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Atmospheric deposition of cadmium to the Baltic Sea

Hazardous substances

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Atmospheric deposition of cadmium to the Baltic Sea

HELCOM Baltic Sea Environment Fact Sheet (BSEFS), 2024

Authors: Oleg Travnikov, Jan Gačnik, EMEP MSC-E

Key Message

Airborne cadmium deposition to the Baltic Sea has been calculated for the period 1990–2022 using the EMEP MSC-E model (GLEMOS). According to the model calculations, annual total atmospheric deposition levels of cadmium to the Baltic Sea decreased by 78% from 1990 to 2020, with a higher rate of decrease observed in the earlier part of the assessment period (1990–1996).

Results and Assessment

Relevance of the BSEFS for describing developments in the environment

This Fact Sheet presents the levels and trends of cadmium atmospheric deposition to the Baltic Sea and its nine sub-basins during the period 1990-2022 based on the EMEP officially reported data. The most recent emission data reported by HELCOM Contracting Parties are described in the BSEFS report on "Atmospheric emissions of cadmium in the Baltic Sea region."

Policy relevance and policy references

The updated Baltic Sea Action Plan outlines the ecological objective that concentrations of hazardous substances in the environment should be close to background levels for naturally occurring substances. HELCOM Recommendation 31E/1 identifies a list of regional priority substances for the Baltic Sea.

At the European level, the relevant policy for controlling heavy metal emissions to the atmosphere is set under the framework of the 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. One of the core obligations of the Protocol is to reduce emissions of these metals to levels below those recorded in 1990. The Protocol entered into force in 2003 and has been signed and/or ratified by 41 countries.

Assessment

The model assessment of cadmium long-range transport and deposition in the Baltic Sea region for the period 1990–2022 was based on anthropogenic emissions officially reported by HELCOM and other EMEP countries. In addition to these emissions, natural and secondary sources, such as wind-driven resuspension of particle-bound cadmium from terrestrial and aquatic surfaces, were also considered. Despite the relatively high uncertainties in official emissions from some HELCOM countries, the model's estimates of cadmium pollution levels in the Baltic Sea region generally align well with observed air concentrations and wet deposition fluxes (within a factor of 2) (Travnikov et al., 2024).

Model simulations indicate that atmospheric cadmium input to the Baltic Sea declined by 78% between 1990 and 2022 (normalized deposition; Figure 1, Table 1). The most substantial reductions occurred in the Sound sub-basin (88%) and the Archipelago Sea sub-basin (86%) (Figure 2). The lowest declines were observed in the Bothnian Sea (77%) and the Gulf of Riga (78%) sub-basins. The decrease in cadmium deposition to the Baltic Sea during 1990-2022 was not uniform, with two distinct sub-periods showing different rates of decline: 1990-1997 and 1998-2022.

The deposition trend in each sub-period was analysed using the Mann-Kendall test (Gilbert, 1987; Connor et al., 2012; Pohlert, 2023). Cadmium deposition shows a significantly decreasing trend (negative monotonicity, $p < 0.001$, $\tau = -0.879$). Between 1990 and 1997, the strongest decline occurred, with an average annual decrease of about 0.9 tonnes per year (Sen's slope, $p < 0.05$, 95% confidence interval). In the subsequent period (1998-2022), the annual decline slowed to about 0.3 tonnes per year (Sen's slope, $p < 0.001$, 95% confidence interval). All these statistical parameters indicate that cadmium deposition is decreasing; however, the rate of decrease is slowing. Statistical parameters for deposition trends in individual sub-basins of the Baltic Sea are provided in Table 2.

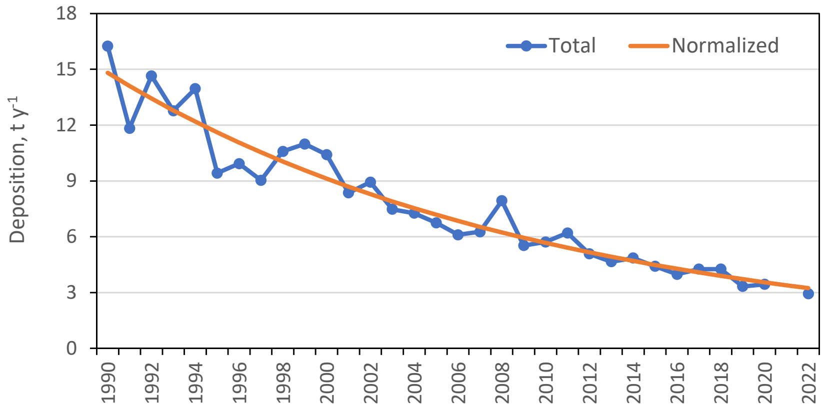

Figure 1. Changes in modelled (blue line) and normalised (orange line) total annual atmospheric deposition of cadmium to the Baltic Sea for the period 1990-2020 (t y^{-1}). Normalised deposition trend is obtained using the methodology described below in metadata section 5.

Figure 3 shows the spatial distribution of annual total cadmium deposition fluxes within the Baltic Sea region in 1990 and 2022. Cadmium deposition vary significantly across the sub-basins. In 2022, the highest spatially averaged flux was recorded in the Sound sub-basin, which has the smallest area and is influenced by significant nearby land-based emission sources. The lowest flux was observed in the Bothnian Bay sub-basin, which can be attributed to its relatively large area and low surrounding emission levels.

In 2022, HELCOM Contracting Parties contributed 44% of the total cadmium deposition to the Baltic Sea (Table 3), with Germany (12%) and Poland (10%) being the largest contributors (Figure 4). The remaining 56% of total deposition comes from other European countries, as well as non-European anthropogenic, natural and secondary sources. It is important to note that the contributions of emissions from Contracting Parties vary significantly across sub-regions. The reduction in atmospheric cadmium input from anthropogenic sources is the result of various factors, including emission abatement measures, economic contraction, and industrial restructuring in both HELCOM and other EMEP countries during the assessment period. The largest contributions to total cadmium deposition from anthropogenic sources come from the Industry, Electricity Production, and Residential Combustion sectors.

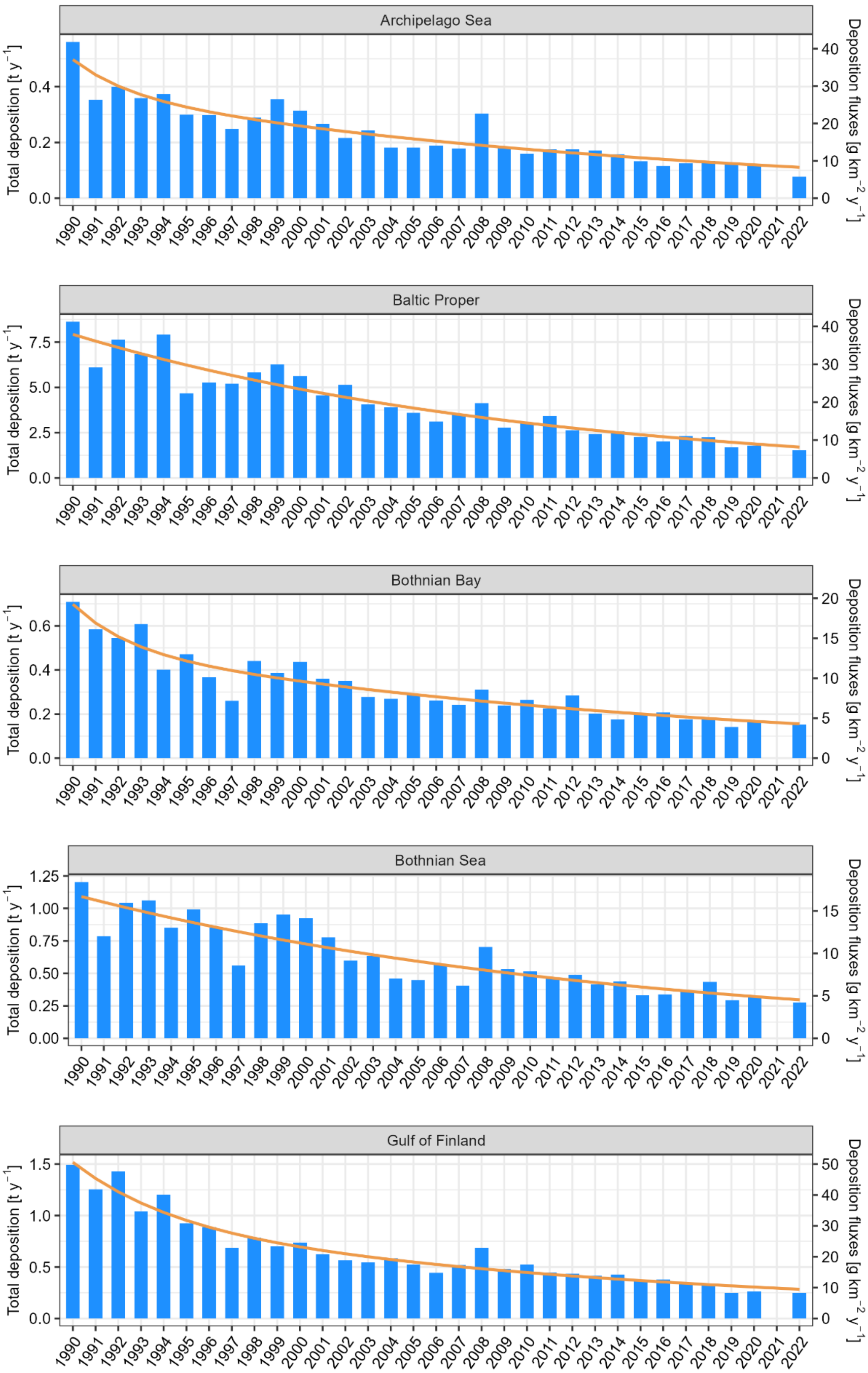

Figure 2. Time-series of calculated total annual atmospheric deposition of cadmium to nine sub-basins of the Baltic Sea (left axis) and average deposition fluxes (right axis) for the period 1990-2022. Blue bars represent calculated

values, and the orange line depicts the normalized trend. The cadmium pollution in the Baltic region for 2021 was not assessed (see Section 2 of Metadata).

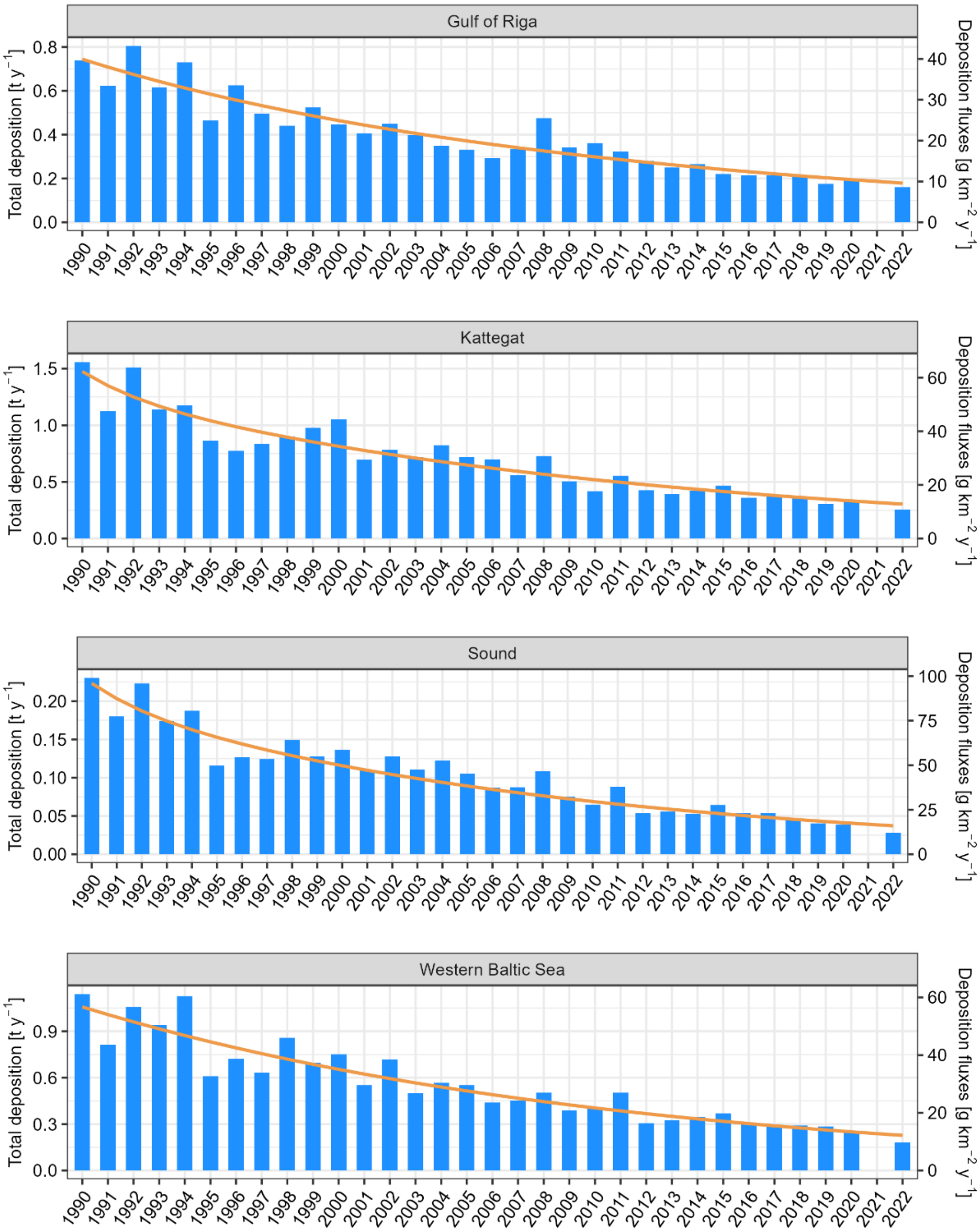

Figure 2 (continued). Time-series of computed total annual atmospheric deposition of cadmium to nine sub-basins of the Baltic Sea (left axis) and average deposition fluxes (right axis) for the period 1990-2022. Blue bars represent calculated values, and the orange line depicts the normalized trend. The cadmium pollution in the Baltic region for 2021 was not assessed (see Section 2 of Metadata).

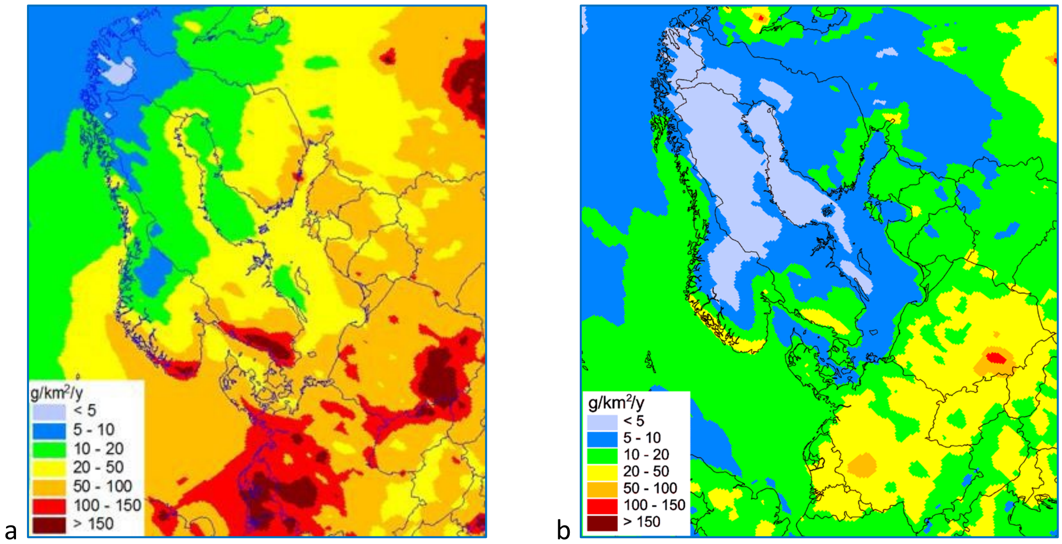

Figure 3. Spatial distribution of modelled annual total cadmium deposition fluxes in the Baltic Sea region for 1990 (a) and 2022 (b).

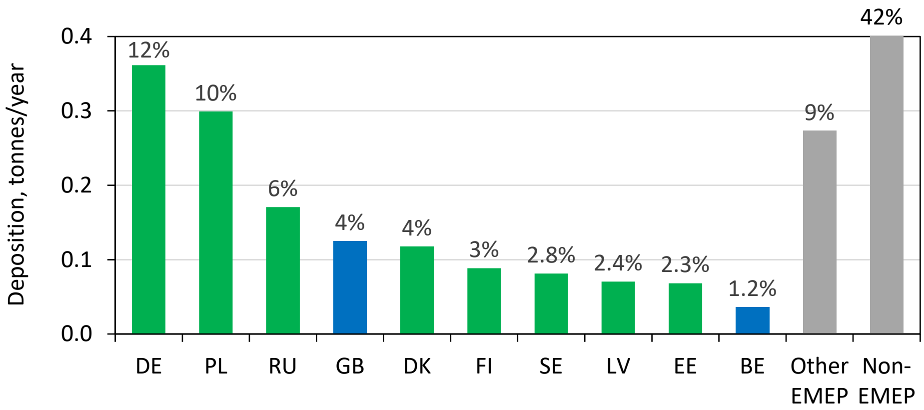

Figure 4. Top ten countries with the highest contributions to the annual total deposition of cadmium to the Baltic Sea, estimated for 2022. Coloured bars indicate contributions from anthropogenic emissions by HELCOM contracting parties (green) and non-HELCOM countries (blue). The bar labelled ‘Other EMEP’ represents the combined contribution of anthropogenic emissions from other EMEP countries, while the bar ‘Non-EMEP’ depicts the total contribution from other anthropogenic, natural, and secondary emissions.

Data

Supporting Excel here

Numerical data on calculated cadmium deposition to the Baltic Sea are provided in the tables below.

Table 1. Total annual deposition of cadmium to the nine Baltic Sea sub-basins, along with actual and normalized (1) deposition to the entire Baltic Sea (BAS) for the period 1990-2020. Units: t y^{-1}.

Year	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	14.82
1991	0.35	0.58	0.79	6.11	1.25	0.62	1.13	0.18	0.81	11.83	14.11
1992	0.40	0.54	1.04	7.63	1.43	0.80	1.51	0.22	1.06	14.65	13.43
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	12.19
1995	0.30	0.47	0.99	4.68	0.92	0.47	0.87	0.12	0.61	9.42	11.61
1996	0.30	0.37	0.85	5.28	0.89	0.63	0.77	0.13	0.72	9.93	11.06
1997	0.25	0.26	0.56	5.20	0.68	0.50	0.83	0.12	0.63	9.04	10.54
1998	0.29	0.44	0.89	5.83	0.79	0.44	0.90	0.15	0.86	10.59	10.04
1999	0.35	0.39	0.95	6.26	0.70	0.52	0.98	0.13	0.70	10.99	9.57
2000	0.31	0.44	0.93	5.61	0.74	0.45	1.05	0.14	0.75	10.41	9.12
2001	0.27	0.36	0.78	4.56	0.63	0.41	0.70	0.11	0.55	8.36	8.69
2002	0.22	0.35	0.60	5.13	0.56	0.45	0.78	0.13	0.72	8.94	8.29
2003	0.24	0.28	0.63	4.05	0.54	0.40	0.72	0.11	0.50	7.48	7.90
2004	0.18	0.27	0.46	3.91	0.58	0.35	0.82	0.12	0.57	7.27	7.53
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	6.53
2008	0.30	0.31	0.70	4.12	0.68	0.47	0.73	0.11	0.50	7.94	6.23
2009	0.18	0.24	0.53	2.77	0.48	0.34	0.51	0.08	0.39	5.53	5.94
2010	0.16	0.26	0.52	3.01	0.53	0.36	0.42	0.07	0.40	5.72	5.67
2011	0.18	0.23	0.47	3.41	0.45	0.32	0.56	0.09	0.50	6.20	5.41
2012	0.18	0.28	0.49	2.63	0.44	0.28	0.43	0.05	0.30	5.08	5.16
2013	0.17	0.20	0.41	2.43	0.42	0.25	0.39	0.06	0.32	4.66	4.92
2014	0.16	0.18	0.44	2.57	0.43	0.27	0.42	0.05	0.34	4.86	4.70
2015	0.13	0.20	0.33	2.26	0.36	0.22	0.47	0.06	0.37	4.41	4.48
2016	0.12	0.21	0.34	2.01	0.38	0.21	0.36	0.05	0.30	3.98	4.28
2017	0.13	0.18	0.36	2.33	0.33	0.21	0.37	0.05	0.29	4.26	4.08
2018	0.13	0.18	0.43	2.26	0.33	0.21	0.37	0.05	0.29	4.26	3.90
2019	0.13	0.14	0.29	1.71	0.25	0.18	0.31	0.04	0.28	3.33	3.72
2020	0.12	0.17	0.31	1.78	0.26	0.19	0.32	0.04	0.24	3.44	3.55
2021	n/a (2)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2022	0.08	0.15	0.28	1.55	0.25	0.16	0.26	0.03	0.18	2.93	3.23

(1) Normalized depositions were calculated using the methodology described below in Section 5 of Metadata.

(2) The cadmium pollution in the Baltic region for 2021 was not assessed (see Section 2 of Metadata).

Table 2. Trends in cadmium deposition to the Baltic Sea and its nine sub-basins for two periods: 1990-1997 and 1998-2022. Missing values indicate the absence of a statistically significant trend ($p > 0.05$, 95% confidence interval).

Basin	Deposition in 1990, t/y	Slope over 1990-1997, % 1990 / y	Deposition in 1998, t/y	Slope over 1998-2022, % 1998 / y
Archipelago Sea	0.56	-5.3	0.29	-2.6
Bothnian Bay	0.71	-8.0	0.44	-2.4
Bothnian Sea	1.20	-	0.89	-2.5
Baltic Proper	8.62	-	5.83	-2.9
Gulf of Finland	1.49	-7.3	0.79	-2.5
Gulf of Riga	0.74	-4.9	0.44	-2.9
Kattegat	1.56	-7.0	0.90	-3.1
Sound	0.23	-6.9	0.15	-3.3
Western Baltic Sea	1.14	-	0.86	-2.5
Baltic Sea	16.25	-5.8	10.59	-2.7

Table 3. Contribution by country to the annual total deposition of cadmium to the nine Baltic Sea sub-basins for the year 2022. HELCOM: contribution from anthropogenic sources in HELCOM countries; EMEP: contribution from anthropogenic sources in other EMEP countries; Other: combined contributions from natural, secondary, and remote non-EMEP sources. Units: t y^{-1}.

Country	ARC	BOB	BOS	BAP	GUF	GUR	KAT	SOU	WEB	BAS
DK	8.95E-04	9.39E-04	3.03E-03	4.89E-02	1.76E-03	1.87E-03	3.44E-02	5.77E-03	2.02E-02	1.18E-01
EE	2.21E-03	1.58E-03	4.61E-03	1.25E-02	3.82E-02	8.96E-03	1.51E-04	1.13E-05	1.07E-04	6.83E-02
FI	6.19E-03	1.99E-02	2.05E-02	1.11E-02	2.81E-02	2.50E-03	2.22E-04	1.82E-05	1.27E-04	8.86E-02
DE	7.28E-03	8.95E-03	2.37E-02	2.05E-01	1.27E-02	1.13E-02	4.45E-02	4.54E-03	4.30E-02	3.61E-01
LV	2.01E-03	1.20E-03	4.56E-03	2.58E-02	8.23E-03	2.82E-02	3.18E-04	3.25E-05	2.24E-04	7.06E-02
LT	7.56E-04	5.50E-04	1.83E-03	1.48E-02	2.21E-03	4.51E-03	2.82E-04	3.40E-05	1.96E-04	2.52E-02
PL	7.15E-03	7.20E-03	1.79E-02	2.13E-01	1.74E-02	1.70E-02	9.51E-03	9.81E-04	9.40E-03	2.99E-01
RU	4.18E-03	3.15E-02	2.31E-02	5.75E-02	4.30E-02	7.81E-03	1.62E-03	2.38E-04	1.58E-03	1.71E-01
SE	3.21E-03	1.66E-02	1.76E-02	3.48E-02	3.25E-03	2.45E-03	2.75E-03	2.95E-04	5.03E-04	8.14E-02
AL	2.39E-06	6.59E-06	7.14E-06	4.38E-05	1.91E-05	7.87E-06	1.20E-06	1.17E-07	1.31E-06	8.95E-05
AM	4.02E-07	1.62E-06	1.74E-06	1.63E-05	4.55E-06	1.82E-06	2.60E-07	8.25E-08	7.30E-07	2.75E-05
AT	3.11E-04	3.25E-04	9.97E-04	6.75E-03	9.15E-04	6.38E-04	5.81E-04	4.36E-05	6.12E-04	1.12E-02
AZ	1.23E-06	6.10E-06	5.47E-06	2.89E-05	1.43E-05	5.75E-06	6.18E-07	1.14E-07	9.82E-07	6.35E-05
BA	6.55E-05	1.69E-04	2.32E-04	2.10E-03	4.53E-04	2.59E-04	1.25E-04	1.10E-05	6.92E-05	3.49E-03
BE	7.20E-04	1.05E-03	2.69E-03	1.81E-02	1.21E-03	1.07E-03	6.63E-03	5.21E-04	4.10E-03	3.61E-02
BG	3.27E-05	1.01E-04	8.45E-05	1.13E-03	2.64E-04	1.63E-04	3.07E-05	3.63E-06	4.77E-05	1.86E-03
BY	4.33E-04	4.54E-04	1.24E-03	9.66E-03	1.68E-03	1.57E-03	3.19E-04	3.64E-05	1.88E-04	1.56E-02
CH	1.57E-04	1.13E-04	3.81E-04	3.16E-03	3.71E-04	2.35E-04	4.83E-04	3.41E-05	4.02E-04	5.33E-03
CY	6.58E-08	1.46E-07	3.11E-07	1.26E-06	4.36E-07	2.49E-07	2.07E-08	3.52E-09	3.17E-08	2.52E-06
CZ	9.95E-04	1.06E-03	3.06E-03	2.18E-02	2.33E-03	1.93E-03	1.68E-03	1.51E-04	1.63E-03	3.46E-02
ES	6.26E-04	4.40E-04	1.84E-03	1.07E-02	1.67E-03	9.01E-04	2.92E-03	1.91E-04	1.74E-03	2.10E-02
FR	7.84E-04	9.30E-04	2.73E-03	1.75E-02	1.50E-03	1.12E-03	5.80E-03	4.51E-04	3.60E-03	3.44E-02
GB	2.45E-03	3.44E-03	9.16E-03	6.55E-02	4.65E-03	4.60E-03	2.01E-02	1.81E-03	1.32E-02	1.25E-01
GE	1.14E-06	6.02E-06	4.71E-06	5.46E-05	1.39E-05	6.14E-06	7.72E-07	2.63E-07	2.35E-06	8.99E-05
GR	5.77E-06	1.82E-05	1.99E-05	2.08E-04	4.87E-05	2.84E-05	6.28E-06	7.52E-07	1.03E-05	3.47E-04
HR	6.27E-05	1.11E-04	2.07E-04	1.75E-03	3.72E-04	2.24E-04	1.32E-04	1.10E-05	9.23E-05	2.96E-03
HU	2.41E-04	3.43E-04	7.25E-04	5.56E-03	1.08E-03	6.78E-04	3.50E-04	3.58E-05	4.78E-04	9.49E-03
IE	6.54E-05	9.26E-05	2.59E-04	1.67E-03	1.16E-04	1.23E-04	4.88E-04	4.61E-05	2.95E-04	3.16E-03
IS	8.91E-06	2.23E-05	3.39E-05	1.27E-04	1.81E-05	1.28E-05	2.87E-05	2.78E-06	1.74E-05	2.72E-04
IT	1.78E-04	2.14E-04	5.20E-04	3.46E-03	6.43E-04	3.20E-04	4.76E-04	2.39E-05	2.21E-04	6.05E-03
KY	1.01E-07	1.39E-06	5.86E-07	1.66E-06	4.63E-07	1.75E-07	6.50E-08	8.24E-09	6.51E-08	4.51E-06
KZ	4.98E-05	2.45E-04	3.92E-04	1.16E-03	2.75E-04	1.33E-04	1.99E-05	3.96E-06	3.35E-05	2.31E-03
LI	1.46E-06	9.98E-07	3.03E-06	2.96E-05	3.43E-06	2.21E-06	3.77E-06	2.66E-07	3.30E-06	4.81E-05
LU	2.49E-05	3.45E-05	8.29E-05	5.86E-04	3.80E-05	3.37E-05	1.62E-04	1.50E-05	1.09E-04	1.09E-03
MC	1.23E-08	1.01E-08	3.34E-08	1.80E-07	3.77E-08	1.43E-08	3.74E-08	1.87E-09	1.99E-08	3.47E-07
MD	1.80E-05	4.29E-05	3.44E-05	1.10E-03	1.30E-04	1.03E-04	1.24E-05	4.39E-06	3.87E-05	1.49E-03
ME	3.53E-06	1.03E-05	1.01E-05	9.77E-05	2.60E-05	1.42E-05	2.14E-06	2.14E-07	2.60E-06	1.67E-04
MK	3.04E-06	1.16E-05	8.32E-06	1.50E-04	3.17E-05	1.78E-05	1.71E-06	6.35E-07	1.02E-05	2.35E-04
MT	3.94E-08	6.03E-08	1.24E-07	9.74E-07	9.80E-08	6.60E-08	3.96E-08	4.40E-09	4.25E-08	1.45E-06
NL	6.39E-04	9.19E-04	2.40E-03	1.67E-02	1.11E-03	9.83E-04	6.15E-03	4.93E-04	4.04E-03	3.34E-02
NO	8.56E-04	1.49E-03	4.12E-03	9.06E-03	1.24E-03	8.78E-04	2.38E-03	1.33E-04	6.67E-04	2.08E-02
PT	7.23E-05	5.83E-05	2.87E-04	1.60E-03	1.84E-04	9.91E-05	2.79E-04	2.34E-05	2.31E-04	2.84E-03
RO	1.26E-04	3.40E-04	3.37E-04	6.66E-03	1.04E-03	7.00E-04	1.19E-04	3.15E-05	3.18E-04	9.67E-03
RS	1.12E-04	2.82E-04	3.24E-04	3.15E-03	9.12E-04	4.58E-04	1.37E-04	1.64E-05	1.68E-04	5.56E-03
SI	5.79E-05	8.26E-05	1.91E-04	1.37E-03	2.65E-04	1.67E-04	1.21E-04	8.36E-06	8.34E-05	2.35E-03
SK	1.54E-04	1.89E-04	4.69E-04	3.92E-03	6.06E-04	4.57E-04	2.66E-04	2.49E-05	3.32E-04	6.42E-03
TJ	7.60E-08	8.86E-07	4.42E-07	1.25E-06	3.54E-07	1.30E-07	5.16E-08	6.49E-09	5.48E-08	3.25E-06
TM	1.04E-06	4.06E-06	6.40E-06	1.63E-05	8.64E-06	3.00E-06	5.20E-07	6.35E-08	4.96E-07	4.05E-05
TR	2.75E-05	8.86E-05	1.12E-04	9.13E-04	2.44E-04	1.33E-04	2.26E-05	3.50E-06	3.08E-05	1.57E-03
UA	1.57E-04	2.67E-04	4.11E-04	6.94E-03	8.53E-04	5.95E-04	1.56E-04	2.99E-05	2.87E-04	9.69E-03
UZ	3.16E-06	1.98E-05	2.36E-05	4.98E-05	1.35E-05	6.00E-06	1.67E-06	1.98E-07	1.44E-06	1.19E-04
HELCOM	0.03	0.09	0.12	0.62	0.15	0.08	0.09	0.01	0.08	1.28
EMEP	0.01	0.01	0.03	0.22	0.02	0.02	0.05	0.00	0.03	0.41
Other	0.03	0.05	0.13	0.70	0.07	0.06	0.11	0.01	0.07	1.24
Total	0.08	0.15	0.28	1.55	0.25	0.16	0.26	0.03	0.18	2.93

Metadata

Technical information

1. Source:

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

2. Description of data:

   The atmospheric deposition of cadmium to the Baltic Sea for the period 1990 to 2022 was estimated using the GLEMOS model (v2.2.2) developed by EMEP/MSC-E (https://github.com/glemos-model). Due to time constraints, recalculation of the deposition time series for 1990-2021 was not performed. Instead, trend analysis the entire period from 1990-2022 was conducted using previously calculated results. Cadmium pollution levels for 1990-2020 were previously simulated and published in BSEFS based on emission data officially reported by EMEP countries in 2021. These data are available in the WebDab database of the EMEP Centre on Emission Inventories and Projections (CEIP) (https://www.ceip.at/webdab-emission-database/). A detailed description of the emission data, gap-filling methods, and expert estimates can be found in the CEIP Technical Report (Poupa, 2021). Cadmium pollution for 2022 was simulated using the same GLEMOS version and the most recent official emissions reporting from EMEP in 2024 (Travnikov et al., 2024). Pollution of the Baltic region with cadmium for 2021 was not assessed.

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 Cadmium atmospheric deposition were estimated for the continuous period 1990 – 2020 and 2022.

5. Methodology and frequency of data collection:

   The atmospheric input and source allocation budget of cadmium deposition to the Baltic Sea was calculated using the GLEMOS model. GLEMOS is a multi-scale, multi-pollutant simulation framework developed for both operational and research applications within EMEP (Tarrason and Gusev, 2008; Travnikov et al., 2009; Jonson and Travnikov, 2010; Travnikov and Jonson, 2011). The model simulates the dispersion and cycling of various pollutant classes, including heavy metals and persistent organic pollutants, with flexible options for simulation domains ranging from global to local scales and varying spatial resolutions. Vertically, the model domain extends up to 10 hPa (approximately 30 km), consisting of 20 irregular terrain-following sigma layers, 10 of which cover the lowest 5 km of the troposphere. The height of the lowest layer is about 75 metres. The model simulations of transport and deposition of the selected pollutants were conducted with a spatial resolution 0.2°×0.2°. Source-receptor matrices required for source attribution analysis were calculated based on model runs at a 0.4°×0.4° resolution.

   Anthropogenic cadmium emission data used in the modelling were prepared based on gridded emission fields provided by CEIP for the EMEP longitude-latitude grid system with a spatial resolution of 0.1 x 0.1 degrees. These gridded emissions were supplemented with additional parameters required for model runs, such as seasonal variations, vertical distribution, and chemical speciation. Boundary conditions for model simulations over the EMEP domain were estimated using GLEMOS simulations on a global scale (Ilyin et al., 2022). Additionally, the parameterisation of cadmium wind re-suspension from soil and seawater is described in (Gusev et al., 2006; Ilyin et al., 2007).

Meteorological data used for the calculations from 1990-020 and 2022 were obtained using the WRF meteorological data pre-processor (Skamarock et al., 2008), based on data from the European Centre for Medium-Range Weather Forecasts (ECMWF). Normalised annual deposition values for the period 1990-2022 were obtained using the results of model simulations and bi-exponential approximation described in (Colette et al., 2016). The applied approximation method reflects the non-linear character of long-term deposition trends typical for heavy metals and POPs, showing a stronger reduction initially, followed by a slower reduction or even growth in the later part of the period. This method has been extensively tested for trend analysis within EMEP and used in pollution assessments (Maas and Grennfelt, 2016).

Quality information

6. Strengths and weaknesses:

Strength: annually updated information on atmospheric input of cadmium to the Baltic Sea and its sub-basins based on officially reported emissions data.

Weakness: uncertainties in the provided model estimates due to both the incompleteness/uncertainties of the emissions data and the limitations of the applied modelling approaches.

7. Uncertainty:

Uncertainties in the model estimates can arise from several factors. One major source is the uncertainty in officially reported emission data. The uncertainties in cadmium emission inventories vary from about 20-30% for Poland, Sweden, and Latvia, to as high as 130-360% for Estonia and Denmark. In addition, uncertainties in both the spatial and vertical distribution of emissions contribute to the overall emission-related uncertainties.

Another source of uncertainty is inaccuracies in the model parameterisations and input data. Most of the parameterisations of physical processes used in GLEMOS were adapted from the previous MSCE-HM model, which was used for operational modelling under EMEP (Travnikov and Ilyin, 2005). The MSCE-HM model has been verified through multiple intercomparison campaigns with other regional heavy metal transport models (Gusev et al., 2000; Ryaboshapko et al., 2001, 2005) and has been assessed in sensitivity and uncertainty studies (Travnikov, 2000). These studies concluded that heavy metal airborne transport modelling results were in satisfactory agreement with available measurements, with discrepancies generally not exceeding a factor of two (UNEP, 2010a; 2010b).

The modelling results are evaluated against observational data, which are also subject to uncertainties. To assess measurement uncertainties, annual laboratory intercomparisons are conducted under the supervision of CCC. In most cases, cadmium analyses in the majority of laboratories meet the data quality objectives (CCC, 2021). However, it is important to note that laboratory intercomparisons address only the analytical component of measurement uncertainty, while other sources, such as sampling, storage, and shipping, remain unaccounted for.

8. Further work required:

Further work is needed to reduce uncertainties in the cadmium modelling approaches used in the GLEMOS model. This can be achieved through the combined efforts of the measurement, emission, and modelling communities.

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