Atmospheric deposition of BDE-99 on the Baltic Sea

HELCOM Baltic Sea Environment Fact Sheet (BSEFS), 2021

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Key message

Levels of annual total atmospheric deposition of BDE-99 to the Baltic Sea have decreased in period from 2000 to 2019 by 91%, although higher decrease is estimated for the period 2000-2005 comparing to the subsequent period 2006-2019.

Results and Assessment

Relevance of the BSEFS for describing developments in the environment

This BSEFS shows the levels and trends in atmospheric deposition of BDE-99 to the Baltic Sea. The deposition of BDE-99 represents the pressure of emission sources to the atmosphere on the Baltic Sea aquatic environment.

Policy relevance and policy reference

The updated Baltic Sea Action Plan states the ecological objectives that concentrations of hazardous substances in the environment are to be close to background values for naturally occurring substances. HELCOM Recommendation 31E/1 identifies the list of regional priority substances for the Baltic Sea.

The relevant policy to the control of emissions of PBDEs to the atmosphere on European scale is set in the framework of UN ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP) by the Protocol on Persistent Organic Pollutants (1998).

For EU member states the policy frame is set by the EU IED Directive, whereas for the Russian Federation the corresponding policy framework is embraced by the Russian Federal Act on the environmental protection and the Act on protection of atmospheric air.

Assessment

Long-term changes of atmospheric input and source allocation of selected PBDE congener (namely BDE-99) deposition to the Baltic Sea and its catchment area were estimated using model simulations on the basis of available PBDE emission expert estimates. Developed experimental emission scenario is subject of high uncertainties. Nevertheless, it can be applied for preliminary analysis of contemporary levels of PBDE pollution and their temporal variations on the basis of model predictions and measurements.

Model predictions indicate that airborne input of BDE-99 to the Baltic Sea has declined by 91% in the period from 2000 to 2019 (Figure 1, Table 1). According to results of model simulations the rates of decline of BDE-99 deposition to the Baltic Sea were different in the periods 2000-2005 and 2006-2019. Trends of deposition fluxes for both periods were analysed using Mann-Kendall test methodology [*Gilbert*, 1987; *Connor et al.,* 2012]. In the period from 2000 to 2005, stronger decline is estimated with the mean annual rate of deposition decline about 2.9 kg per year with the confidence factor equal to 99.9%. The subsequent period (2006-2019) is characterised by less intensive mean annual decline rate of about 0.7 kg per year with confidence factor 99.9%. The values of the confidence factors indicates that the trends for the both parts of the assessment period are significant. Reduction of atmospheric input of BDE-99 to the Baltic Sea is connected with the realization of various abatement measures, which took place in the HELCOM countries as well as other EMEP countries.

The highest level of total annual BDE-99 deposition fluxes over the Baltic Sea in 2019 is estimated for the Sound sub-basin (Figures 2, 3). The lowest deposition flux is obtained for the Bosnian Bay sub-basin. The HELCOM countries contributed to BDE-99 deposition over the Baltic Sea in 2019 about 63%, with the largest shares made by Germany and Poland (Figure 4). The contribution of other EMEP countries is estimated to 28% (Table 2).

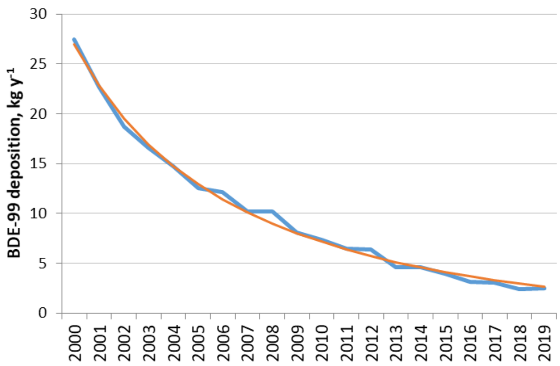

Figure 1. Long-term changes of total annual modelled atmospheric deposition (blue line) and estimates of normalized deposition (red line) of BDE-99 to the Baltic Sea for the period 2000-2019, (kg y^{-1}). Normalized depositions were obtained using the methodology described below in the metadata section 5.

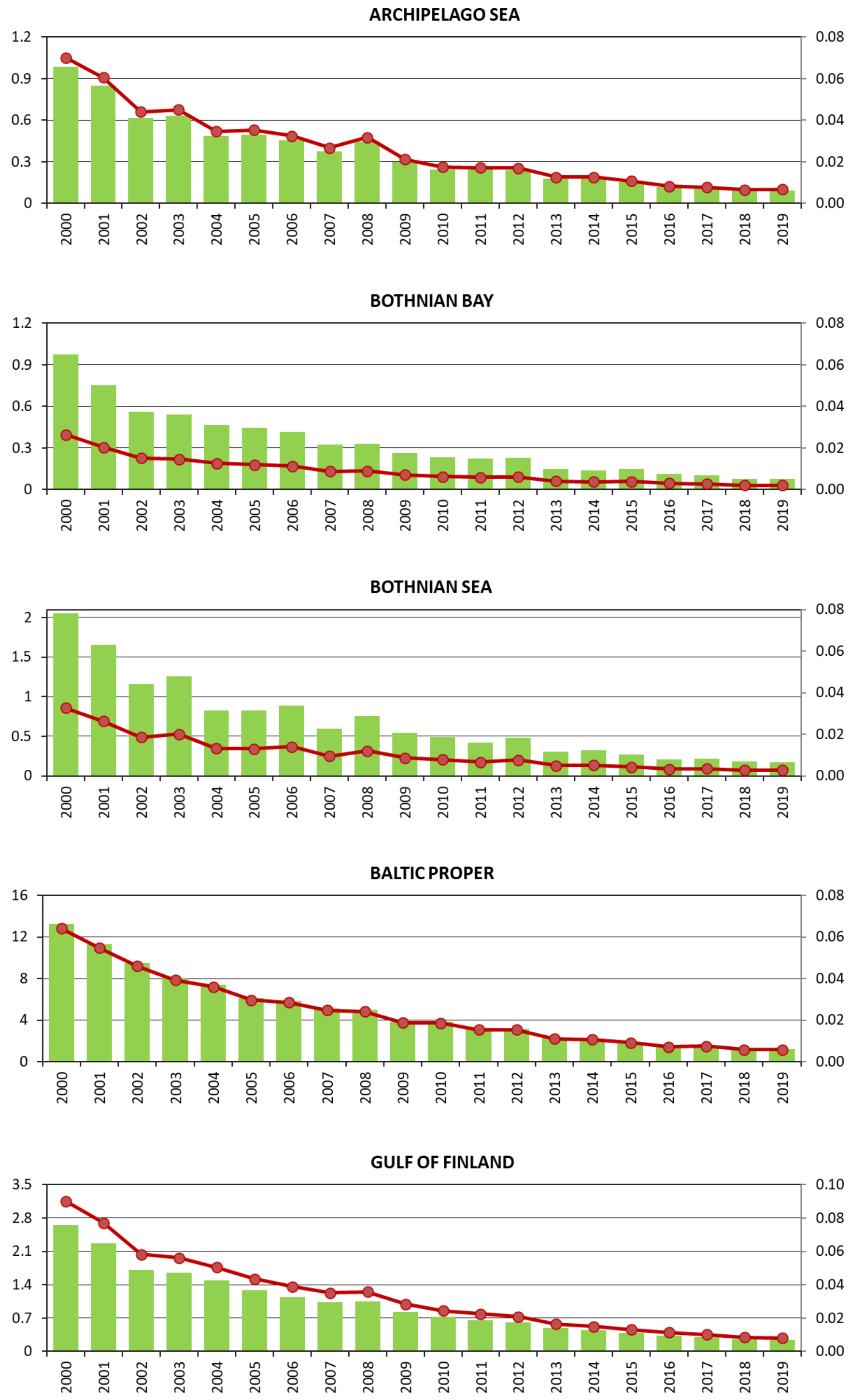

Figure 2. Time-series of computed total annual atmospheric deposition of BDE-99 to nine sub-basins of the Baltic Sea for the period 2000-2019 in kg y^{-1} as green bars (left axis) and total deposition fluxes in g km^{-2} y^{-1} as red lines (right axis).

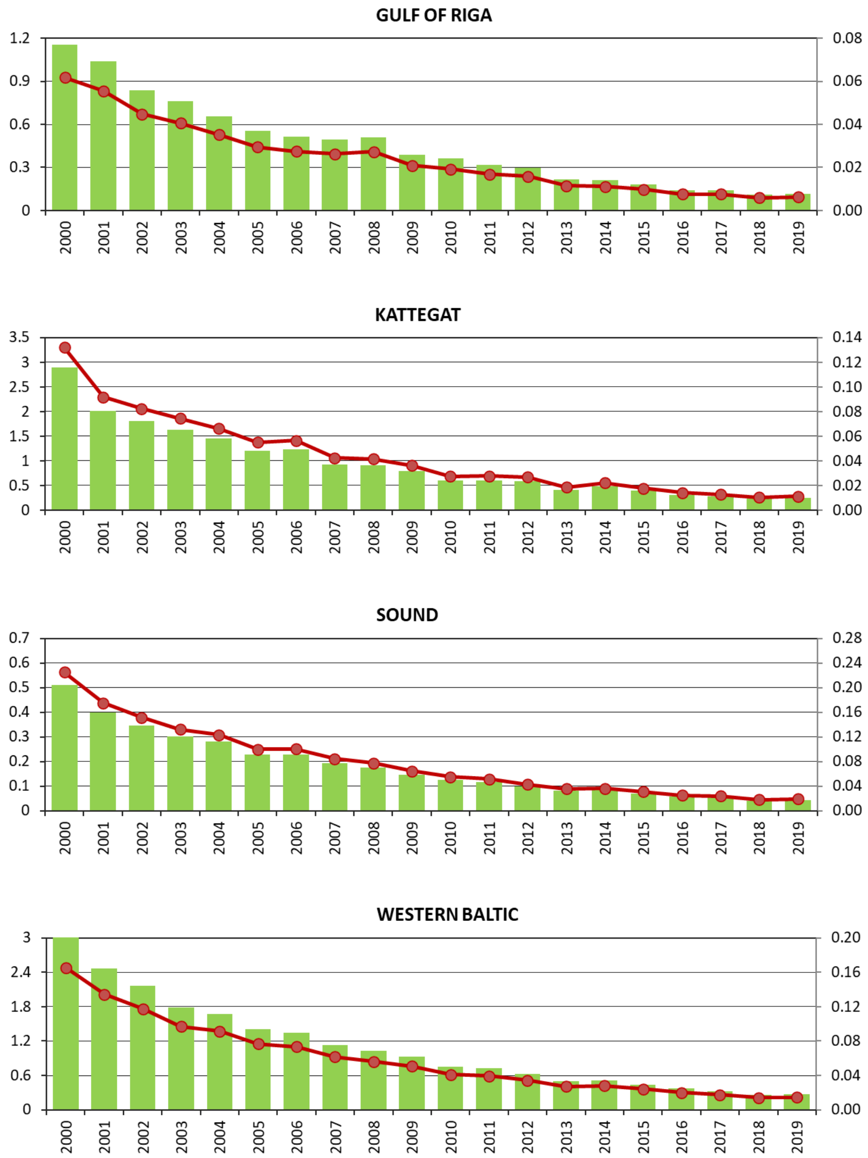

Figure 2. (continued). Time-series of computed total annual atmospheric deposition of BDE-99 to nine sub-basins of the Baltic Sea for the period 2000-2019 in kg y^{-1} as green bars (left axis) and total deposition fluxes in g km^{-2} y^{-1} as red lines (right axis).

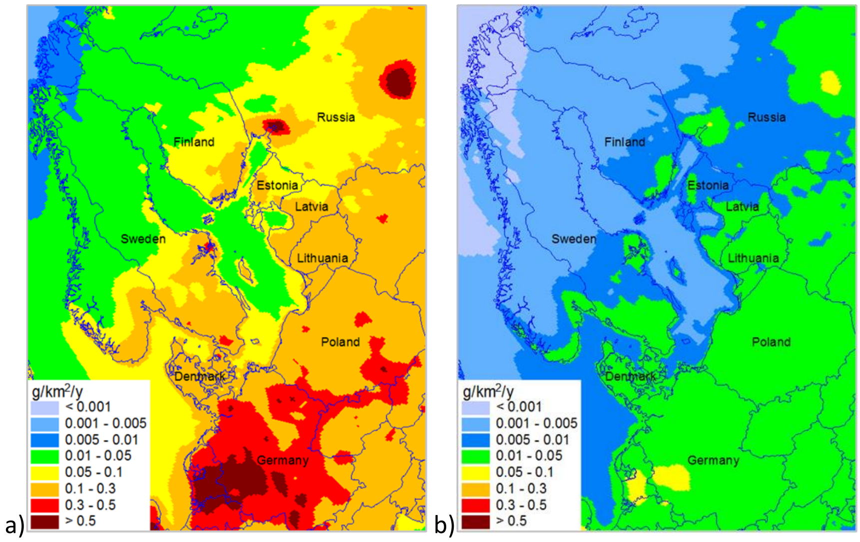

Figure 3. Spatial distribution of modelled annual total BDE-99 deposition fluxes in the Baltic Sea region for 2000 (a) and 2019 (b), g km^{-2} y^{-1}.

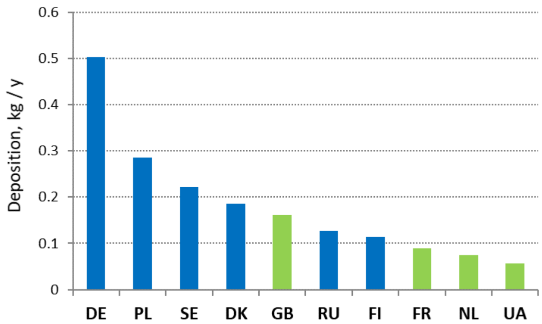

Figure 4. Ten countries with the highest contribution to annual total deposition of BDE-99 to the Baltic Sea estimated for 2019, kg y^{-1}. Green bars indicate non-HELCOM countries.

Data

Numerical data on computed BDE-99 depositions to the Baltic Sea are given in the following tables.

Table 1. Computed total annual deposition of BDE-99 to nine Baltic Sea sub-basins, the whole Baltic Sea (BAS) and normalized deposition* to the Baltic Sea (Norm) for the period 2000-2019. Units: kg y^{-1}.

	ARC	BOB	BOS	BAP	GUF	GUR	KAT	SOU	WEB	BAS	Norm
2000	0.98	0.97	2.05	13.23	2.65	1.16	2.89	0.51	3.03	27.47	27.00
2001	0.85	0.75	1.65	11.29	2.27	1.04	2.01	0.40	2.46	22.72	22.83
2002	0.62	0.56	1.16	9.50	1.71	0.84	1.80	0.34	2.16	18.70	19.55
2003	0.63	0.54	1.26	8.09	1.65	0.76	1.63	0.30	1.78	16.64	16.91
2004	0.49	0.47	0.82	7.43	1.49	0.66	1.45	0.28	1.68	14.75	14.76
2005	0.49	0.44	0.82	6.11	1.28	0.55	1.20	0.23	1.41	12.55	12.96
2006	0.45	0.42	0.89	5.89	1.14	0.51	1.24	0.23	1.35	12.12	11.44
2007	0.38	0.32	0.60	5.13	1.03	0.49	0.93	0.19	1.13	10.21	10.14
2008	0.45	0.33	0.76	4.99	1.05	0.51	0.91	0.18	1.03	10.20	9.01
2009	0.30	0.26	0.55	3.86	0.83	0.39	0.79	0.15	0.93	8.06	8.03
2010	0.25	0.23	0.49	3.83	0.72	0.36	0.60	0.13	0.75	7.35	7.16
2011	0.24	0.22	0.42	3.17	0.66	0.32	0.61	0.12	0.72	6.48	6.40
2012	0.24	0.23	0.48	3.18	0.61	0.30	0.58	0.10	0.63	6.35	5.72
2013	0.18	0.15	0.31	2.27	0.49	0.22	0.41	0.08	0.50	4.59	5.12
2014	0.18	0.14	0.32	2.20	0.44	0.21	0.48	0.08	0.51	4.57	4.58
2015	0.15	0.15	0.27	1.90	0.39	0.18	0.39	0.07	0.44	3.94	4.10
2016	0.12	0.11	0.20	1.49	0.34	0.14	0.31	0.06	0.37	3.14	3.68
2017	0.11	0.10	0.21	1.54	0.30	0.14	0.28	0.05	0.32	3.06	3.29
2018	0.09	0.08	0.18	1.20	0.25	0.11	0.23	0.04	0.26	2.44	2.95
2019	0.09	0.08	0.18	1.21	0.24	0.12	0.25	0.04	0.27	2.47	2.65

* - normalized depositions were obtained using the methodology described below in the metadata section 5.

Table 2. Computed contributions by country to annual total deposition of BDE-99 to nine Baltic Sea sub-basins for the year 2019. Units: kg year^{-1}. (*HELCOM*: contribution of anthropogenic sources of HELCOM countries; *EMEP*: contribution of anthropogenic sources in other EMEP countries; *Other*: contributions of secondary and remote non-EMEP emission sources).

Country	**ARC**	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**KAT**	**SOU**	**WEB**	**BAS**
DK	1.37E-03	7.84E-04	2.52E-03	5.44E-02	1.63E-03	2.10E-03	5.59E-02	1.76E-02	4.99E-02	1.86E-01
EE	1.64E-03	5.84E-04	1.39E-03	4.82E-03	2.24E-02	5.02E-03	9.80E-05	1.12E-05	7.02E-05	3.61E-02
FI	1.82E-02	1.55E-02	1.62E-02	9.28E-03	5.10E-02	2.79E-03	2.60E-04	3.23E-05	1.86E-04	1.13E-01
DE	9.78E-03	7.33E-03	1.91E-02	2.72E-01	1.23E-02	1.43E-02	4.88E-02	7.65E-03	1.13E-01	5.03E-01
LV	1.92E-03	6.84E-04	2.23E-03	1.12E-02	3.50E-03	1.91E-02	2.18E-04	2.35E-05	1.51E-04	3.91E-02
LT	1.73E-03	8.30E-04	2.50E-03	2.06E-02	2.53E-03	5.80E-03	4.60E-04	5.81E-05	3.00E-04	3.48E-02
PL	1.04E-02	5.89E-03	1.65E-02	2.09E-01	1.06E-02	1.35E-02	1.08E-02	1.42E-03	8.16E-03	2.86E-01
RU	3.36E-03	5.00E-03	9.35E-03	3.17E-02	7.21E-02	3.35E-03	1.06E-03	1.34E-04	6.79E-04	1.27E-01
SE	1.07E-02	1.12E-02	2.98E-02	1.25E-01	6.42E-03	5.50E-03	2.38E-02	6.00E-03	4.12E-03	2.22E-01
AL	5.94E-05	6.78E-05	2.35E-04	7.58E-04	7.70E-05	7.54E-05	9.40E-05	8.05E-06	5.94E-05	1.43E-03
AM	1.04E-05	2.54E-05	4.45E-05	9.01E-05	2.67E-05	1.30E-05	1.32E-05	9.61E-07	6.19E-06	2.31E-04
AT	6.75E-04	6.87E-04	1.38E-03	1.15E-02	9.63E-04	9.56E-04	1.15E-03	1.31E-04	1.09E-03	1.85E-02
AZ	1.76E-05	4.68E-05	6.72E-05	1.42E-04	4.82E-05	1.98E-05	1.84E-05	1.56E-06	8.39E-06	3.70E-04
BA	1.27E-04	1.32E-04	4.02E-04	2.10E-03	2.28E-04	2.26E-04	1.58E-04	1.50E-05	1.15E-04	3.51E-03
BE	8.33E-04	7.94E-04	1.88E-03	1.70E-02	1.15E-03	1.14E-03	5.47E-03	6.12E-04	6.19E-03	3.51E-02
BG	1.71E-04	1.68E-04	5.30E-04	2.17E-03	2.71E-04	1.96E-04	2.83E-04	2.52E-05	1.31E-04	3.95E-03
BY	1.43E-03	1.28E-03	3.04E-03	1.19E-02	3.20E-03	2.86E-03	5.53E-04	5.62E-05	3.05E-04	2.46E-02
CH	3.95E-04	3.61E-04	8.88E-04	7.14E-03	5.49E-04	4.99E-04	1.18E-03	1.47E-04	1.42E-03	1.26E-02
CY	3.72E-06	4.22E-06	1.71E-05	3.06E-05	4.89E-06	3.69E-06	3.01E-06	2.49E-07	1.48E-06	6.90E-05
CZ	1.46E-03	1.14E-03	2.82E-03	2.48E-02	1.56E-03	1.84E-03	2.38E-03	2.71E-04	2.13E-03	3.84E-02
ES	4.65E-04	4.66E-04	1.14E-03	7.83E-03	7.92E-04	7.51E-04	1.72E-03	1.72E-04	1.58E-03	1.49E-02
FR	2.33E-03	2.32E-03	5.19E-03	4.62E-02	3.24E-03	3.36E-03	1.23E-02	1.40E-03	1.34E-02	8.97E-02
GB	5.15E-03	4.06E-03	1.18E-02	7.41E-02	6.12E-03	5.41E-03	2.87E-02	2.71E-03	2.32E-02	1.61E-01
GE	5.56E-05	8.31E-05	2.05E-04	3.74E-04	1.05E-04	6.25E-05	3.23E-05	2.49E-06	1.46E-05	9.35E-04
GR	8.71E-05	9.06E-05	2.87E-04	1.11E-03	1.54E-04	1.20E-04	1.88E-04	1.32E-05	8.66E-05	2.14E-03
HR	1.58E-04	1.80E-04	3.97E-04	2.97E-03	3.27E-04	3.30E-04	1.88E-04	1.85E-05	1.55E-04	4.72E-03
HU	7.89E-04	8.18E-04	1.77E-03	1.25E-02	1.30E-03	1.30E-03	1.00E-03	1.03E-04	6.85E-04	2.03E-02
IE	1.69E-04	1.17E-04	4.00E-04	2.14E-03	1.92E-04	1.59E-04	7.52E-04	6.96E-05	5.80E-04	4.58E-03
IS	3.56E-06	6.96E-06	9.22E-06	3.74E-05	4.46E-06	3.43E-06	1.17E-05	1.21E-06	9.22E-06	8.71E-05
IT	9.98E-04	1.03E-03	2.71E-03	1.78E-02	2.20E-03	1.98E-03	1.65E-03	1.84E-04	2.02E-03	3.06E-02
KZ	7.01E-06	1.68E-05	2.03E-05	5.77E-05	2.17E-05	7.74E-06	7.25E-06	8.38E-07	3.44E-06	1.43E-04
LU	2.67E-05	2.69E-05	5.76E-05	5.84E-04	3.65E-05	4.14E-05	1.57E-04	1.81E-05	1.78E-04	1.13E-03
MD	3.29E-04	2.37E-04	8.86E-04	2.96E-03	5.74E-04	3.91E-04	2.70E-04	2.86E-05	1.52E-04	5.83E-03
ME	1.77E-05	1.80E-05	7.40E-05	2.43E-04	2.55E-05	2.51E-05	2.78E-05	2.43E-06	1.64E-05	4.50E-04
MK	6.93E-05	6.32E-05	2.58E-04	6.43E-04	7.68E-05	6.57E-05	8.51E-05	7.00E-06	4.19E-05	1.31E-03
NL	1.65E-03	1.47E-03	3.76E-03	3.51E-02	2.07E-03	2.15E-03	1.20E-02	1.41E-03	1.52E-02	7.48E-02
NO	7.92E-04	7.78E-04	2.09E-03	5.41E-03	7.90E-04	6.63E-04	2.30E-03	1.34E-04	7.48E-04	1.37E-02
PT	5.78E-05	6.12E-05	1.23E-04	9.28E-04	9.57E-05	9.52E-05	2.18E-04	2.29E-05	1.88E-04	1.79E-03
RO	1.22E-03	1.01E-03	3.29E-03	1.40E-02	2.37E-03	1.74E-03	1.29E-03	1.35E-04	6.96E-04	2.57E-02
RS	4.30E-04	4.45E-04	1.51E-03	5.58E-03	6.63E-04	6.29E-04	6.03E-04	5.41E-05	3.23E-04	1.02E-02
SI	7.80E-05	9.51E-05	1.71E-04	1.57E-03	1.75E-04	1.70E-04	1.02E-04	1.02E-05	9.21E-05	2.46E-03
SK	6.00E-04	5.53E-04	1.24E-03	8.82E-03	7.64E-04	8.15E-04	7.21E-04	7.66E-05	5.18E-04	1.41E-02
TR	5.84E-04	6.81E-04	2.18E-03	6.34E-03	1.14E-03	7.92E-04	6.25E-04	4.94E-05	2.53E-04	1.26E-02
UA	3.05E-03	2.42E-03	7.62E-03	3.05E-02	5.47E-03	4.11E-03	2.34E-03	2.58E-04	1.42E-03	5.72E-02
Other	0.01	0.01	0.02	0.11	0.02	0.01	0.02	0.004	0.03	0.24
HELCOM	0.06	0.05	0.10	0.74	0.18	0.07	0.14	0.03	0.18	1.55
EMEP	0.02	0.02	0.06	0.36	0.04	0.03	0.08	0.01	0.07	0.69
Total	0.09	0.08	0.17	1.20	0.24	0.12	0.24	0.05	0.28	2.47

Metadata

Technical information

1. Source:

Meteorological Synthesizing Centre East (MSC-E) of EMEP

2. Description of data:

Atmospheric deposition of BDE-99 to the Baltic Sea for the period from 2000 to 2019 were estimated using the GLEMOS model developed at EMEP/MSC-E (http://en.msceast.org/index.php/j-stuff/glemos). Model simulations for this study were made using experimental emission scenario, constructed on the basis of TNO emission inventory for PBDEs [*Denier van der Gon et al.*, 2005]. The information on BDE-99 emission data used in model simulations is presented below in the section "Methodology and frequency of data collection".

3. Geographical coverage:

Model predictions of BDE-99 atmospheric deposition were obtained for the European region and surrounding areas covered by the EMEP modelling domain.

4. Temporal coverage:

Expert estimates of annual atmospheric deposition of BDE-99 were prepared for the period 2000 – 2019.

5. Methodology and frequency of data collection:

This study represents a pilot model evaluation of polybrominated diphenyl ethers (PBDE) atmospheric input to the Baltic Sea and its sub-basins for the period 2000-2019. PBDEs are a group of persistent toxic chemicals that was manufactured and used as flame retardants in various products including furniture, plastics, textiles, and electronic equipment during several past decades. They were produced for the commercial purposes in a form of technical mixtures such as penta-BDE, octa-BDE, and deca-BDE since 1970s. Due to the harmful properties their production and use were banned in the European Union and globally since early 2000s [*Abbasi et al.*, 2003].

Atmospheric input and source allocation of PBDE deposition to the Baltic Sea were estimated using the latest version of GLEMOS model using the EMEP domain (https://www.ceip.at/ms/ceip_home1/ceip_home/new_emep-grid/). Global modelling framework GLEMOS is a multi-scale multi-pollutant simulation platform developed for operational and research applications within the EMEP programme [*Tarrason and Gusev,* 2008; *Travnikov et al.,* 2009; *Jonson and Travnikov*, 2010; *Travnikov and Jonson*, 2011]. The framework allows simulations of dispersion and cycling of different classes of pollutants (e.g. heavy metals and persistent organic pollutants) in the environment with a flexible choice of the simulation domain (from global to local scale) and spatial resolution. The vertical structure consists of 20 irregular terrain-following sigma layers covering the height up to 10 hPa (ca. 30 km). Among these layers 10 lowest layers cover the first 5 km of the troposphere and height of the lowest model layer is about 75 m.

Information on PBDE emissions to the environment is not currently reported on a regular basis by the EMEP countries. A number of research-oriented inventories of regional and global PBDE emissions have been developed in various studies [*Prevedouros et al.*, 2004; *Denier van der Gon et al.*, 2005; *Palm et al.*, 2004; *Birgul et al.*, 2012; *Cousins*, 2012; *NCP*, 2013; *Abbasi et al.*, 2019]. The construction of experimental scenario of long-term changes of BDE-99 emissions in the EMEP region was performed by MSC-E and is described in the joint EMEP report for HELCOM [*Bartnicki et al.*, 2016]. The scenario was developed on the basis of TNO inventory of penta-BDEs emissions

[*Denier van der Gon et al.*, 2005]. Expert estimates of TNO for penta-BDE emissions were elaborated for the year 2000 and included total annual emissions from individual countries as well as gridded geographical distribution within the EMEP region. The approach for estimating the emissions of selected PBDE congener BDE-99 was based on the results of the studies [*Palm et al.*, 2004; *La Guardia et al.*, 2006] performing analysis of chemical composition of penta-BDE emissions. Scenario of long-term variations of emissions was elaborated on the basis of estimates of temporal variations of penta-BDE emissions described in [*Birgul et al.*, 2012]. In addition, long-term measurements of BDE-99 at several EMEP monitoring sites were used. Similar approach was applied in this study to obtain estimates of BDE-99 emissions for the period 2000-2019. It should be noted that this scenario is subject of high uncertainty. Nevertheless, it can be applied for preliminary analysis of contemporary levels of PBDE pollution on the basis of model predictions and measurements.

Additional information required for model simulations includes data on meteorological parameters and atmospheric reactants. Meteorological data used in model simulations for 2000-2019 were obtained using WRF meteorological data pre-processor [*Skamarock et al*., 2008] on the basis of meteorological re-analyses data (ERA-Interim) of European Centre for Medium-Range Weather Forecasts (ECMWF). Data on atmospheric concentrations of chemical reactants and particulate matter were imported from the MOZART model [*Emmons et al*., 2010]. Parameterization of the model for the selected BDE-99 congener is presented in the report [*Vulykh et al.*, 2006].

Normalized values of BDE-99 deposition for the period 2000-2019 were obtained on the basis of results of model simulations using bi-exponential approximation [*Colette et al*., 2016].

Quality information

6. Strength and weakness:

Strength: expert estimates of atmospheric input of BDE-99 to the Baltic Sea and its sub-basins.

Weakness: officially reported inventories of PBDE emissions are not prepared by the EMEP countries.

7. Uncertainty:

Modelling approach, developed by the MSC-E for POPs, has been verified using regular comparisons of modelling results with measurements of the EMEP monitoring network [*Gusev et al*., 2005, 2006; *Shatalov et al.,* 2005; *Ilyin et al.*, 2021] and thoroughly reviewed at the workshop held in October, 2005 under supervision of the EMEP Task Force of Measurements and Modelling (TFMM). It was concluded that “MSC-E model is suitable for the evaluation of long-range transboundary transport and deposition of POPs in Europe” [ECE/EB.AIR/GE.1/2006/4]. Model performance for BDE-99 was evaluated previously in framework of the study described in [*Bartnicki et al.*, 2016].

8. Further work required:

Further work is required to develop national inventories of PBDE emissions as well as to reduce uncertainties of modelling approach applied for PBDE in the EMEP GLEMOS model.

References

Abbasi G., L. Li, and K. Breivik [2019] Global Historical Stocks and Emissions of PBDEs. Environ. Sci. Technol. 2019, 53, 6330−6340.

Birgul et al. [2012] Atmospheric polybrominated diphenyl ethers (PBDEs) in the United Kingdom, Environmental Pollution, vol.169, pp. 105-111.

Bartnicki J., A. Gusev, W. Aas, and A. Benedictow [2016] Atmospheric Supply of Nitrogen, Cadmium, Mercury, Benzo(a)pyrene and PBDEs to the Baltic Sea in 2014. Summary Report for HELCOM. MSC-W Technical Report 1/2016. (https://emep.int/publ/helcom/2016/index.html).

Colette et al. [2016]. Air pollution trends in the EMEP region between 1990 and 2012. EMEP: CCC-Report 1/2016. 105 p.

Connor J.A., Farhat S.K., Vanderfort M. [2012] GSI Mann-Kendall toolkit for constituent trend analysis. User's manual, version 1.0. GSI Environmental Inc., (https://www.academia.edu/26179389/GSI_MANN-KENDALL_TOOLKIT_For_Constituent_Trend_Analysis_USERS_MANUAL?auto=download).

Cousins A.P. [2012] Modelling the fate of organic contaminants in the Baltic Sea. Application of the POPCYCLING-Baltic model. IVL Swedish Environmental Research Institute. Available at: www.cohiba-project.net/publications.

Denier van der Gon, H.A.C., van het Bolsher M., Visschedijk A.J.H., Zanveld P.Y.J. [2005] Study to the effectiveness of the UNECE Persistent Organic Pollutants and cost of possible additional measures. Phase I: Estimation of emission reduction resulting from the implementation of the POP Protocol. TNO report B&AO-A R 2005/194. April, 2005.

Emmons L.K., Walters S., Hess P.G., Lamarque J.-F., Pfister G.G., Fillmore D., Granier C., Guenther A., Kinnison D., Laepple T., Orlando J., Tie X., Tyndall G., Wiedinmyer C., Baughcum S.L., and Kloster S. [2010] Description and evaluation of the Model for Ozone and Related chemical Tracers, version 4 (MOZART-4), Geosci. Model Dev., 3, 43–67, doi:10.5194/gmd-3-43-2010.

Gusev A., I. Ilyin, L.Mantseva, O.Rozovskaya, V. Shatalov, O. Travnikov [2006] Progress in further development of MSCE-HM and MSCE-POP models (implementation of the model review recommendations. EMEP/MSC-E Technical Report 4/2006. (http://www.msceast.org/reports/4_2006.pdf).

Gusev A., E. Mantseva, V. Shatalov, B.Strukov [2005] Regional multicompartment model MSCE-POP EMEP/MSC-E Technical Report 5/2005. (http://www.msceast.org/reports/5_2005.pdf).

Ilyin I., N.Batrakova, A.Gusev, M.Kleimenov, O.Rozovskaya, V.Shatalov, I.Strizhkina, O.Travnikov, K.Breivik, H.L.Halvorsen, P.B.Nizzetto, K.A.Pfaffuffer, W.Aas, K.Mareckova, S.Poupa, R.Wankmueller, B.Ullrich, and A.Degórska [2021] Heavy metals and POPs: Pollution assessment of toxic substances on regional and global scales. EMEP Status Report 2/2021. (https://en.msceast.org/reports/2_2021.pdf).

Jonson J. E. and Travnikov O. (Eds.). [2010] Development of the EMEP global modeling framework: Progress report. Joint MSC-W/MSC-E Report. EMEP/MSC-E Technical Report 1/2010.

La Guardia M.J., R.C. Hale, and E. Harvey [2006] Detailed Polybrominated Diphenyl Ether (PBDE) Congener Composition of the Widely Used Penta-, Octa-, and Deca-PBDE Technical Flame-retardant Mixtures. Environ. Sci. Technol. 2006, 40, 6247-6254.

NCP [2013] Canadian Arctic Contaminants Assessment Report On Persistent Organic Pollutants – 2013. Muir D, Kurt-Karakus P, Stow J. (Eds). Northern Contaminants Program, Aboriginal Affairs and Northern Development Canada, Ottawa ON.

Palm A., E. Brorström-Lundén, K. Breivik [2004] Transport and fate of polybrominated diphenyl ethers in the Baltic and Arctic regions. TemaNord 2004:554. Nordic Council of Ministers, Copenhagen 2004. ISBN 92-893-1074-X.

Prevedouros K., K.C. Jones, and A.J. Sweetman [2004] European-Scale Modeling of Concentrations and Distribution of Polybrominated Diphenyl Ethers in the Pentabromodiphenyl Ether Product. Environ. Sci. Technol. 2004, 38, 5993-6001.

Skamarock W.C., Klemp J.B., Dudhia J., Gill D.O., Barker D.M., Duda M.G., Huang X-Y., Wang W. and Powers J.G. [2008] A Description of the Advanced Research WRF Version 3. NCAR/TN–475+STR NCAR technical note.

Shatalov V., Gusev A., Dutchak S., Holoubek I., Mantseva E., Rozovskaya O., Sweetman A., Strukov B. and N.Vulykh [2005] Modelling of POP Contamination in European Region: Evaluation of the Model Performance. Technical Report 7/2005. (http://www.msceast.org/reports/7_2005.pdf).

Tarrasón L. and Gusev A. [2008] Towards the development of a common EMEP global modeling framework. MSC-W Technical Report 1/2008.

Travnikov O., J.E. Jonson, A.S Andersen, M. Gauss, A. Gusev, O. Rozovskaya, D. Simpson, V. Sokovykh, S. Valiyaveetil and P. Wind [2009] Development of the EMEP global modelling framework: Progress report. Joint MSC-E/MSC-W Report.EMEP/MSC-E Technical Report 7/2009.

Travnikov O. and Jonson J. E. (Eds.). [2011] Global scale modelling within EMEP: Progress report. EMEP/MSC-E Technical Report 1/2011.

Vulykh N., S. Dutchak, E. Mantseva, V. Shatalov [2006] EMEP contribution to the preparatory work for the review of the CLRTAP Protocol on persistent organic pollutants. New substances: Model assessment of potential for long-range transboundary atmospheric transport and persistence of PentaBDE, Endosulfan, Dicifol, HCBD, PeCB, PCN. EMEP/MSC-E Technical Report 1/2006. Available at: https://en.msceast.org/reports/1_2006.pdf.