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EXPERIENCES IN DISPERSION MODELLING IN THE DEVELOPMENT OF AIR QUALITY MANAGEMENT SYSTEM IN KRAKOW

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Abstract: The study shows how dispersion modelling results influenced the development of air quality management methods in Krakow city within the period of 2004-2013. Key findings on particulate matter origins are presented as well as past and current air quality improvement tools.

Key words: *Krakow, air quality management, PM10, emission inventory, source apportionment*

INTRODUCTION

According to the survey of 386 European Union cities prepared by the New York Times (based on EEA data), taking into account average number of days in 2011 when particulate concentrations exceeded the EU limit, Krakow is the 3rd most polluted city in Europe. The situation has not changed much since last decade in Krakow. The figure below presents a series of annual concentrations of PM10 measured at monitoring stations located in Krakow. The trends in 24-hour concentration of PM10 are similar.

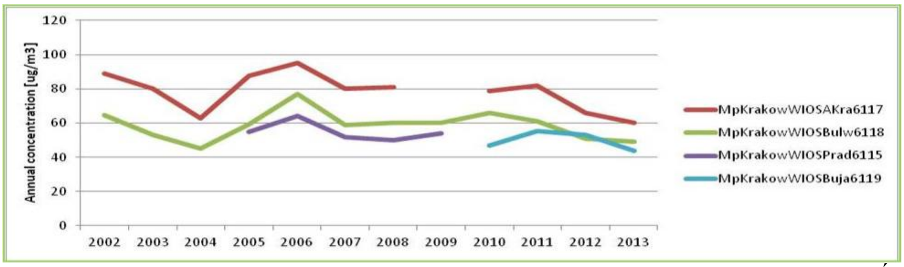

Figure 1. Annual concentrations of PM10 in Krakow (National Monitoring of the Environment–PMŚ/Regional Inspectorate of Environmental Protection in Krakow–WIOŚ)

The level of benzo(a)pyrene annual concentrations measured at 2 monitoring stations exceeds the target value of 1 ng/m^3 and fluctuates between 5 and 10 ng/m^3. Annual concentration of NO_2 also exceeds the limit value of 40 µg/m^3.

The mixture of many disadvantageous factors determinates the high level of air pollution in Krakow. The city is characterized by difficult orographic and meteorological factors such as location in the Vistula Valley where low wind speed and thermal inversions are frequently observed (Fig. 2).

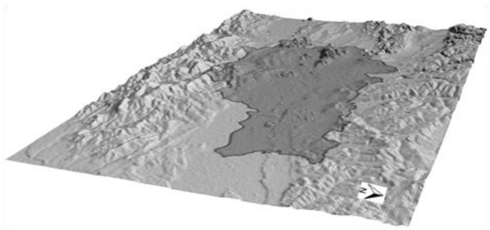

Figure 2. Topography of the Krakow city

Emissions of pollution from typical urban sources like domestic heating, small combustion or industrial sources and transportation are high as the city is the 2nd largest in Poland. Additionally, the location of heavy industry (e.g. steelworks) and two large power plants (one in Krakow, the other about 10 km from the city) causes high industrial emissions.

The city has got long history of the fight against air pollution. In 1992 Low Emission Reduction Program in Krakow was funded by the U.S. Agency for International Development. The change from coal stoves and boilers to the alternative sources of energy (e.g. gas, electric heating systems) was launched. In 1998-1999 the inventory of the industrial emission sources was conducted and air pollution dispersion modelling using CALPUFF was prepared. After implementation of European law in Poland one of the first Air Quality Action Plans (AQAP) in Poland was prepared for Krakow in 2004-05. The next AQAPs were prepared in 2009 and 2012. Meantime the detailed analyses of emission sources were conducted to improve the source apportionment in modelling and better understand the contribution of different sources to air pollution including the JRC project (Junninen et al., 2009). Finally the solid fuel prohibition act was established as a local regulation by the regional authorities in 2013. Recently the implementation of the act has been launched.

One of the really interesting questions is why, despite of many actions undertaken, the air quality has not been improved in Krakow. Lack of the understanding the complex problem of air quality resulted in inadequate actions conducted by local and regional authorities and insufficient support of the citizens. 10 years was needed to develop data, tools and knowledge, to build citizens' participation and support, to prepare difficult and hopefully effective action plan for Krakow. The study shows how dispersion modelling results influenced the development of air quality management methods within the period of 2004-2013 and helped in better understanding of the causes of poor air quality in Krakow.

AIR QUALITY PROJECTS IN KRAKOW

In 2005 the first Air Quality Action Plan was prepared. The main research question was to understand what sources are responsible for poor air quality. According to common knowledge the heavy industry and power plants were regarded as the main pollution sources. On the other hand the regional authorities suspected that domestic heating sources and transportation may play an important role in air quality. Therefore the project was focused on urban scale and local sources. ADMS-Urban model was chosen for modelling purposes. Detailed transport emission inventory was prepared. It was based on measurements of transport intensity on the main streets and empirical emission factors. Inventory for 1999 was updated for domestic heating emissions. It included the data based on detailed inventory of sources conducted during the Low Emission Reduction Program from 1992-1996. Industrial emissions inventory was prepared during earlier project and was updated using environmental fees and permits data. Background concentration (regional, long-range and aerosols) were estimated using regional measurements interpolation. Modelling for the baseline 2003 and evaluation of the model for PM10, NO_2 and SO_2 was run. Two scenarios were also modelled. Results of the first AQAP confirmed the largest contribution to air pollution from transportation and domestic heating sources but still contribution of domestic combustion sources seemed to be underestimated. The JRC project conducted in 2005/2006 also indicated that domestic heating may be a main pollution source in Krakow (Junninen et al., 2009).

The second AQAP (2009) was prepared for all zones in Malopolska Region including Krakow city as a separate zone. One of the main objectives of the project was to analyse again the domestic heating sources contribution to air quality. The detailed inventory was prepared. The methodology was based on the heat demand calculation for the city's districts. The type of the heat delivery system (gas, central, electrical, individual solid fuel) was analysed. EMEP/CORINAIR emission factors for small domestic combustion sources were used to calculate emissions. Industrial and transportation emissions databases as well as background concentrations were updated. The project was again focused on urban level and ADMS-Urban model was used. The 2007 year was chosen for the baseline and model evaluation. Three substances were analysed: PM10, B(a)P and NO_2. A set of scenarios was prepared to develop the best action plan. The second objective of the project was to achieve better understanding of the problem by citizens and participation of the stakeholders (local authorities, gas, energy and heat distribution plants, media). In effect the consultation process was prepared very carefully including workshop meetings with local authorities and large consultation conference for stakeholders and media. Regarding the projects' objectives, modelling had two important functions: source apportionment and pollution visualization. During the consultation process two new questions arose. Local authorities needed to find the best set of measures concerning replacement of the solid fuel domestic combustion sources to optimize the environmental and economic factors of the process. The analysis of the real impact of heavy industry in the eastern part of Krakow was demanded because of many complaints of the citizens living close to the steelworks on the episodes of dust deposition.

Regional authorities prepared two additional studies: *The implementation of the solid fuel prohibition act* and *The detailed inventory of emissions from Nowa Huta Industrial Zone*. The first study included the inventory of solid fuels yards located in the city. Further improvement of domestic heating emission inventory was undertaken. Parameters of the fuels were collected to assess the quality of the coal used in Krakow and to verify the emission factors. The PM10 dispersion modelling was run using ADMS-Urban for 2009 baseline year. Two scenarios were analysed: the prohibition of the poor quality solid fuels and the prohibition of the all solid fuels use in Krakow. The economic assessment and law analysis were also prepared for the scenarios. The project concerning industrial emissions involved the PM10 dispersion modelling using the ADMS-Urban to study the impact of the industrial zone (NOG) on the city. Detailed inventory of the industrial emissions was prepared with the special regard to the diffuse emissions. Impact of the industry on the air quality in the city for selected exceedances days was also analysed.

After the second AQAP the media started to write regularly on air quality problem in local papers. Regional air quality portal with PM10, NO_2 and other pollutants concentration forecasts using GEM–AQ model was developed (Struzewska et al., 2012).

The last AQAP involved the modelling of PM2,5, PM10, B(a)P and NO_2 at the regional level using CALMET/CALPUFF. The emission inventory was prepared separately to achieve better quality. The methodology was based on division of the city's districts into smaller units with homogeneous urban facilities (building/transport/industry) structure. The heat demand was analysed for all units partly based on specific data and partly based on statistical data. The project included new elements compared to the previous AQAPs: analysis of PM2,5 pollution, assessment of the pollution transport from neighbouring regions and short term action plan. The project was focused also on the consultation process, economic analyses and study on the health effect of the pollution to achieve the action plan accepted by citizens and other stakeholders. Citizens of Krakow started to see the air quality problem and called for more determined actions. Finally the solid fuel prohibition act was established as a local regulation by the regional authorities.

RESULTS

The figures and the table below present the most important results concerning modelling and its use for the whole air quality management process. The emission inventory methodology improvement is illustrated. The 'low emission' inventory was developed intensively and the industrial emissions were verified. Differences in transportation emissions in the specific years are mainly due to the changes in transport intensity and transport system development in the city. The spatial emissions distribution is presented in the figure 3.

Table 1. Improvement of emission inventories in Krakow for the period 2003-2009 (tonnes)

Type of the sources	**2003**	**2007**	**2009**
Low emission	409.3	762.0	838.7
Transportation	598.2	539.6	539.6
Industry	1112.0	980.7	1247.9
SUM	**2119.5**	**2282.3**	**2626.2**

The emissions from residential heating sources are distributed across all area of the city with higher density in the central and northern districts. The industrial diffuse emissions are also included on the picture. The highest industrial point emissions are situated in the NOG Zone in the eastern part of Krakow. The transport emission density is the highest in the central part of the city across main streets and internal ring roads.

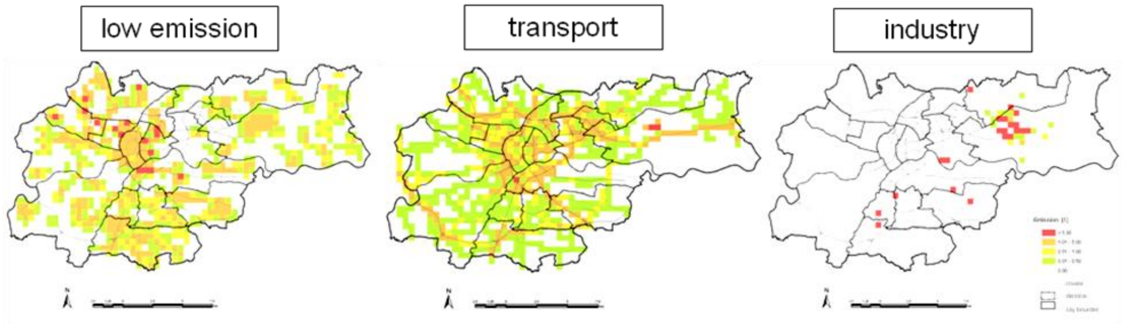

Figure 3. PM10 Emissions distribution in Krakow in 2009

The figure 4 illustrates model results (annual concentration of PM10) for the different projects. The development of the low emission inventory improved model's performance. The exceedance area extends from 2003 to 2009 and these changes are due to the different meteorology conditions but also to the emissions inventory methodology improvement.

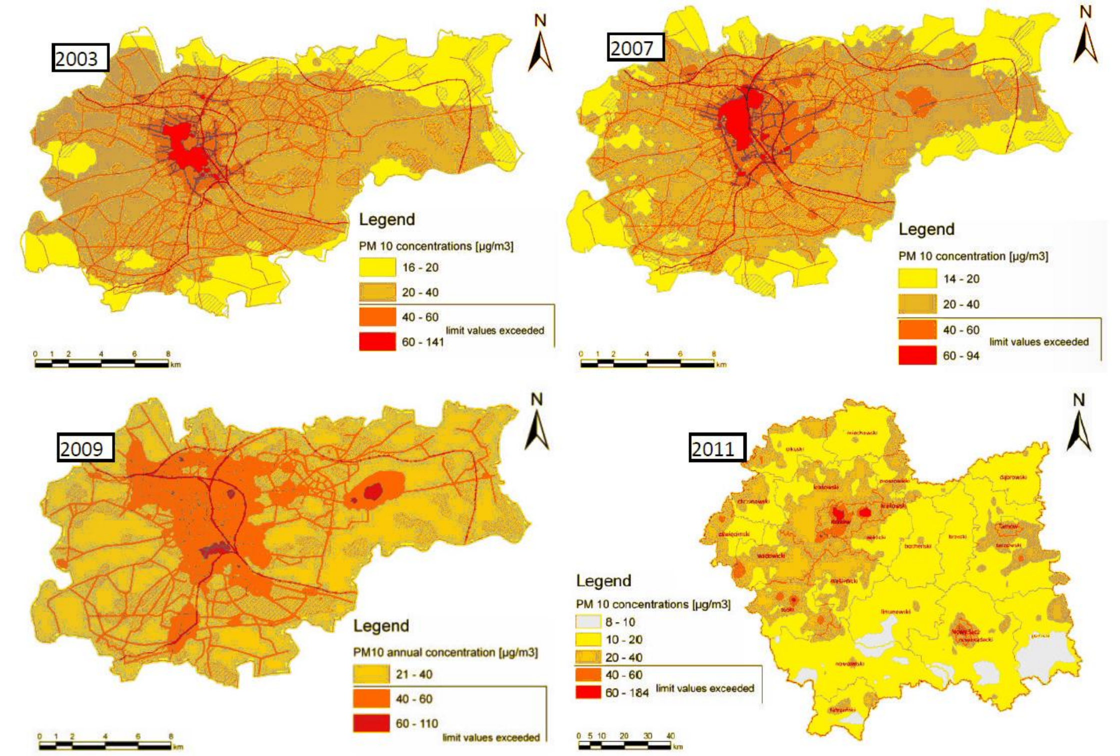

Figure 4. Annual concentration of PM10 in Krakow (urban scale - 2003, 2007, 2009; regional scale model - 2011)

The exceedance areas are situated in the city centre, in the NOG Zone and along the main streets/roads. The PM10 concentration exceeding the limit value was measured also in the Swoszowice district (south of the city) and was calculated by model only for the last projects for 2009 and 2011 after detailed emission inventory. Exceedance area is much larger for 24-hours PM10 limits. Area where B(a)P annual concentration is above the target value includes almost the entire city.

The use of the modelling for air quality management is well illustrated in the figures below.

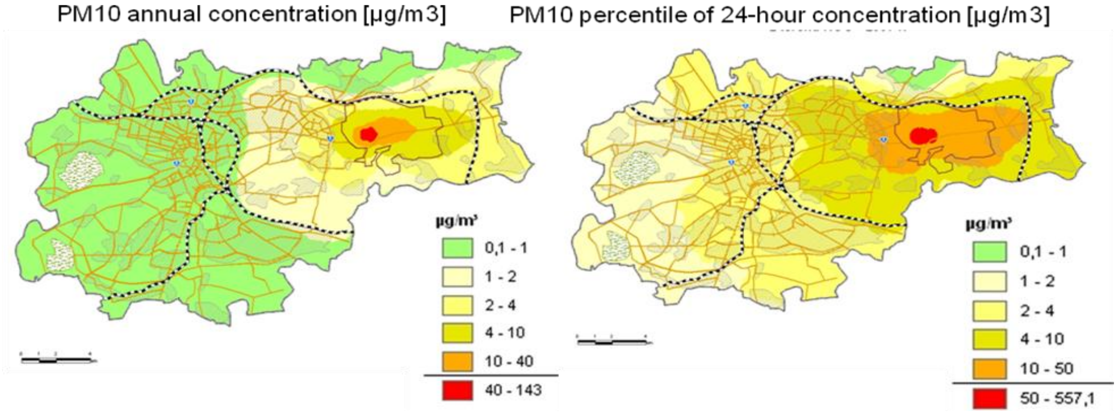

Figure 5. Influence of NOG industrial area on Krakow air quality in 2009 (left – annual concentrations, right – 90.4 percentile of 24 hours concentrations)

The maps in the figure 5 present the influence of the industry from NOG Zone on the air quality in the city. Detailed analyses of the daily concentrations during exceedance periods showed that the share of industrial emissions in the 24 hours concentration varies from 3% to 94 % with medium share of 23% at the measurement point located next to the Zone.

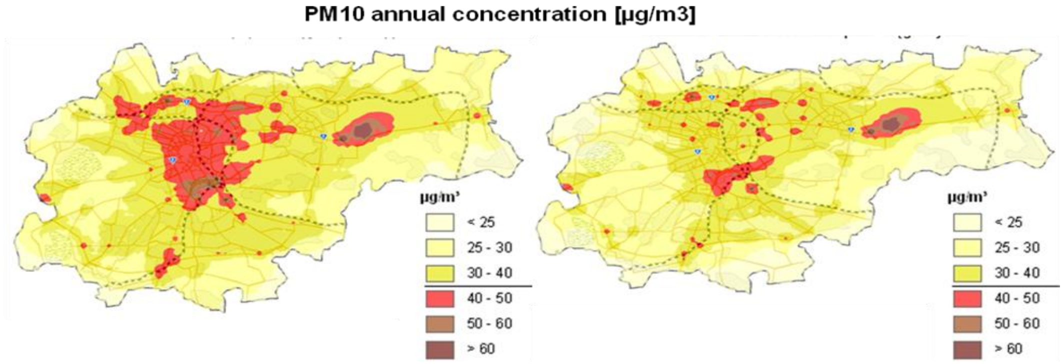

Figure 6. Influence of solid fuel prohibition scenarios on the air quality in Krakow (left –'good quality coal' right – 'full prohibition' option)

The results of the implementation of solid fuel use prohibition scenarios are presented in the figure 6. The full prohibition of solid fuel use gives much better air quality effect than the option of 'good quality coal'.

CONCLUSIONS

Dispersion modelling is a very important tool in air quality management. Understanding the reasons of poor quality is possible through the source apportionment methods. In the case of Krakow city application of urban scale modelling showed the high share of residential combustion and transportation in the PM10 concentrations recorded within the city area. Another function of modelling is visualization of the air quality problems to allow citizens to know the causes of air pollution and present the possible short and long term improvement options. Experiences of 10-years process of air quality management system development indicate the important role of emission inventory completeness and accuracy for air quality modelling. Bottom-up local scale methodology in emission inventory is generally required to achieve good results of modelling.

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