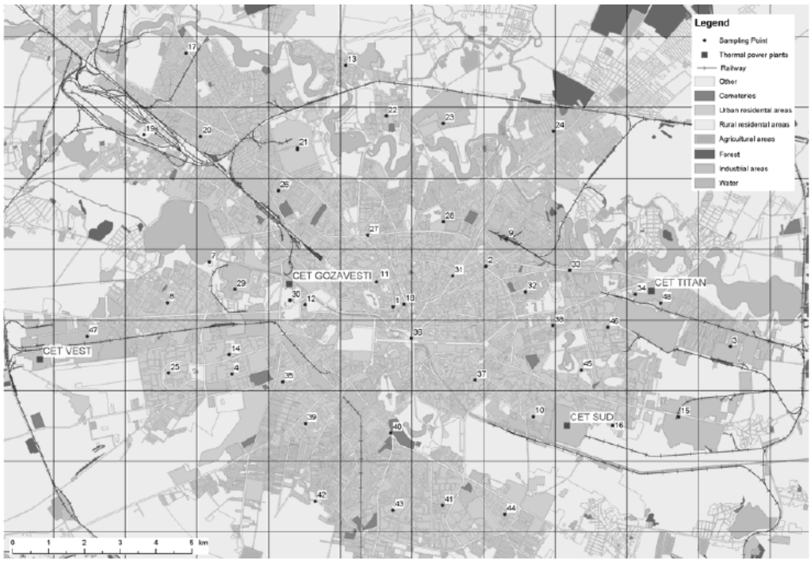

Fig. 2 – Spatial distributions of the passive sampler locations in Bucharest.

At least one representative location was selected for each grid cell. These sampling points were not directly influenced by local pollution sources and all of them had similar environmental constraints. The approximate locations of the sampling points within each grid cell were determined by using information from preliminary assessment, measurement data records, information about emission sources, information about traffic situation and meteorological data records.

All over the City of Bucharest 48 sampling sites have been selected for the passive sampling campaign comprising 9 traffic-related sites, 8 industrial sites, 1 suburban site, 2 background sites, and 28 sites with focus on residential areas [12].

5. RESULTS AND DISCUSSIONS

In order to evaluate the appropriateness of the monitoring stations proposed in Bucharest, the reasons presented above have been considered for each location and type of station.

The preliminary assessment showed that the pollutant concentration levels exceeded the Upper Assessment Threshold (UAT) for both short-term (hourly or daily average concentrations) and long-term pollution (annual average concentations) [6].

As a consequence and based on the number of inhabitants in Bucharest (over 2 millions) the minimum of six fixed monitoring stations is required for the assessment of nitrogen oxides, sulphur dioxide, particulate matter and lead in the agglomeration of Bucharest.

For the pollutants covered by the second Daughter Directive, benzene and carbon monoxide when the UAT is exceeded, the same number of stations is required including at least one traffic-oriented station and one urban-background station.

For the assessment of the ozone levels at least 4 monitoring stations are required in the agglomeration of Bucharest according to the 3rd Daughter Directive [3].

Therefore, using the above mentioned criteria for the number of monitoring stations, a maximum number of eight monitoring stations with corresponding sites have been agreed by the Beneficiary, the Ministry of Environment and the Consultant.

5.1. DISCUSSION OF THE MEASUREMENT RESULTS

The final results of the passive sampling campaigns are presented as average time-weighted concentration over the actual sampling period. Isopleths were calculated by interpolation from the measurements obtained by diffusive sampling [12]. The comparison between measured concentrations during summer and winter campaigns split up for different types of sites is shown in the Table 2.

Table 2

Average measured concentration of nitrogen dioxide, sulphur dioxide, ozone and benzene in µg/m3 for different type of sites

Pollutant	Type of site	Summer				Winter			
		Average	Maximum	Minimum	Median	Average	Maximum	Minimum	Median
Nitrogen dioxide	Residential	20	27	13	21	9.6	17	2	9.8
	Industrial	16	25	12	13	6.8	10	4.1	5.3
	Traffic	25	49	35	43	18	24	10	17
Sulphur dioxide	Residential	2.3	3.8	0.9	2.2	5.3	46	1.4	2.9
	Industrial	3.3	8.2	2	2.6	3.3	8.2	2	2.6
	Traffic	6.8	11	5.3	6.7	5.2	5.9	4.3	5.2
Ozone	Residential	59	67	44	60	14	18	10	14
	Industrial	65	74	57	66	15	18	8.1	16
Benzene	Residential	12	22	5.2	12	6.1	10	3.1	6.2
	Industrial	8.9	14	5.2	8.4	4.7	6	3.3	5.4
	Traffic	32	59	22	29	19	32	12	17

5.1.1. Nitrogen dioxide

The results of both campaigns (summer and winter) showed similar spatial distribution patterns, although the concentration levels in winter were significantly lower than during the summer campaign. This can be caused by the favourable dispersion (intense wind) conditions during the winter campaign and/or caused by enhanced NO_2 oxidation in summer due to higher ozone levels (no NO_x concentration levels are available to test this hypothesis). Spatial distribution of the average measured NO_2 concentration during summer campaign is presented in Fig. 3.

Not unexpected, the highest concentrations were detected at the traffic sites both during the summer and the winter campaign. During the winter campaign some high nitrogen dioxide values were detected in the residential areas in the south of Bucharest mainly in Berceni and Drumul Taberei, with values similar to those measured at the traffic sites.

The lowest nitrogen dioxide values for both the summer and winter campaign were measured at the rural background site at Balotesti followed by the suburban background site at the EPA at Lacul Morii.

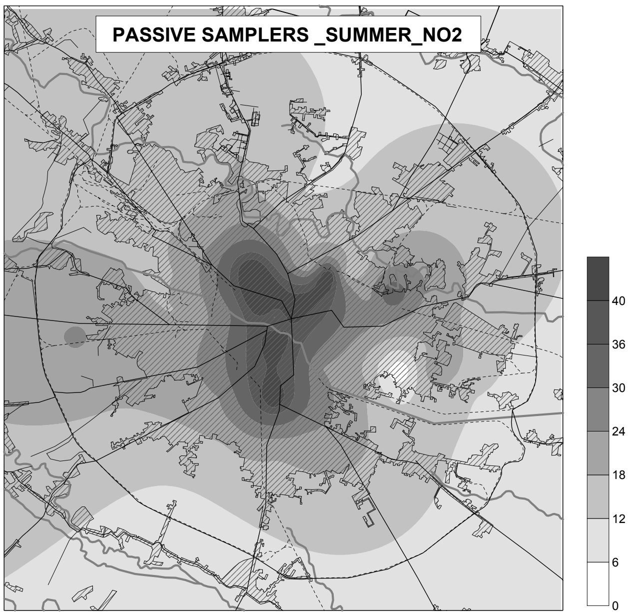

Fig. 3 – Spatial distribution of the measured concentration during summer passive sampling campaign. The values are expressed in μg/m^3.

5.1.2. Sulphur dioxide

The highest concentrations were detected at the traffic sites, which mean that the low-level traffic emissions from Diesel cars generate significant ground-level concentrations. The average concentrations of the traffic and industrial sites were nearly identical for both campaigns. On the other hand a strong impact from domestic heating and power plants (that partialy burn fuel oil during winter) was visible during the winter campaign.

5.1.3. Ozone

Ozone concentrations were significantly higher in the summer than in the winter period due to enhanced ozone formation influenced by high solar radiation and temperature. The ozone depletion close to the NO_x sources is well reflected by the measurements; as such, the highest detected concentration occurred in the summer in the suburban areas at the city boundaries.

5.1.4. Benzene

In the urban areas the benzene concentrations are mainly generated by traffic emissions. Therefore peak concentrations were measured at traffic sites both in the summer and in the winter, indicating almost a three times higher level than at the residential areas.

5.2. RESULTS OF AQ MODELLING DURING MEASUREMENT CAMPAIGN

Generally, the model results reasonably match the measurements, chiefly as spatial distributions. However, inaccuracies might occur both due to meteorological data and data derived from the emission inventory. The results for the three-modelled pollutants are presented in Table 3.

Table 3

Modelled concentrations of nitrogen dioxide, sulphur dioxide and ozone during measurement campaigns

Pollutant	Type of site	Summer			Winter		
		Average	Maximum	Minimum	Average	Maximum	Minimum
Nitrogen dioxide	Residential	29.3	48.5	19.4	22.8	29.5	16.1
	Industrial	22.1	35.5	12	19.4	27	14.4
	Traffic	37.9	44	26.5	27.9	31.3	20.7
Sulphur dioxide	Residential	2.1	4	1	8.6	21.2	3
	Industrial	4.9	6.9	4	6.1	13	2.9
	Traffic	5.4	6.5	4	7	8.2	5.7
Ozone	Residential	54	63	44	15.4	19	12.6
	Industrial	59.8	65	54	17.5	20.1	15.1

The spatial distribution of the modelled average concentration of NO_2 during the summer campaign is shown in Fig. 4.

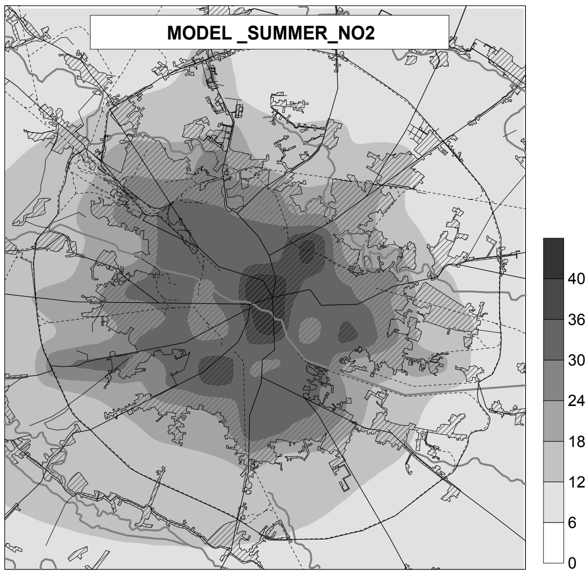

Fig. 4 – Spatial distribution of the average modelled concentration during summer passive sampling campaign. All types of sources were included; also traffic sources have been modeled as area sources. The values are expressed in $\mu g/m^3$.

The modelled SO_2 concentrations were higher than measured ones indicating a possible overestimation of the SO_2 emissions. The ozone-modelled concentrations were comparable with the measured values but a lower spatial correlation was observed.

The modelled concentrations during summer campaign at the traffic sites indicated lower values than measured ones. This is not unexpected as long as the traffic is inserted into the model as area source, which implies a homogeneous distribution of the traffic emissions in the grid cells. During the winter, comparable or even higher values at the traffic sites were obtained with the model mainly due to specific meteorological conditions consisting of strong winds and precipitations for most of the period.

Hence, the model provided satisfactory results, which could be improved if more accurate emission and meteorological data are used.

5.3. SELECTION OF FIXED MONITORING SITES FOR THE AGGLOMERATION OF BUCHAREST

Based on the passive sampling campaigns and on the modelling results, for the air quality monitoring network of the City of Bucharest the following sites, as shown in Table 4 have been proposed.

Table 4

Fixed measurement stations for the air quality monitoring network for the agglomeration of Bucharest

No.	Fixed measurement point	Sector	Type of station	Type of area	Area feature
1	Cercul Militar al Armatei	1	Traffic	Urban	City centre street canyon
2	Mihai Bravu	2	Traffic	Urban	Intersection at main street link
3	Titan	3	Industrial	Urban	Residential
4	Drumul Taberei	6	Industrial	Urban	Residential
5	Balotesti	Outside city	Background	Rural - Regional	Natural (forest)
6	Magurele	Outside city	Background	Rural - Near City	Agricultural/residential
7	Lacul Morii (at EPA)	6	Background	Suburban	Commercial/natural
8	Berceni	4	Industrial	Urban	Residential

The town centre traffic sites at Cercul Militar as well as the traffic site at the highly frequented road Soseaua Mihai Bravu have been confirmed by these passive sampling campaigns to be appropriate traffic-oriented sites.

The residential sites at Drumul Taberei and Titan are also of particular interest due to nearby industrial areas and thermal power plants. The determined distribution pattern indicated high pollution levels in these densely populated areas.

The measurement results obtained at Balotesti were lower than those of all other sites in the City; hence it can be classified as a rural background site. The second proposed background site at Magurele is obviously influenced either by local sources like traffic and domestic heating or the thermal power plant CET PROGRESUL. According to the classification scheme in the Commission Decision 2001/752/EC the site at Magurele is a rural background site nearby a City in an agricultural and residential area.

The pollution level at the background site in Magurele is similar to suburban background levels, which were measured at the Lacul Morii close to the EPA headquarter.

The results of the passive sampling campaigns also indicated high pollution levels in the south of the City. Therefore, an additional fixed measurement site is strongly recommended in the residential area of Berceni.

6. CONCLUSIONS

Two basic procedures corroborated with EC Directives and regulations underlie the design of the AQ monitoring network in Bucharest: the first one consists in using an advanced new generation dispersion model to make evident the pollutant concentration pattern for all source types existing in this City and the second one in organising and carrying out two measurement campaigns using passive sampling methods in order to confirm experimentally the sites pre-selected by the modelling procedure. The proposed algorithm during the preliminary assessment of running the dispersion model including separately different types of sources (stacks, area sources from residential heating, linear sources derived from traffic) refined the procedure of selecting the appropriatness of different types of monitoring stations.

The passive sampling experiment was split in two campaigns aimed to obtain information on air quality over two weeks in the summer and the winter season. In summer the distribution pattern of nitrogen dioxide and sulphur dioxide was similar to that of benzene, which indicates similar sources, in particular road traffic. On the other hand the sulphur dioxide pollution level in winter also indicates an additional influence by emissions of the thermal power plants and domestic heating.

It is highly recommended to re-evaluate the appropriateness of the locations of the selected stations after one or two years of operation, using the information, which is available at this stage. In this way, air pollution modelling will be an extremely usefull tool for future assessment of the existing monitoring network.

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