Chapter 4. COUNTRY-SCALE POLLUTION ASSESSMENT (POLAND)

A series of country-scale studies of heavy metal pollution in the EMEP countries has been carried out by MSC-E for long period in close co-operation with national experts [*Travnikov et al*., 2018]. This year a case study for Poland has been completed and the results of the study have been published in a special Technical Report [*Ilyin et al*., 2018]. Main results of the study are briefly discussed below.

4.1. Heavy metal pollution levels in Poland

The country-specific study for Poland was aimed at analysis of factors affecting Cd pollution levels in the country and providing the country with detailed information on Cd pollution. Assessment of Cd pollution involved emission data prepared by national experts and CEIP, measurement data from the EMEP and national monitoring networks, and atmospheric transport modelling performed by MSC-E. Results were produced with fine spatial resolution (0.1°x0.1°) and related to 2014. The work was carried out in cooperation with national experts from Poland and the Czech Republic. Detailed information about results of the study is available in [*Ilyin et al*., 2018].

Evaluation of the modelling results shows that at most stations the modelled and observed Cd air concentrations are comparable in the warm period. However, in the cold period the model underestimates the observed levels. A number of reasons of the underestimation were considered. It was found out that the main reason was low Cd emissions in the cold period from the emission sector 'Residential combustion'.

In order to improve quality of the assessment and to identify country's regions, where the emission estimates require further refinement, an emission scenario has been developed. Original national total emission of Cd in Poland is 14 t/y. For comparison, total national emission prescribed by the scenario is 17 t/y (26% higher). However, this value is within the uncertainty of annual national emissions estimated by national experts at about 70% [*Dębski et al*., 2017]. The scenario emissions of Cd from the 'Residential combustion' sector are higher than the value in the national emission data by a factor 2.6 (5.7 vs. 2.2 t/y). However, the changes vary among the country's provinces. The most substantial increase of Cd emission is noted for the southern and south-western part of Poland (Fig. 4.1).

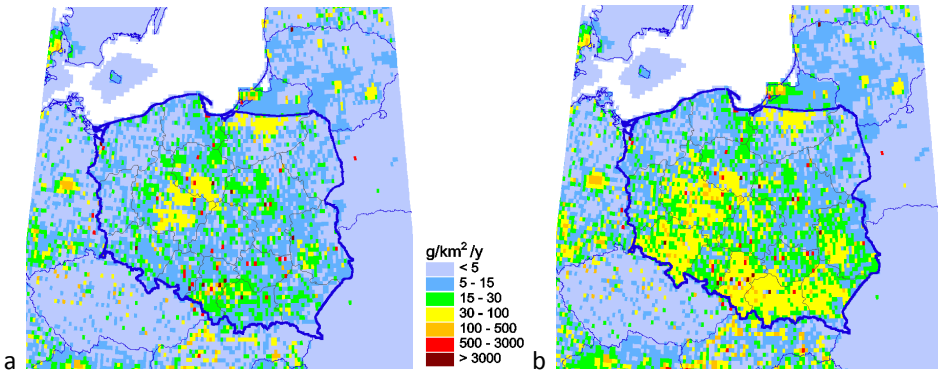

Fig. 4.1. *Original (a) and scenario (b) emissions of Cd in Poland in 2014*

The suggested emission scenario favoured significant improvement of modelling results when compared with observed levels both at Polish monitoring stations and the stations located outside the country. In particular, the comparison between modelled and measured Cd concentrations in air at the EMEP and national monitoring stations in Poland and the Czech Republic demonstrated the increase of the mean relative bias from -24% to -4% in cold period, and the increase of the spatial correlation coefficient form 0.79 to 0.83.

Thus, ***the study demonstrates that available emission data may contain significant uncertainties, which affect results of pollution assessment. Use of emission scenarios or expert (non-official) emission estimates can produce more realistic, from the viewpoint of agreement with observed values, alternative results of the assessment.*** However, this activity requires close cooperation with national experts and relevant EMEP centres and Task Forces.

Country-specific information on Cd pollution levels in Poland prepared within the study includes spatial distributions of pollution levels with fine resolution, source-receptor relationships for particular country's provinces (voevodships), pollution from various emission sectors and large point sources as well as information on pollution levels in large cities. The assessment is based on emissions data prescribed by the emission scenario.

For the country as a whole the major contributor to Cd deposition is the sector 'Industry', which makes up 43% of total anthropogenic deposition in Poland (Fig. 4.2). The second largest contributor is 'Residential Combustion' (29%). Other sectors contribute around 5% in sum, and contribution of foreign sources is about 20%.

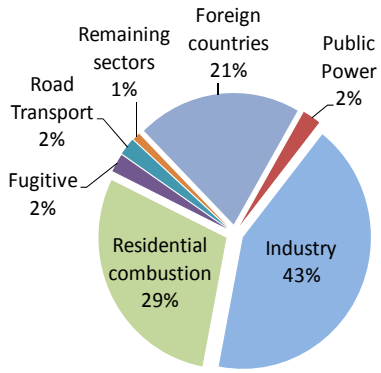

Fig. 4.2. *Contribution of the major emission sectors to deposition from anthropogenic sources in Poland*

However, the shares of emission sectors vary in the provinces of the country. In four voivodships (Opolskie, Slaskie, Malopolskie, Swietokrzyskie) the contribution of the 'Industry' sector to anthropogenic deposition exceeds 50% (Fig. 4.3). The largest contribution of 'Residential combustion' is noted for the western part of the country: Wielkopolskie (40%), Lubuskie (40%), Dolnoslaskie (36%) voivodships. The contribution of emissions from the sector 'Fugitive' is the highest in the northern and central parts: Pomorskie (8%), Mazowieckie (8%) and Kujawsko-Pomorskie (7%) voivodships. The share of the sectors 'Public Power' and 'Road Transport' varies from 2% to 4% throughout the country.

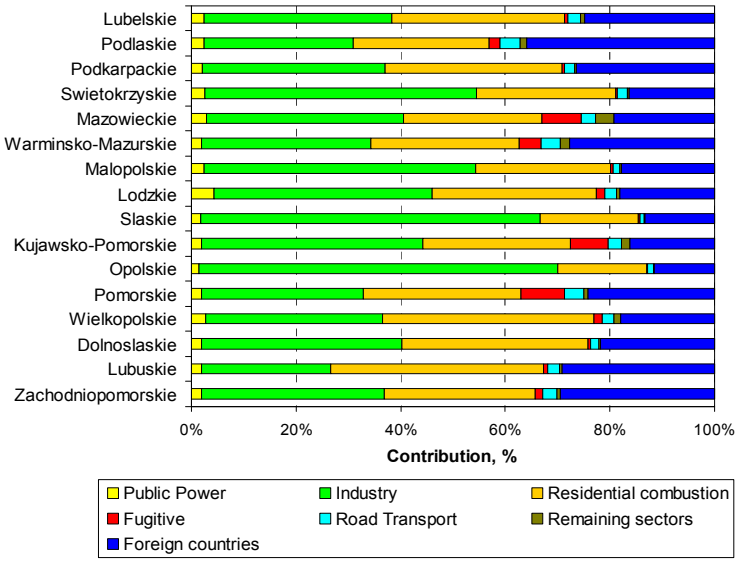

Fig. 4.3. *Contributions of main national emission sectors and foreign sources to deposition in Polish voivodships in 2014*

4.2. City pollution by heavy metals

Most of population in Europe lives in urban areas. Investigation of pollution levels in cities is currently one of priority tasks of the Convention. MSC-E has started preparatory work on evaluation of heavy metal pollution levels in cities of the EMEP region. Primary attempt to evaluate pollution levels in urban areas is carried out in the framework of country-specific case study for Poland. In this study Cd pollution levels and their seasonal variations in the selected Polish cities are analysed.

Cities can be considered as a source of pollution for ambient atmosphere as well as a receptor of pollution which comes from sources located in other parts of the country or in other countries. There are numerous studies [e.g., *Kiesewetter et al*., 2015; *Elser et al*., 2016; *Kiesewetter and Amann*, 2014] focused on differentiation of pollution levels in cities between several components such as contributions from intercontinental transport, transboundary transport, national sources and sources located in a city. The latter is called urban increment, i.e. contribution of city sources to pollution levels in the city.

The urban increment of heavy metal pollution was calculated for Polish cities by means of source-receptor calculations with fine spatial resolution (0.1°x0.1°). For this purpose, anthropogenic emissions of Cd in gridcells of the model domain, which belong to the cities, are marked as city sources. Therefore, emissions from particular cities and emissions from other territory of Poland are distinguished in national polish emission data. As a result, for each selected city contribution of the city's sources and contribution of other anthropogenic sources (national and foreign) are calculated. Similar approach is used also by other researches [e.g. *Thunis et al*., 2016, *Guo et al*., 2016]. In this study contribution of urban sources was assessed for 23 Polish cities (Fig. 4.4).

Although the model has not been designed to simulate urban-scale pollution levels, the calculated concentrations reasonably agree with the observed values. The model successfully reproduces spatial pattern (correlation coefficient 0.71) and magnitude (relative bias -8%) of the observed

concentrations of Cd measured at urban locations (Fig. 4.5). In 60% of stations the difference between modelled and observed values lies within a factor of 2. At some stations the model underestimates the observed levels, and in one city – overestimates by more than a factor of 2. These discrepancies could be caused by both uncertainties of emissions in cities and uncertainties of model parameterizations which do not take fully into account peculiarities of dispersion of pollution levels over urban territories. As seen, at most of the stations the main contribution to pollution levels is made by anthropogenic emissions. Seasonal variability of the observed concentrations was also reproduced by the model.

Fig. 4.4. *Location of the selected Polish cities*

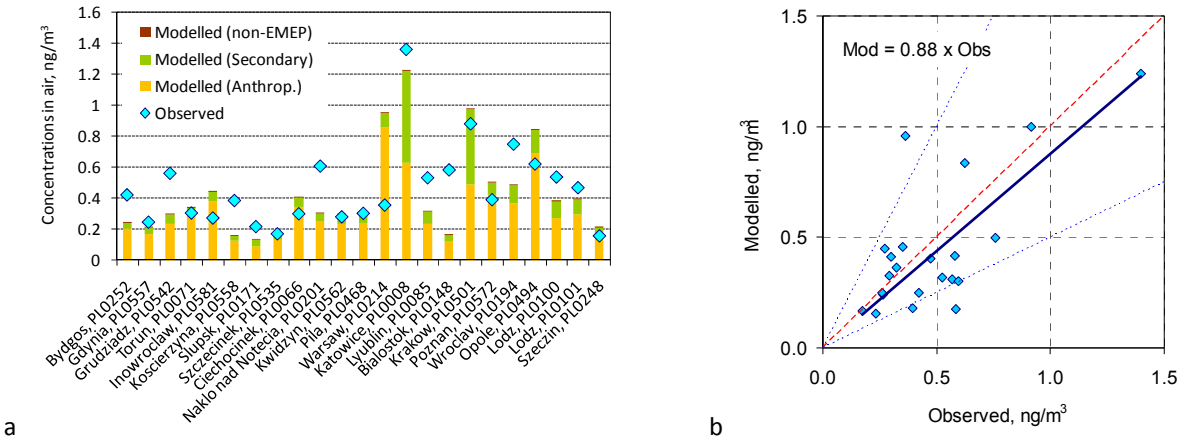

Fig. 4.5. *Annual mean modelled and observed concentrations of Cd at urban background stations in selected Polish cities depicted as bar charts for particular stations (a) and as scatter plot (b). Red dashed line in (b) indicates 1:1 ratio, and dashed blue lines indicate a two-fold difference between modelled and observed values.*

Calculated annual mean concentrations of Cd in air caused by contribution of anthropogenic sources located outside city area (external sources) and city sources (urban increment) to annual mean air concentrations of Cd are shown in Fig. 4.6 for various Polish cities. In large cities such as Warsaw, Krakow, Gdansk, Katowice, Poznan the city sources contribute significant faction (20–70%) of anthropogenic concentrations. In other considered cities the urban increment is relatively small making up from 1-2% to about 10-15%.

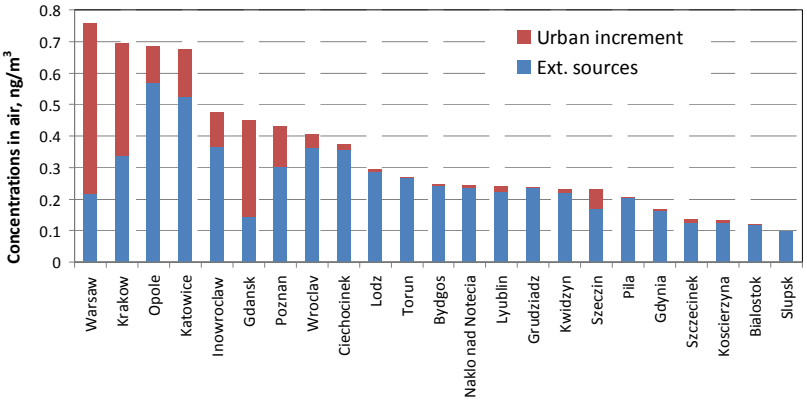

Fig. 4.6. *Calculated concentrations of Cd in air caused by anthropogenic sources outside city (external) and by city sources (urban increment).*

Verification of these results is hampered by very limited information. Therefore, information on PM2.5 and PM10 contributions from urban sources is also taken into account, because their emission sources and atmospheric behaviour resembles those of Cd. Detailed modelling study of PM pollution levels in Warsaw is presented in [*Holnicki et al*., 2017a]. It is shown that contribution of city emission sources is dominating and ranging from 62% to 70% for PM2.5 and from 76% to 78% for PM10. Besides, analysis of population-weighted exposure demonstrated that contribution of local sources of PM2.5, PM10 and Cd amounted to about 50%, 40% and 90%, respectively [*Holnicki et al*., 2017b]. In work [*Pastuszka et al*., 2009] it was shown that wintertime concentrations of Cd on fine particles (PM2.5) in the center of the Zabrze city (Upper Silesia) is about 60% higher than the concentrations at the urban background level. For Cd on coarse particles (PM10) the difference is 90%. Urban increments of PM10 during short-term episodes in cities Krakow, Zabrze, Jelenia Gora and Warsaw, calculated on the base of observed values at regional background and traffic stations, varies from about 20% to 60% [*Reizer and Juda-Rezler*, 2016]. These values of the urban increment are comparable with the values obtained in the current study.

Evaluation of model-based urban increments for large cities in Europe, including Poland, was carried out using the SHERPA tool [*Thunis et al*., 2017]. Contribution of intercontinental and transboundary transport of PM2.5 as well as external and internal emissions of Polish cities was considered.

Results of the comparison of the urban increments estimated by the SHERPA tool and calculated in this study are presented in Fig. 4.7. Since two different pollutants are considered, fractions of urban increment are compared instead of absolute values of the concentrations. For large cities (Warsaw, Katowice, Krakow, Poznan, Gdansk, Szeczin) the fractions of concentrations caused by city sources of Cd are comparable with

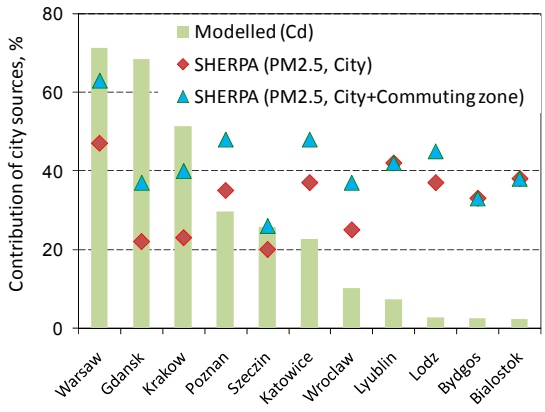

Fig. 4.7. *Contribution of city sources to mean annual cadmium air concentrations (this study) and PM2.5 derived from the results of SHERPA project*

those of PM2.5. For some cities the difference between the results of the current and SHERPA studies is significant. For example, the urban increment of Cd concentrations for cities Lodz, Lyublin, Bydgos and Bialostok vary from 2 to 7%, while the increment of PM2.5 is 30-45%. This discrepancy can be caused by differences between spatial distributions of Cd and PM emissions. Besides, the calculations of urban increments are based on different models – GLEMOS in this study and CHIMERE [*Menut et al*., 2014] in SHERPA study. Differences in the model formulations also give rise to discrepancies in final results. Nevertheless, in spite of the mentioned reasons, values of the urban increments based on this study and the SHERPA tool are comparable by the order of magnitude for most of considered cities.

An alternative way to estimate the urban increment is based on comparison of measured concentrations in a city and at rural station located near the city [*Lenschow et al*., 2001]. This approach was used for evaluation of seasonal variability of urban increments of Cd air concentrations in cities of north-western Poland located nearby (within 100-km distance) rural station PL0077A (Fig. 4.8). Besides, for comparison purposes similar analysis was performed for concentrations of PM10 measured at the same stations.

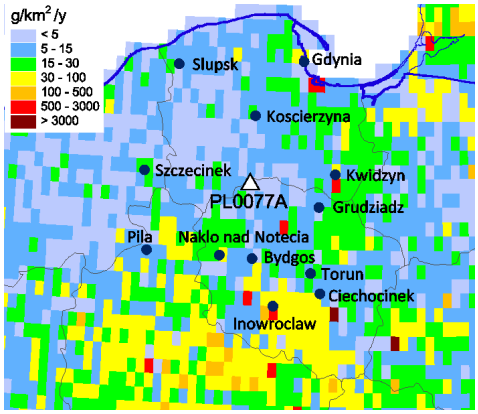

Fig. 4.8. *Emission flux of Cd with resolution 0.1°x0.1° and location of regional background (white triangle) and urban-background (dark circles) measurement stations.*

Seasonal variability of monthly mean modelled and measurement-based urban increments are compared (Fig. 4.9). Since the absolute magnitudes of the Cd and PM10 increments differ significantly, they were normalized by the corresponding maximum monthly-mean values. Observed seasonal changes of the normalized urban increments of Cd are well reproduced by the model at a number of stations, for example, at Bydgos, Ciechocinek, Naklo nad Notecia, Koscierzyna and Kwidzyn. At these stations minimum of the urban increment is noted for warm period, while the maximum – for cold period. Similar seasonal behaviour is also exhibited by urban increment of PM10 concentrations. At the same time, at other stations (e.g., Grudziadz) no distinct seasonal variability of modelled urban increment is noted, while the increments based on observations undergo seasonal changes.

The obtained discrepancies in seasonal changes of the modelled and measured increments may be caused by uncertainties/inconsistencies in emission data. For instance, seasonal variability of Cd concentrations is significantly affected by emissions from the sector 'Residential combustion'. Emissions from this sector are much higher in cold period and smaller in warm period. However, for some cities where the measurement stations are located, emission values from this sector in the corresponding grid cells are minor or even absent in the used emissions inventory (Fig. 4.10).

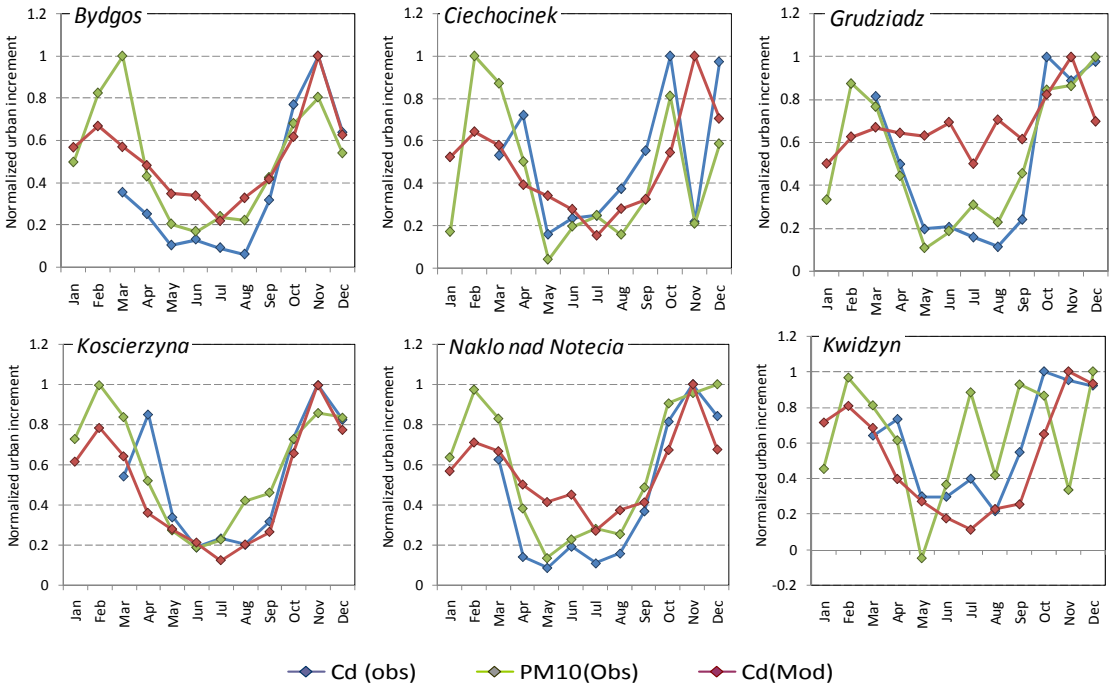

Fig. 4.9. *Seasonal changes of normalized Cd urban increments obtained on the base of modelling results as well as Cd and PM10 urban increments derived from measurements*

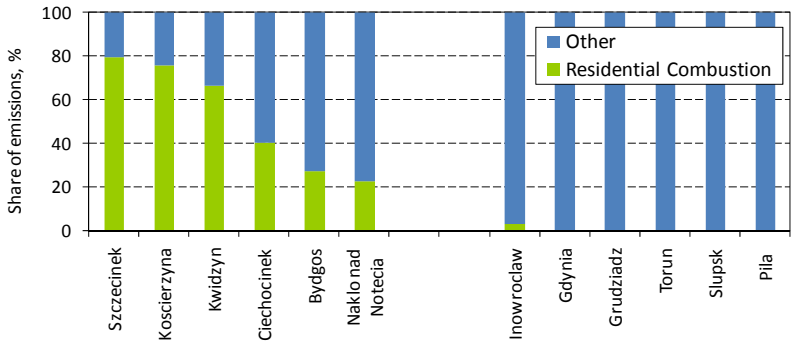

Fig. 4.10. *Fractions of emissions from residential combustion and sum of other sectors in grid cells where cities are located. Left part of the bar chart: stations where seasonal variability of urban increment reproduced; right part: stations where seasonal variability of urban increment not reproduced by the model.*

Thus, the suggested method of direct fine resolution modelling allows matching modelled and observed air concentrations of Cd in Polish cities with sufficient quality. Comparison of the urban increments calculated in the current study with results of other studies, based on modelling or observations, revealed reasonable agreement of the applied methods for large cities. As a rule, larger cities are characterized by higher contribution of emissions from urban sources to Cd and PM pollution compared to smaller cities. At the same time, contribution of sources located outside urban areas is substantial even in large cities.