Atmospheric deposition of Cadmium on the Baltic Sea

HELCOM Baltic Sea Environment Fact Sheet (BSEFS), 2022

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Key message

Levels of annual total atmospheric deposition of cadmium to the Baltic Sea have decreased in period from 1990 to 2020 by 79%, although the rate of decrease was higher in the earlier part (1990-1996) of the assessment period.

Results and Assessment

Relevance of the BSEFS for describing developments in the environment

This BSEFS shows the levels and trends in cadmium atmospheric deposition to the Baltic Sea. The deposition of cadmium represents the pressure of the emission sources on the Baltic Sea aquatic environment as described in the BSEFS “Atmospheric emissions of cadmium in the Baltic Sea region”.

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 heavy metals to the atmosphere on European scale is set in the framework of UN ECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). The CLRTAP Protocol on Heavy Metals (1998) targets three particularly harmful metals: cadmium, lead and mercury. According to one of the basic obligations emissions of these three metals must be reduced below the emission levels in 1990. The Protocol entered into force in 2003 and was signed and/or ratified by 41 countries.

Assessment

Model assessment of cadmium long-range transport and deposition within the Baltic Sea region in period 1990-2020 was carried out taking into account anthropogenic emissions officially reported by HELCOM and other EMEP countries. Uncertainties of officially reported Cd emission inventories vary from about 20-30% for Poland, Sweden, and Latvia up to 130-360% for Estonia and Denmark. In addition to anthropogenic emissions, natural and secondary emissions due to wind re-suspension of particle-bound cadmium from terrestrial and seawater compartments were considered. In spite of relatively high uncertainties of official emissions of some of the HELCOM countries, model estimates of cadmium pollution levels in the Baltic Sea region show, in general, reasonable agreement with observed concentrations and deposition fluxes.

Model simulations indicate that atmospheric input of cadmium to the Baltic Sea declined by 79% in the period from 1990 to 2020 (Figure 1, Table 1). The most substantial decline of cadmium deposition took place in the Sound sub-basin (-83%) followed by the Gulf of Finland (-82%) sub-basin (Figure 2). The lowest decline is noted for the Bothnian Sea (-74%) and the Gulf of Riga (-74%) sub-basins. The decline of cadmium deposition to the Baltic Sea in the period 1990-2020 was non-uniform. Two sub-periods can be selected with different deposition decline rates, namely, 1990-1997 and 1998-2020. Deposition trend in each part was analysed using Mann-Kendall test [*Gilbert*, 1987; *Connor et al*, 2012]. In the period from 1990 to 1997, the strongest decline took place with mean annual rate of deposition decline about 0.9 tonnes per year with confidence factor equal to 98.4%. The subsequent period from 1998 to 2020 is characterised by smaller mean annual decline rate of about 0.3 tonnes with confidence factor >99%. The values of the confidence factors indicates that the trends for the both parts of the assessment period are significant.

Temporal variations of total cadmium depositions are affected by changes of anthropogenic emissions of countries as well as changes of secondary emissions. It should be noted also that only a fraction of cadmium, emitted by the sources of particular country, deposits to the Baltic Sea. This fraction depends on the location of the country and prevailing atmospheric transport pathways. In particular, the largest fraction of total national emissions, deposited to the Baltic Sea, is estimated for Denmark (about 30%) while the lowest one for Russia (about 0.5%).

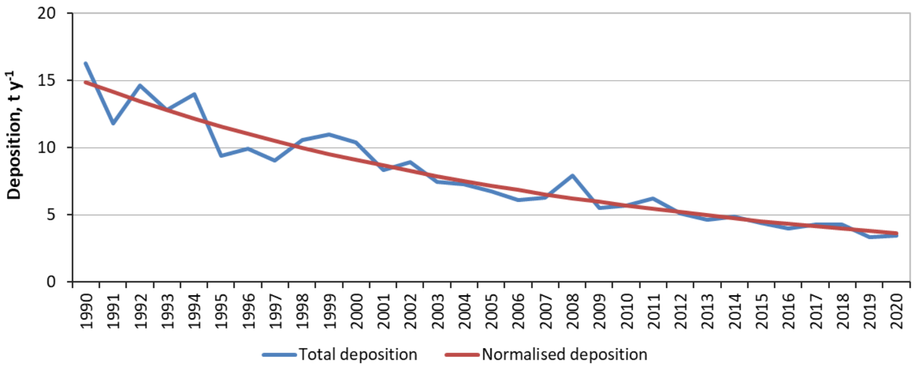

Figure 1. Changes of modelled (blue line) and normalized (red line) total annual atmospheric deposition of cadmium to the Baltic Sea for the period 1990-2020, (t y^{-1}). Normalized depositions were obtained using the methodology described below in the metadata section 5.

Spatial distributions of annual total deposition fluxes of cadmium in 1990 and 2020 within the Baltic Sea region are shown in Figure 3. Total deposition fluxes of cadmium vary significantly among the sub-basins. The highest spatially averaged total deposition flux in 2020 among the Baltic Sea sub-basins is noted for the Sound sub-basin. This sub-basin has the lowest area and is characterized by significant land-based emission sources located nearby. The lowest flux is estimated for the Bothnian Bay sub-basin that is explained by its relatively large area and low levels of emissions in the surrounding areas.

The HELCOM Contracting Parties contributed 43% to total deposition of cadmium to the Baltic Sea in 2020 (Table 2). The largest contribution is made by Germany (16%) and Poland (12%) (Figure 4). It is important to note that contributions of emissions of the Contracting Parties to deposition in particular sub-regions differ significantly. Reduction of atmospheric input of cadmium from anthropogenic sources to the Baltic Sea is a result of various activities including abatement measures, economic contraction, and industrial restructuring, which took place in the HELCOM countries as well as other EMEP countries during the considered period. The main contribution to total Cd deposition from anthropogenic sources is made by emissions from *Industry*, *Production of electricity* and *Residential Combustion* sectors.

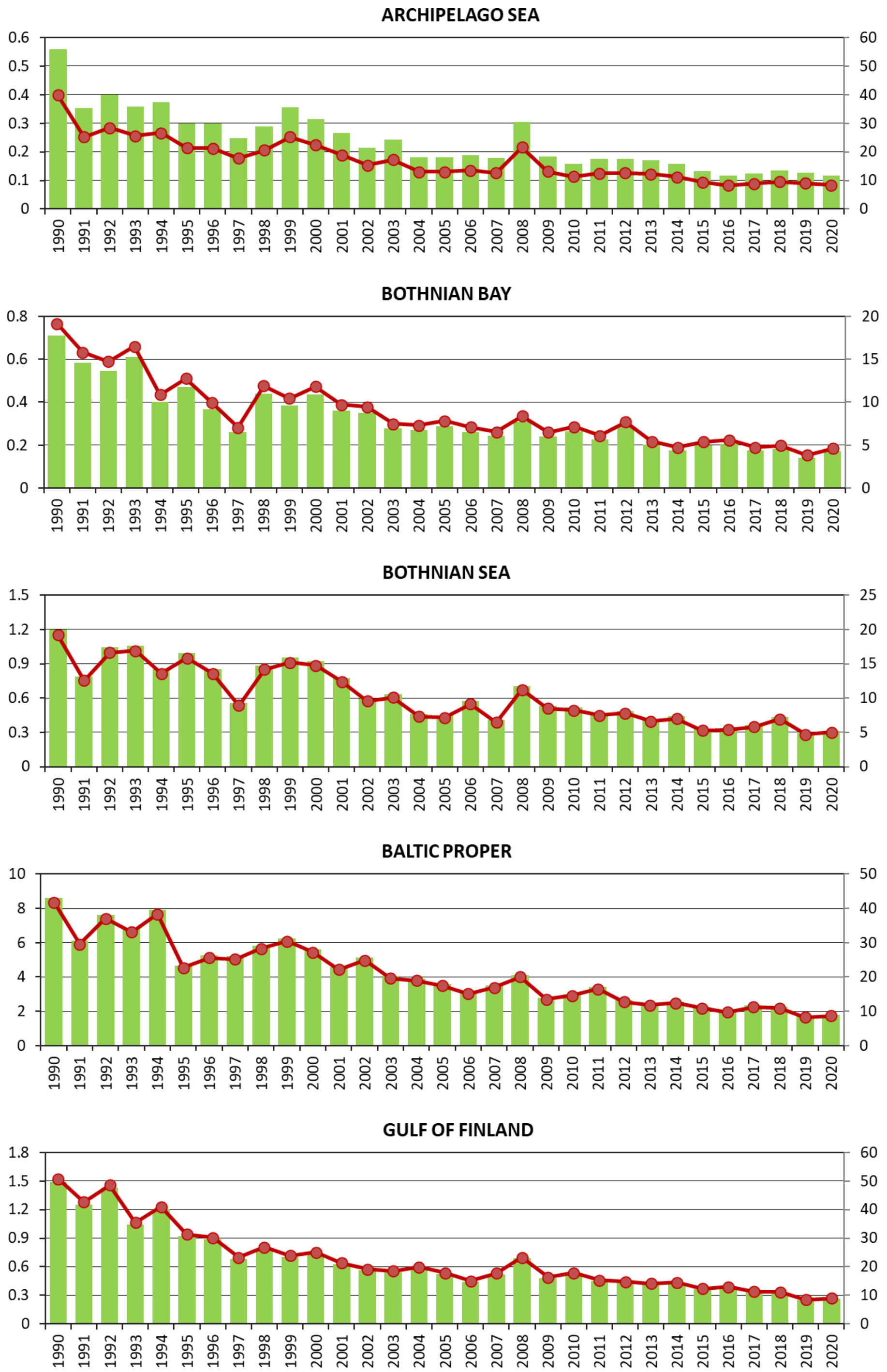

Figure 2. Time-series of computed total annual atmospheric deposition of cadmium to nine sub-basins of the Baltic Sea for the period 1990-2020 in t y^{-1} as green bars (left axis) and total deposition fluxes in g km^{-2} y^{-1} as red lines (right axis).

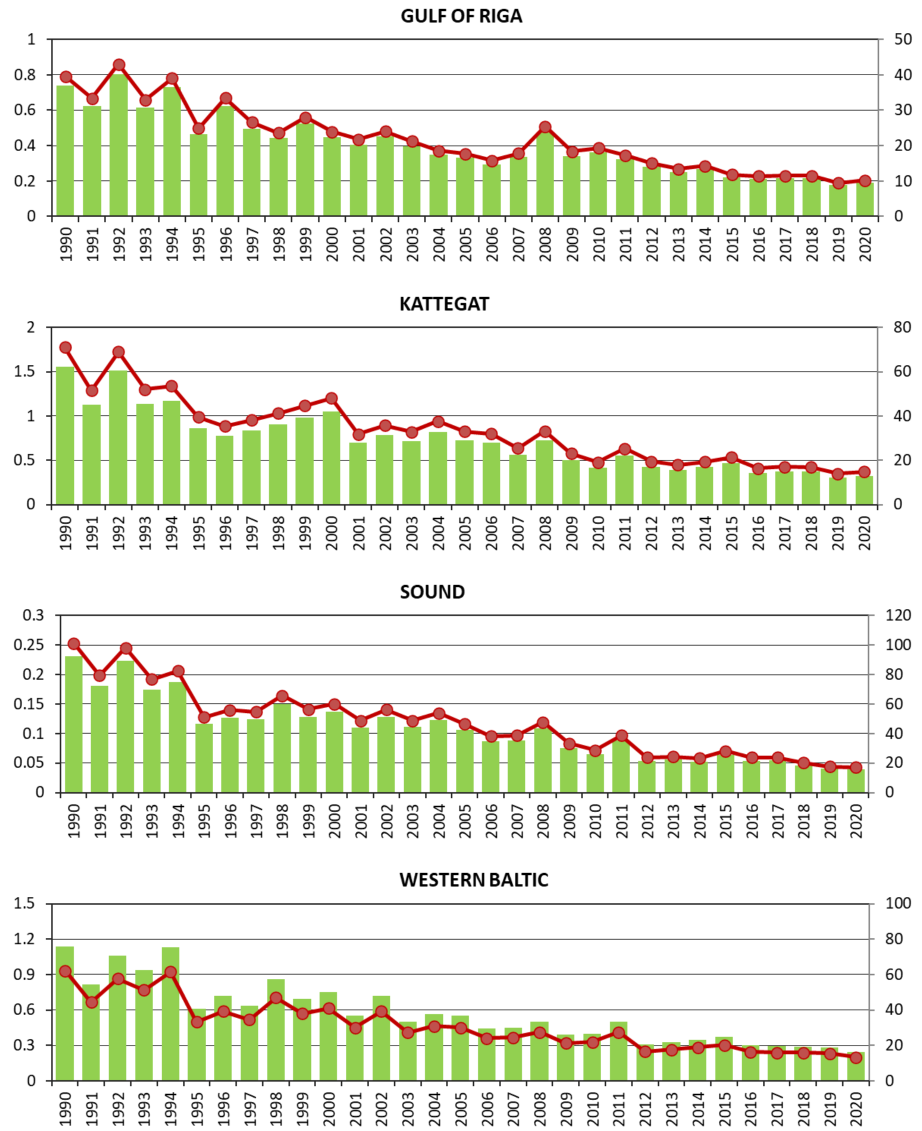

Figure 2 (continued). Time-series of computed total annual atmospheric deposition of cadmium to nine sub-basins of the Baltic Sea for the period 1990-2020 in t y^{-1} as green bars (left axis) and total deposition fluxes in g km^{-2} y^{-1} as red lines (right axis).

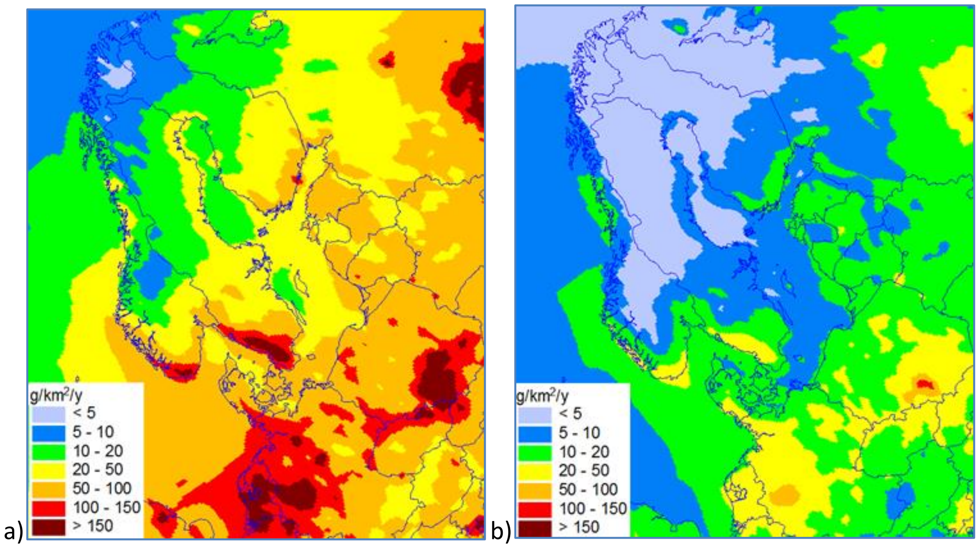

Figure 3. Spatial distribution of modelled annual total cadmium deposition fluxes in the Baltic Sea region for 1990 (a) and 2020 (b), g km^{-2} y^{-1}.

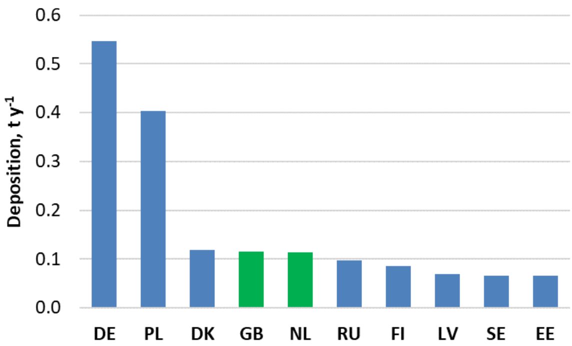

Figure 4. Ten countries with the highest contribution to annual total deposition of cadmium to the Baltic Sea estimated for 2020, t y^{-1}. Green bars indicate non-HELCOM countries.

Data

Numerical data on computed cadmium depositions to the Baltic Sea are given in the following tables.

Table 1. Computed total annual deposition of cadmium to nine Baltic Sea sub-basins, the whole Baltic Sea (BAS) and normalized deposition* to the Baltic Sea (Norm) for the period 1990-2020. Units: t y^{-1}.

	ARC	BOB	BOS	BAP	GUF	GUR	KAT	SOU	WEB	BAS	Norm
1990	0.56	0.71	1.20	8.62	1.49	0.74	1.56	0.23	1.14	16.25	14.88
1991	0.35	0.58	0.79	6.11	1.25	0.62	1.13	0.18	0.81	11.83	14.14
1992	0.40	0.54	1.04	7.63	1.43	0.80	1.51	0.22	1.06	14.65	13.45
1993	0.36	0.61	1.06	6.84	1.04	0.62	1.14	0.17	0.94	12.77	12.79
1994	0.37	0.40	0.85	7.91	1.20	0.73	1.17	0.19	1.13	13.96	12.17
1995	0.30	0.47	0.99	4.68	0.92	0.47	0.87	0.12	0.61	9.42	11.58
1996	0.30	0.37	0.85	5.28	0.89	0.63	0.77	0.13	0.72	9.93	11.03
1997	0.25	0.26	0.56	5.20	0.68	0.50	0.83	0.12	0.63	9.04	10.51
1998	0.29	0.44	0.89	5.83	0.79	0.44	0.90	0.15	0.86	10.59	10.01
1999	0.35	0.39	0.95	6.26	0.70	0.52	0.98	0.13	0.70	10.99	9.54
2000	0.31	0.44	0.93	5.61	0.74	0.45	1.05	0.14	0.75	10.41	9.09
2001	0.27	0.36	0.78	4.56	0.63	0.41	0.70	0.11	0.55	8.36	8.67
2002	0.22	0.35	0.60	5.13	0.56	0.45	0.78	0.13	0.72	8.94	8.27
2003	0.24	0.28	0.63	4.05	0.54	0.40	0.72	0.11	0.50	7.48	7.88
2004	0.18	0.27	0.46	3.91	0.58	0.35	0.82	0.12	0.57	7.27	7.52
2005	0.18	0.29	0.45	3.60	0.52	0.33	0.72	0.11	0.55	6.75	7.18
2006	0.19	0.26	0.57	3.12	0.44	0.29	0.70	0.09	0.44	6.11	6.85
2007	0.18	0.24	0.41	3.49	0.52	0.33	0.56	0.09	0.45	6.27	6.54
2008	0.30	0.31	0.70	4.12	0.68	0.47	0.73	0.11	0.50	7.94	6.24
2009	0.18	0.24	0.53	2.77	0.48	0.34	0.51	0.08	0.39	5.53	5.96
2010	0.16	0.26	0.52	3.01	0.53	0.36	0.42	0.07	0.40	5.72	5.69
2011	0.18	0.23	0.47	3.41	0.45	0.32	0.56	0.09	0.50	6.20	5.44
2012	0.18	0.28	0.49	2.63	0.44	0.28	0.43	0.05	0.30	5.08	5.20
2013	0.17	0.20	0.41	2.43	0.42	0.25	0.39	0.06	0.32	4.66	4.96
2014	0.16	0.18	0.44	2.57	0.43	0.27	0.42	0.05	0.34	4.86	4.74
2015	0.13	0.20	0.33	2.26	0.36	0.22	0.47	0.06	0.37	4.41	4.53
2016	0.12	0.21	0.34	2.01	0.38	0.21	0.36	0.05	0.30	3.98	4.33
2017	0.13	0.18	0.36	2.33	0.33	0.21	0.37	0.05	0.29	4.26	4.14
2018	0.13	0.18	0.43	2.26	0.33	0.21	0.37	0.05	0.29	4.26	3.96
2019	0.13	0.14	0.29	1.71	0.25	0.18	0.31	0.04	0.28	3.33	3.79
2020	0.12	0.17	0.31	1.78	0.26	0.19	0.32	0.04	0.24	3.44	3.62

* - 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 cadmium to nine Baltic Sea sub-basins for the year 2020. Units: t y^{-1}. HELCOM: contribution of anthropogenic sources of HELCOM countries; EMEP: contribution of anthropogenic sources in other EMEP countries; Other: contributions of sources other than primary anthropogenic emissions (natural, secondary (re-suspension), and remote non-EMEP sources).

Country	**ARC**	**BOB**	**BOS**	**BAP**	**GUF**	**GUR**	**KAT**	**SOU**	**WEB**	**BAS**
DK	1.41E-03	1.28E-03	3.58E-03	4.17E-02	2.00E-03	2.23E-03	3.96E-02	6.20E-03	2.10E-02	1.19E-01
EE	2.62E-03	2.87E-03	5.67E-03	1.12E-02	3.60E-02	7.23E-03	1.05E-04	1.16E-05	9.91E-05	6.58E-02
FI	5.81E-03	2.18E-02	1.63E-02	7.91E-03	3.19E-02	1.63E-03	1.31E-04	1.52E-05	1.26E-04	8.56E-02
DE	1.20E-02	9.50E-03	2.61E-02	3.18E-01	1.55E-02	1.83E-02	6.72E-02	8.44E-03	7.16E-02	5.47E-01
LV	3.26E-03	2.13E-03	6.34E-03	2.32E-02	7.84E-03	2.52E-02	2.43E-04	2.56E-05	2.00E-04	6.85E-02
LT	9.05E-04	5.76E-04	1.90E-03	9.94E-03	1.67E-03	3.53E-03	1.34E-04	1.42E-05	1.10E-04	1.88E-02
PL	1.57E-02	9.90E-03	3.11E-02	2.79E-01	2.19E-02	2.40E-02	1.31E-02	1.42E-03	7.11E-03	4.04E-01
RU	4.14E-03	1.78E-02	1.53E-02	2.76E-02	2.45E-02	5.55E-03	1.01E-03	9.64E-05	6.89E-04	9.66E-02
SE	3.33E-03	1.61E-02	1.50E-02	2.30E-02	3.14E-03	2.15E-03	2.38E-03	2.65E-04	4.65E-04	6.58E-02
AL	1.32E-05	3.10E-05	6.38E-05	1.89E-04	2.95E-05	1.50E-05	1.14E-05	7.79E-07	4.76E-06	3.58E-04
AM	1.91E-06	2.98E-06	6.97E-06	1.91E-05	2.20E-06	1.31E-06	1.65E-06	1.20E-07	6.66E-07	3.69E-05
AT	9.55E-04	7.33E-04	1.86E-03	1.66E-02	1.37E-03	1.41E-03	1.21E-03	1.27E-04	6.57E-04	2.49E-02
AZ	2.36E-06	6.23E-06	9.30E-06	2.43E-05	5.92E-06	2.35E-06	2.15E-06	1.67E-07	1.89E-06	5.47E-05
BA	4.24E-04	4.79E-04	9.49E-04	5.91E-03	6.22E-04	5.39E-04	2.78E-04	2.40E-05	1.51E-04	9.38E-03
BE	8.70E-04	7.14E-04	1.98E-03	2.14E-02	1.31E-03	1.62E-03	7.07E-03	7.49E-04	5.52E-03	4.12E-02
BG	2.18E-04	4.88E-04	1.13E-03	2.07E-03	4.68E-04	2.47E-04	1.47E-04	1.11E-05	6.87E-05	4.84E-03
BY	9.07E-04	8.50E-04	2.58E-03	9.17E-03	2.24E-03	2.34E-03	1.75E-04	2.03E-05	1.29E-04	1.84E-02
CH	5.25E-04	4.34E-04	1.15E-03	9.55E-03	6.01E-04	6.22E-04	1.21E-03	1.33E-04	9.23E-04	1.51E-02
CY	4.55E-07	1.34E-06	2.80E-06	4.23E-06	6.93E-07	3.65E-07	1.47E-07	9.87E-09	7.06E-08	1.01E-05
CZ	1.88E-03	1.21E-03	3.71E-03	3.35E-02	2.18E-03	2.32E-03	2.36E-03	2.80E-04	1.36E-03	4.88E-02
ES	1.01E-03	1.58E-03	3.24E-03	1.46E-02	1.60E-03	1.28E-03	3.27E-03	3.36E-04	2.61E-03	2.95E-02
FR	9.72E-04	9.70E-04	2.39E-03	2.02E-02	1.32E-03	1.51E-03	6.14E-03	6.27E-04	4.51E-03	3.86E-02
GB	2.80E-03	2.54E-03	6.86E-03	5.80E-02	5.22E-03	5.40E-03	1.99E-02	1.81E-03	1.24E-02	1.15E-01
GE	1.47E-05	2.69E-05	5.27E-05	1.23E-04	1.80E-05	9.62E-06	9.33E-06	7.05E-07	4.04E-06	2.59E-04
GR	8.43E-05	2.00E-04	4.74E-04	1.07E-03	2.93E-04	1.08E-04	6.09E-05	4.24E-06	3.13E-05	2.32E-03
HR	3.19E-04	2.64E-04	6.16E-04	4.45E-03	5.32E-04	5.13E-04	1.83E-04	1.78E-05	1.35E-04	7.03E-03
HU	7.13E-04	6.08E-04	1.46E-03	1.12E-02	1.24E-03	1.21E-03	9.16E-04	7.82E-05	4.41E-04	1.79E-02
IE	6.17E-05	6.72E-05	1.54E-04	1.27E-03	1.22E-04	1.13E-04	3.88E-04	3.68E-05	2.37E-04	2.45E-03
IS	5.18E-07	1.00E-06	1.62E-06	6.65E-06	8.58E-07	7.60E-07	1.70E-06	1.89E-07	1.03E-06	1.43E-05
IT	5.36E-04	6.66E-04	1.50E-03	8.22E-03	9.62E-04	7.39E-04	6.68E-04	6.14E-05	4.21E-04	1.38E-02
KY	3.60E-06	6.36E-06	1.25E-05	3.24E-05	5.73E-06	3.19E-06	1.38E-06	1.08E-07	5.16E-07	6.58E-05
KZ	2.03E-04	3.35E-04	6.85E-04	1.87E-03	4.63E-04	1.81E-04	1.54E-04	1.20E-05	7.73E-05	3.98E-03
LI	3.42E-06	2.74E-06	7.43E-06	6.17E-05	3.67E-06	3.81E-06	7.47E-06	7.72E-07	5.63E-06	9.67E-05
LU	3.82E-05	3.67E-05	8.90E-05	8.69E-04	4.57E-05	5.56E-05	2.69E-04	2.88E-05	2.17E-04	1.65E-03
MC	1.74E-08	2.16E-08	4.71E-08	3.09E-07	2.86E-08	2.88E-08	3.60E-08	3.39E-09	2.66E-08	5.18E-07
MD	3.55E-04	5.63E-04	1.27E-03	3.47E-03	4.08E-04	4.15E-04	1.61E-04	1.35E-05	7.84E-05	6.73E-03
ME	1.55E-05	2.84E-05	5.72E-05	2.43E-04	2.32E-05	1.79E-05	1.65E-05	1.21E-06	6.47E-06	4.09E-04
MK	2.43E-05	5.42E-05	1.09E-04	3.60E-04	4.88E-05	2.45E-05	2.77E-05	1.81E-06	1.19E-05	6.61E-04
MT	3.00E-07	5.05E-07	1.30E-06	4.59E-06	1.04E-06	3.58E-07	4.56E-07	3.86E-08	2.07E-07	8.80E-06
NL	2.37E-03	1.74E-03	5.19E-03	5.91E-02	3.94E-03	4.39E-03	1.94E-02	2.07E-03	1.59E-02	1.14E-01
NO	6.45E-04	1.38E-03	2.76E-03	3.51E-03	9.75E-04	5.92E-04	7.36E-04	3.92E-05	2.49E-04	1.09E-02
PT	1.14E-04	2.36E-04	5.30E-04	1.57E-03	2.18E-04	1.56E-04	3.70E-04	3.58E-05	2.65E-04	3.49E-03
RO	9.99E-04	1.78E-03	3.72E-03	1.12E-02	1.24E-03	1.09E-03	7.32E-04	5.58E-05	3.01E-04	2.11E-02
RS	8.96E-04	1.13E-03	2.15E-03	1.43E-02	1.30E-03	1.30E-03	8.43E-04	6.69E-05	3.97E-04	2.24E-02
SI	3.20E-04	2.50E-04	6.26E-04	4.43E-03	5.16E-04	4.98E-04	1.59E-04	1.59E-05	1.17E-04	6.93E-03
SK	6.41E-04	4.91E-04	1.30E-03	1.09E-02	1.16E-03	1.14E-03	8.09E-04	7.08E-05	3.61E-04	1.69E-02
TJ	1.11E-06	1.91E-06	3.77E-06	9.57E-06	1.75E-06	9.46E-07	4.45E-07	3.45E-08	1.68E-07	1.97E-05
TM	2.20E-06	5.59E-06	8.70E-06	2.07E-05	5.58E-06	2.27E-06	1.25E-06	8.49E-08	1.07E-06	4.74E-05
TR	2.02E-04	4.78E-04	8.91E-04	1.70E-03	4.24E-04	1.60E-04	8.79E-05	7.80E-06	4.71E-05	4.00E-03
UA	2.62E-03	4.66E-03	1.06E-02	2.39E-02	4.59E-03	3.59E-03	9.89E-04	1.02E-04	7.38E-04	5.18E-02
UZ	2.23E-05	4.25E-05	8.26E-05	2.00E-04	3.99E-05	2.08E-05	8.24E-06	5.95E-07	3.68E-06	4.20E-04
HELCOM	0.05	0.08	0.12	0.74	0.14	0.09	0.12	0.02	0.10	1.47
EMEP	0.02	0.03	0.06	0.36	0.04	0.03	0.07	0.01	0.05	0.66
Other	0.05	0.06	0.13	0.68	0.08	0.07	0.13	0.02	0.09	1.31
Total	0.12	0.17	0.31	1.78	0.26	0.19	0.32	0.04	0.24	3.44

Metadata

Technical information

1. Source:

Meteorological Synthesizing Centre East (MSC-E) of EMEP.

2. Description of data:

Atmospheric deposition of cadmium to the Baltic Sea for the period from 1990 to 2020 were estimated using the latest version of GLEMOS model developed at EMEP/MSC-E (http://en.msceast.org/index.php/j-stuff/glemos). Annual Cd emissions, officially reported by EMEP countries in 2021, were used in model computations for the years 1990-2019. Pollution levels of Cd in 2020 were evaluated using emission data, reported for the previous year 2019. These data are available from the EMEP Centre on Emission Inventories and Projections (CEIP) (http://www.ceip.at/). Detailed description of reported emission data, gap-filling methods, and expert estimates can be found in the CEIP Technical report [*Poupa*, 2021].

3. Geographical coverage:

Atmospheric depositions of cadmium were estimated for the European region and surrounding areas covered by the EMEP modelling domain.

4. Temporal coverage:

Time-series of annual Cd atmospheric deposition were estimated for the period 1990 – 2020.

5. Methodology and frequency of data collection:

Atmospheric input and source allocation budget of cadmium deposition to the Baltic Sea were computed using the latest version of GLEMOS model over the new EMEP domain (https://www.ceip.at/ms/ceip_home1/ceip_home/new_emep-grid/). Model estimates describe regional scale distribution of pollution levels and source-receptor relationships.

GLEMOS modelling framework 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. In the vertical the model domain covers the height up to 10 hPa (ca. 30 km). The current vertical structure consists of 20 irregular terrain-following sigma layers. Among them 10 layers cover the lowest 5 km of the troposphere and height of the lowest layer is about 75 m.

Anthropogenic Cd emission data for modelling have been prepared based on the gridded emissions fields provided by CEIP for the EMEP longitude-latitude grid system with spatial resolution 0.1x0.1 degree. Gridded emissions are complemented by additional emission parameters required for model runs (e. g. intra-annual variations and vertical distribution). Boundary conditions for model simulations over EMEP domain were estimated using the global scale GLEMOS model simulations [*Ilyin et al.*, 2022].

Meteorological data used in the calculations for 1990-2020 were obtained using WRF meteorological data pre-processor [*Skamarock et al*., 2008] on the basis of meteorological data of European Centre for Medium-Range Weather Forecasts (ECMWF).

Cadmium presents in the atmosphere being bound to aerosol particles. Therefore, atmospheric properties of cadmium, such as wet scavenging, dry deposition velocity or potential to travel over long distances is governed by properties of the particles-carriers.

Cadmium is naturally occurring element with mean content in the Earth's crust 0.15 ppm [*CRC*, 2008]. Therefore, cadmium can enter the atmosphere due to suspension of wind-blown dust. Parameterization of wind re-suspension of cadmium from soil and seawater is described in [*Gusev et al.*, 2006*; Ilyin et al*., 2007]. Information on spatial distribution of background Cd concentrations in topsoil is based on the results of FOREGS project [*Salminen*, 2005]. Besides, enrichment of soil by anthropogenic inputs of Cd was assumed in order to take into account long-term accumulation of Cd from anthropogenic sources and to reach a better fit of the modelled concentrations and wet deposition with the EMEP measurement data. In the current work secondary emissions of Cd from the territories of the HELCOM countries (except for Russia) and the Baltic Sea area were estimated at the level of about 43 t in 1990 and about 4.6 t in 2020.

The changes of cadmium deposition to the Baltic Sea in the period 1990-2020 were non-linear with faster decline in the 1990s and slower decline after the 2000s. In order to characterize varying rate of temporal changes of cadmium atmospheric input, the normalized deposition values were calculated using bi-exponential approximation [*Colette et al.*, 2016], which assumed that long-term changes in the beginning of the period were approximated by "fast" exponent, and decline in subsequent period by "slow" exponent.

Quality information

6. Strength and weakness:

Strength: annually reported data on cadmium emissions to the atmosphere.

Weakness: uncertainties in the officially submitted cadmium emission data and estimates of secondary emissions.

7. Uncertainty:

Discrepancies between the modelled and observed values can be caused by a number of reasons. One of them is uncertainties of officially reported emission data. In addition to this, uncertainties of spatial distribution as well as distribution along the vertical also contributes to the emission-related uncertainties.

Another source of the discrepancies is uncertainties of the model parameterizations and input data. Most of parameterizations of physical processes used in GLEMOS were transferred from previous model MSCE-HM used in operational modelling under EMEP [*Travnikov and Ilyin*, 2005]. The MSCE-HM model has been verified in a number of intercomparison campaigns with other regional HM transport models [*Gusev et al*., 2000; *Ryaboshapko et al.,* 2001, 2005] and has been qualified by means of sensitivity and uncertainty studies [*Travnikov*, 2000]. It was concluded that the results of heavy metal airborne transport modelling were in satisfactory agreement with the available measurements and the discrepancies did not exceed on average a factor of two [*UNEP*, 2010a,b]. The model was 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 HMs in Europe" [*ECE/EB.AIR/GE.1/2006/4*].

Finally, the discrepancies can be contributed by the uncertainties of measurements. Regular laboratory intercomparisons are carried out annually by the supervision of CCC. In the majority of laboratories analyses of Cd satisfy data quality objectives [*CCC*, 2021]. However, it is important to mention that laboratory intercomparison provides only analytical component of the uncertainties of measurement data. Other sources of the uncertainties (sampling, storing, shipping etc.) remain unaccounted.

8. Further work required:

Further work is required to reduce uncertainties in Cd modelling approaches applied in the GLEMOS model. It can be reached through joint efforts of measurement, emission and modelling communities.

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