EXECUTIVE SUMMARY

Heavy metals and persistent organic pollutants (POPs) are toxic substances, which are within the scope of various international bodies including the UNECE Convention on Long-range Transboundary Air Pollution (hereafter, CLRTAP or the Convention). Despite continuous decrease of emissions of these pollutants in the past decades, these substances still cause adverse effects on human health and ecosystems (the Long-term Strategy of the Convention, ECE/EB.AIR/2018/1/Rev.1). The priority heavy metals targeted by the Convention are lead (Pb), cadmium (Cd) and mercury (Hg). The list of considered POPs includes polychlorinated biphenyls (PCBs), polychlorinated dibenzo(p)dioxins and dibenzofurans (PCDD/Fs), hexachlorobenzene (HCB), and polyaromatic hydrocarbons (PAHs). The priority PAHs are benzo(a)pyrene (B(a)P), benzo(b)fluoranthene (B(b)F), benzo(k)fluoranthene (B(k)F), and indeno(1,2,3-cd)pyrene (IP). Research and operational assessment of heavy metal and POP pollution are carried out by relevant EMEP Centres – the Centre of Emission Inventories and Projections (CEIP), the Chemical Coordinating Centre (CCC), the Meteorological Synthesizing Centre – East (MSC-E).

The purpose of the present Status Report is to provide an overview of the EMEP Centres activities in the field of heavy metals and POPs carried out in accordance with the bi-annual workplan of the Convention for 2018-2019 [ECE/EB.AIR/GE.1/2017/20-ECE/EB.AIR/WG.1/2017/13]. The report includes information on emissions, monitoring, and model assessment of heavy metal and POP pollution in 2017; research activities and co-operation with subsidiary bodies to the Convention and international organizations. Detailed technical information aimed to support the Status Report is available in the Supplementary Data Reports on heavy metals [*Ilyin et al.,* 2019] and POPs [*Gusev et al.,* 2019] as well as at the MSC-E website (www.msceast.org).

Emissions

Quality of emissions data reported by countries has been improved significantly. In 2019 emission inventories for heavy metals and POPs were submitted by 45 of 51 Parties. Completeness and consistency of the reported data affects significantly estimated emissions trends in various parts of the EMEP region. Emissions of heavy metals in the western part of the EMEP region show a rather smooth declining trend. In contrast, long-term trend of heavy metal emissions in the eastern part of the region as well as trend of POP emissions exhibit strong variations due to incomplete reporting or effect of inconsistent data from individual countries. In order to improve consistency of the time series the countries recalculate previously reported data. For instance, emissions data for 2016 were considerably (more than 15% difference) changed by 22 countries. Gridded emissions data on the new EMEP grid were reported by 29 countries. Final emissions fields for modelling were generated by MSC-E based on reported emissions data collected and gap-filled by CEIP and supplemented by additional information on vertical distribution, seasonal variation and chemical speciation of heavy metal and POP emissions.

Monitoring

Measurements of heavy metal and POP pollution levels were performed at sites of the EMEP monitoring network under methodological guidance of CCC. Observed concentrations of Pb and Cd in air or precipitation in 2017 were reported from 65 measurement sites. Besides, 28 sites were measuring Hg in either air or precipitation. The PAHs measurements were carried out at 36 stations, and other POPs were observed at 12 sites. The lowest concentrations for heavy metals were generally found in Scandinavia, whereas the highest values were commonly observed in Central and Western Europe. The highest PAH and PCB levels took place at sites located in the central part of Europe, while the highest HCB levels are noted for the Arctic stations (Spitsbergen, Greenland). The analysis of seasonal variability reveals that lighter PCB congeners have higher contribution to total sum of PCBs in summer compared to the heavier congeners. It was also shown that HCB air concentrations are the lowest in summer and the highest in winter. The exception is stations located in the high Arctic (e.g., Zeppelin).

Transition to finer spatial resolution makes possible more thorough analysis of heavy metal and POP levels in highly populated and urbanized areas. In order to refine modelling results and facilitate evaluation of the model performance MSC-E utilized supplementary data from AIRBASE database by European Environmental Agency (EEA). Information on air concentrations of Pb, Cd, Hg and B(a)P from more than 700 European sites was involved into the analysis.

Status of pollution levels in 2017

Model assessment of transboundary pollution of the EMEP countries by heavy metals and POPs in 2017 was carried out by MSC-E. Main results of the assessment are based on the most recent heavy metal and POP emissions dataset for 2016 available at the moment of the study. Updated results based on the new emissions reporting for 2017, which became available in the meantime, will be presented at the website along with updated information for the EMEP countries.

The performed analysis shows that the highest levels of Pb, Cd, and Hg deposition take place in the Balkan countries, Central and Eastern Europe. Considerable deposition also occurs along windward slopes of mountain regions (the western part of Norway, the Alpine and Balkan regions, the south-eastern part of Kazakhstan and north of Kyrgyzstan). Elevated Hg deposition fluxes are also predicted in the high Arctic as a result of intensive Hg oxidation during springtime.

High levels of B(a)P concentration, which exceed the air quality guidelines, take place in the countries of Central and Eastern Europe. Countries of Central Europe (Poland, Slovakia, and Hungary) as well as Romania, Northern Italy, Russia, and Turkey are characterized by elevated concentrations of PCDD/Fs. For PCB-153 the areas of relatively high concentrations comprise countries of Western and, partly, Southern Europe (e.g. Germany, France, Belgium, and Italy). In case of HCB, higher levels are indicated for countries of Central, Southern, and Eastern Europe. Contrary to other POPs, HCB levels in air are more homogeneous indicating its higher persistence in the atmosphere. Spatial

distributions of annual deposition fluxes of HCB, PCDD/Fs, and PCB-153 are similar to those of air concentrations.

Modelled air concentrations of heavy metals generally agree with the levels observed at the EMEP monitoring network. The mean relative bias between the annual average modelled and observed concentrations does not exceed 1% and 12% for Pb and Cd, respectively. The corresponding spatial correlation coefficients are as large as 0.8. Deviation between the modelled and observed Hg^0 air concentrations does not exceed ±15%. Simulated wet deposition of heavy metals agrees with observations within a factor of 2. The modelling results for PAH reproduce the EMEP observations with the mean relative bias for the sum of 4 PAHs about -17% and high spatial correlation (0.8). Validation of individual PAH compounds indicates some under-prediction of observed B(a)P, B(k)F, and IP air concentrations, and over-prediction of B(b)F concentrations. The model tends to under-predict by 40% non-EMEP B(a)P measurements at rural and suburban monitoring sites available from AIRBASE. Simulations of PCB-153 are generally consistent with measured pollution levels in the countries of Northern and Central Europe. For more than a half of monitoring sites the difference between measured and modelled concentrations is within a factor of 2 and spatial correlation coefficient is 0.8. There is a general tendency of under-prediction of observed HCB concentrations by the modelling results with mean bias about -50%.

Main contributors to atmospheric deposition of Pb and Cd in the EMEP countries are anthropogenic sources and wind re-suspension. The contribution of non-EMEP sources is relatively low except for the countries located close to the borders of the EMEP region. Regional anthropogenic emissions sources contribute on average 22% of Hg deposition in the EMEP countries, whereas contribution of intercontinental transport exceeds 75%. However, this large estimate contains implicit contribution of EMEP emissions that flew out through the boundaries and returned back to the region. The contribution of transboundary transport exceeds deposition form national sources in 37, 39 and 36 of 51 EMEP countries for Pb, Cd and Hg, respectively.

Deposition of PAH from foreign sources exceeds deposition form national sources in a half of the 51 EMEP countries. Similar prevalence of transboundary transport over national emissions in deposition of other POPs is estimated in a number of countries varying from 22 for PCDD/Fs to 38 for HCB. Secondary emission sources of PCDD/Fs, PCB-153, and HCB contributed about 50-70% to deposition of these pollutants in the EMEP countries.

Additional information products

Regular model assessment provides valuable information on heavy metal and POP pollution levels as well as the source-receptor relationships. Variety of additional information can be produced to support the policy making process both within the Convention and in other international bodies. It includes evaluation of ecosystem-specific deposition, atmospheric loads to major regional watersheds, marginal seas and remote regions (the Arctic), estimates of exceedances of air quality standards, and pollution assessment on a global scale.

Model estimates of heavy metal deposition to various types of the surface land cover (forests,

grasslands, crops, water bodies, etc.) are performed on a regular base and available at the MSC-E website. These estimates of ecosystem-specific deposition are aimed to support activities within the Working Group on Effects (WGE) and, in particular, evaluation of critical loads exceedences. This relevant information is widely used in the Convention to characterize levels of adverse effects on human health and biota. Future work in this direction requires updating both deposition estimates and the critical loads for heavy metals and POPs.

Aquatic ecosystems are among the most vulnerable receptors of heavy metals and POP pollution, which undergo long-term accumulation and bio-magnification of the contaminants. In many cases, direct atmospheric deposition to the water surface cannot completely characterize contamination of the water body due to additional input of the pollution with ground and surface water run-off from the adjacent territory. Therefore, deposition fluxes of the considered heavy metals and POPs to major watersheds of rivers, lakes and coastal drainage areas within the EMEP region have been calculated and analysed. Among the major rivers in Europe and Central Asia the largest atmospheric load of Hg and B(a)P is to watersheds of the Vistula and Oder rivers in Central Europe. In contrast, the watersheds of the Ugra and Oka rivers located in Russia are the most significantly affected by Cd deposition.

Some PAHs, such as B(a)P, are characterized by toxic properties and are considered as carcinogens, mutagens, and teratogens. Exceedances of the target value adopted within the European Union for annual mean B(a)P air concentrations (1 ng/m^3) has been estimated based on the modelling results for the EMEP region. About 12% of total population of the EMEP countries lived in 2017 on territories characterized by the exceeded EU target level. The information on the target level exceedances is expected to support activities of the Task Force on Health and WGE with regard to the analysis of population exposure to toxic substances and their impacts on human health and ecosystems.

In addition, information on heavy metal and POP deposition to the marginal seas (Baltic, North, Mediterranean, Black, and Caspian) was prepared along with source apportionment for 2017. Similar information was also produced for the Arctic sector covered by the EMEP domain. Finally, the regional model assessment was supported by global scale simulations using the GLEMOS multi-scale modelling system to take into account the effect of inter-regional and intercontinental transport on pollution of the EMEP countries. It was noted that improvement of the global scale assessment requires closer co-operation of the LRTAP Convention with other international bodies (UN Environment, Stockholm Convention, Minamata Convention) in order to facilitate development of global emissions inventories for heavy metals and POPs.

Research activities

Research activities of MSC-E were carried out in accordance with the priorities of the long-term strategy for the Convention and were aimed at improvement of the pollution assessment quality and further development of the modelling tools. The main directions of the research included country-scale pollution assessments for B(a)P (France) and heavy metals (Germany), analysis of key emission sources and trends of B(a)P pollution, evaluation of a new mechanism of Hg photo-reduction in the atmosphere, and further development of the multi-media approach for POPs and Hg.

The current stage of a pilot study for B(a)P on regional and national scales is focused on evaluation of various parameterizations of the key processes governing B(a)P fate in the atmosphere. Two chemical transport models (GLEMOS and CHIMERE) are involved to the study. The analysis of the model simulations is carried out in close cooperation with national experts from France and Spain. Results of study show the critical role of the parameterization of B(a)P degradation in air for evaluation of its long-range transport. Thus, further refinement of the parameterizations of particle-bound B(a)P degradation and gas-particle partitioning processes is needed.

A new study of heavy metal pollution on a country scale has been started this year for Germany. The main objective of the study is generation of detailed information on levels and spatial distribution of atmospheric deposition of three heavy metals (Pb, Cd, Hg) in the country for the period from 2014 to 2016. This year activities include preparation of input information, pilot simulations of heavy metal pollution in the country, and preliminary evaluation against observations. Further work within the study will include finalizing the model assessment of pollution levels, joint analysis of assessment results with national experts, evaluation of national emissions based on both modelling and measurement data, and formulation of recommendations for improvement of the assessment quality both on national and regional scales.

In spite of significant improvements in understanding of Hg oxidation and reduction mechanisms, current knowledge on Hg atmospheric chemistry remains incomplete. An experimental version of the GLEMOS model was applied to test a new mechanism of Hg photo-reduction in gaseous phase over the global scale. The performed analysis of the modelling results shows that the new mechanism applied along with the Br-initiated oxidation chemistry provides reasonable agreement of modelling results with observations. However, remaining discrepancies of modelling results with measurements require further in-depth study of the Br oxidation/reduction chemistry.

Environmental dispersion of some POPs (HCB, PCDD/Fs, PCBs) and Hg is characterized by intensive cycling between various environmental media (atmosphere, ocean, soil, vegetation). This cycling determines a complex character of their dispersion and leads to legacy effect of historical emissions on contemporary pollution levels. To take this phenomenon into account a multi-media modelling approach has been developed and applied in the GLEMOS model for simulation of POP pollution both on regional and global scales. Besides, the approach was recently adapted for multi-media modelling of Hg. New developments of the multi-media approach include refining information on physical-chemical properties and update of the model parameterizations for HCB. For this purpose, sensitivity of the modelling results to parameterizations of HCB air-soil exchange has been studied. Simplified version of GLEMOS was also applied to simulate Hg multi-media cycling on a global scale for the period from the beginning of the 19th century to nowadays. The process of Hg accumulation in different media was studied and contemporary level in the atmosphere and seawater were evaluated against observations.

Analysis of long-term trends of B(a)P pollution was carried out for the period from 2007-2017 to support evaluation of effectiveness of the measures on PAH pollution reduction. Simulated changes of B(a)P air concentrations were compared with observations from the EMEP monitoring network and AIRBASE. It was shown that B(a)P levels demonstrate statistically significant decrease at 30% of sites and statistically significant increase at 7% of sites. Further activity will be focused on the

detailed analysis of temporal trends at particular stations including source apportionment and contribution of various emission sectors.

Cooperation with subsidiary bodies of the Convention and other international bodies

Scientific co-operation is an important part of MSC-E activities aimed at support and improvement of heavy metal and POP pollution assessment within EMEP as well as dissemination of the assessment results to wider international audience. Results of current research activities and future plans of MSC-E were discussed at the recent meeting of the Task Force on Measurements and Modelling (TFMM). The Centre also contributed to the work of the Task Force on Techno-Economical Issues (TF TEI) aimed at promoting the ratification of the CLRTAP Protocols by the EECCA countries. In co-operation with the Arctic Monitoring and Assessment Programme (AMAP) the Centre takes part in the new AMAP Assessments on the Arctic pollution by Hg and POPs. Besides, regular evaluation of airborne pollution load of heavy metals and POPs to the Baltic Sea is carried out in the framework of cooperation with the Helsinki Commission (HELCOM). Finally, MSC-E continues collaboration with the UN Environment as well as Minamata and Stockholm Conventions.

Main challenges and directions of future research

Future directions of the EMEP centre's activities will be aimed at improvement of heavy metal and POP pollution assessment in the EMEP region. The country-scale study for Germany will be continued focusing on detailed analysis of the modelling results and deriving recommendations for improvement of the assessment quality both on national and regional scales. Besides, detailed assessment of PAH pollution in Poland will be launched. A multi-model analysis for B(a)P pollution is planned in the framework of the EMEP EuroDelta-Carb intercomparison exercise in co-operation with TFMM and national experts. The major mechanisms of Hg oxidation and reduction in the atmosphere will be further studied and evaluated. Attribution of long-term changes of Hg and POP pollution to regional and extra-regional (global and secondary) sources will be performed. Finally, MSC-E will continue long-term co-operation with WGE focusing on joint analysis of heavy metal measurements in moss, preparation of information on Hg deposition to water bodies/watersheds, and B(a)P exceedances of air quality guidelines.