IX. ATMOSPHERIC DEPOSITION IN THE TERRITORY OF THE CR

Atmospheric deposition refers to the flux of substances from the atmosphere to the surface of the Earth (Braniš, Hůnová 2009). This is an important process contributing to self-purification of the air; but it is also responsible for the input of pollutants into other components of the environment. Atmospheric deposition has both wet and dry components. The wet component is connected with the occurrence of atmospheric precipitation (vertical deposition: rain, snow, hail, and horizontal deposition: fog, rime, icing) and is thus episodic in character. The dry component corresponds to the deposition of gases and particles by various mechanisms and occurs continuously.

The atmospheric deposition of most monitored substances in Europe has decreased substantially over the past twenty years, but still remains a problem in a number of regions (EEA 2011). In the CR, the chemical composition of atmospheric precipitation and atmospheric deposition has been monitored for a long time at a relatively large number of localities.

In 2021, data on the chemical composition of atmospheric precipitation were provided to the Air Quality Information System (AQIS) from 39 locations in the CR. Measurements in the CR are provided by CHMI (14 localities), CGS (10 localities), VÚLHM (10 localities), HBÚ AV ČR (2 localities), and ÚH AV ČR, ÚVGZ AV ČR and GLÚ AV ČR (1 locality each). Furthermore, data from 2 Slovak localities (SHMI) were provided for border areas (Fig. IX.1, CHMI 2022e).

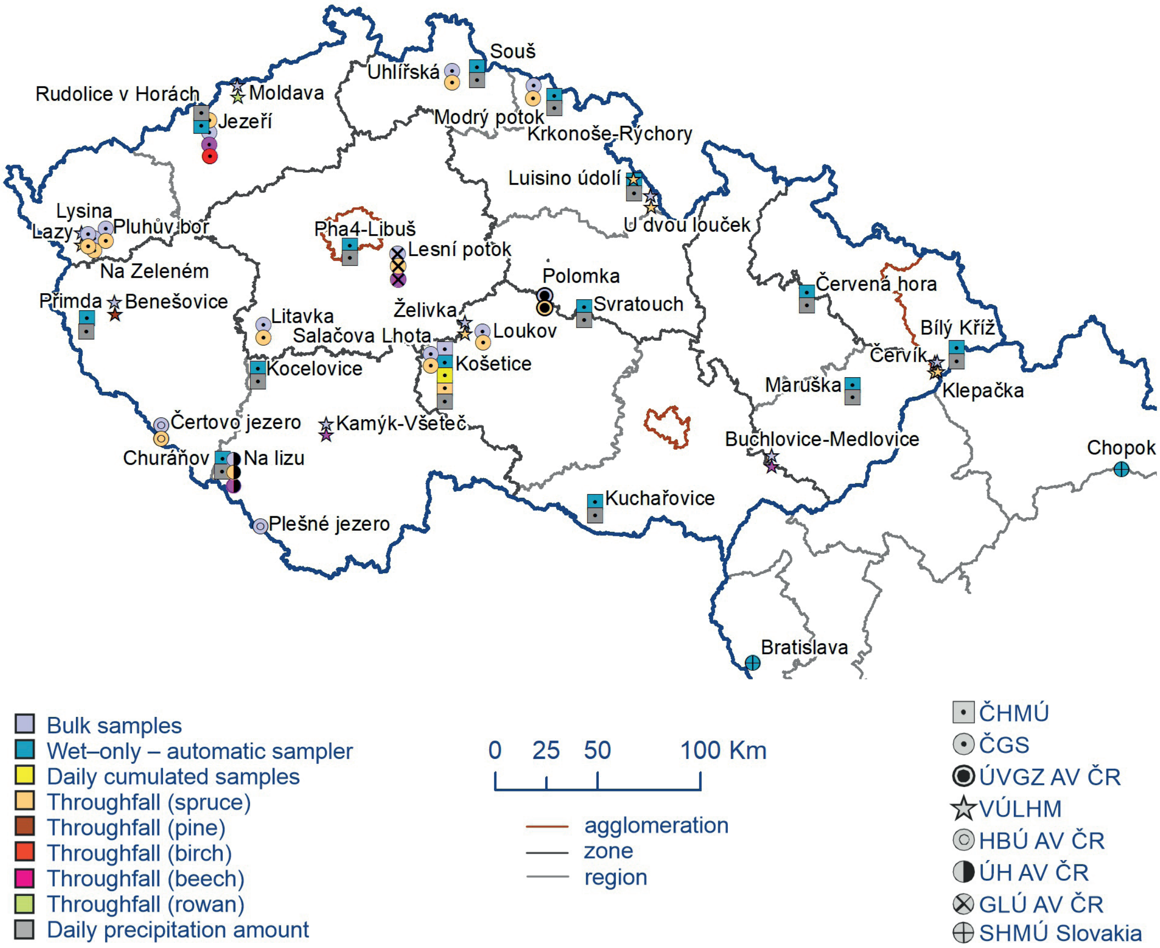

Fig. IX.1 Station networks monitoring atmospheric precipitation quality and atmospheric deposition, 2021

The substances presented in the chapter on atmospheric deposition have no limit values set by legislation, as is the case for ambient air pollutants. Therefore, another colour scale has been chosen to improve the clarity of deposition maps. More detailed information on atmospheric deposition, sampling, measurement and quantification of its components and specifications for preparation of maps are available at CHMI (2022d).

Results

The year 2021 was normal in terms of precipitation. The average annual precipitation of 683 mm represents 100 % of the long-term 1991–2020 normal (for more see Chapter III). Lower precipitation totals compared to 2020 (766 mm) resulted in a decrease in the wet deposition of reduced forms of nitrogen ($N\_NH_4^+$), the total wet deposition of nitrogen, and the total deposition of nitrogen.

Deposition of sulphur

The average sulphur deposition flux in 2021 was 0.385 $g \cdot m^{-2} \cdot year^{-1}$ (Table IX.1). Compared to 2020 (0.388 $g \cdot m^{-2} \cdot year^{-1}$), this is a decrease by 1 %.

The field of total sulphur deposition represents the total level of sulphur deposition on the area of the CR. Its quantification is based on SO_4^{2-} concentrations measured in atmospheric precipitation and SO_2 air pollution concentrations. In 2021, total sulphur deposition amounted to 30 335 t (Tab. IX.2), which is a decrease of less than 1 % compared to 2020 (30 577 t). In 2021, the value of the total sulphur deposition flux was lower than 0.5 $g \cdot m^{-2} \cdot year^{-1}$ on 86 % of the area of the CR. Higher values were observed in the areas of Krušné hory, Jizerské hory, Krkonoše, Orlické hory, Jeseníky, Ostrava, and Moravian-Silesia Beskydy. (Fig. IX.2).

Wet deposition of sulphur ($S\_SO_4^{2-}$) reached the value of 14 786 t in 2021, compared to 13 793 t in 2020 (increase by 7 %). In most of the CR territory (99.8 %), the values of the deposition flux were below 0.5 $g \cdot m^{-2} \cdot year^{-1}$. Higher values of the wet component were observed in the Jizerské and Orlické hory (Fig. IX.3). Dry deposition of sulphur (S_SO_2) reached 15 549 t in 2021, while it was 16 784 t in 2020 (decrease by 7 %). As with the wet component, the S_SO_2 deposition flux values were below 0.5 $g \cdot m^{-2} \cdot year^{-1}$ in most of the CR territory (99.4 %). Higher values of the dry component were monitored in the areas of Krušné hory and Ostrava (Fig. IX.4).

In 2021, throughfall deposition of sulphur ($S\_SO_4^{2-}$) in forested areas of the CR reached 7 174 t, which is a decrease of 4 % compared to 2020 (7 492 t) (Tab. IX.3). The maximum values (0.5 $g \cdot m^{-2} \cdot year^{-1}$) occurred in border mountain areas (0.7 % of the forested area of the CR; Fig. IX.5). A map showing throughfall sulphur deposition was prepared for forested areas on the basis of fields of sulphur concentrations in throughfall precipitation and from verified fields of precipitation, modified by the percentage amount of precipitation measured under vegetation at individual stations, which ranged from 35 % (Salačova Lhota) to 88 % (Lazy) of the total precipitation in open areas in 2021. Throughfall deposition generally includes wet vertical and horizontal deposition (from fogs, low clouds and rime) and the dry deposition of particles and gases in forests.

Table IX.1 Average deposition fluxes of S, N and H in the Czech Republic, 2021

Element	Deposition	$g \cdot m^{-2} \cdot year^{-1}$	$keq \cdot ha^{-1} \cdot year^{-1}$
S (SO_4^{2-})	wet	0.188	0.117
S (SO_2)	dry	0.197	0.123
S	total	0.385	0.240
N (NO_3^-)	wet	0.239	0.171
N (NH_4^+)	wet	0.278	0.199
N (NO_x)	dry	0.185	0.132
N	total	0.702	0.502
H (pH)	wet	0.003	0.028
H (SO_2, NO_x)	dry	0.026	0.253
H	total	0.028	0.281

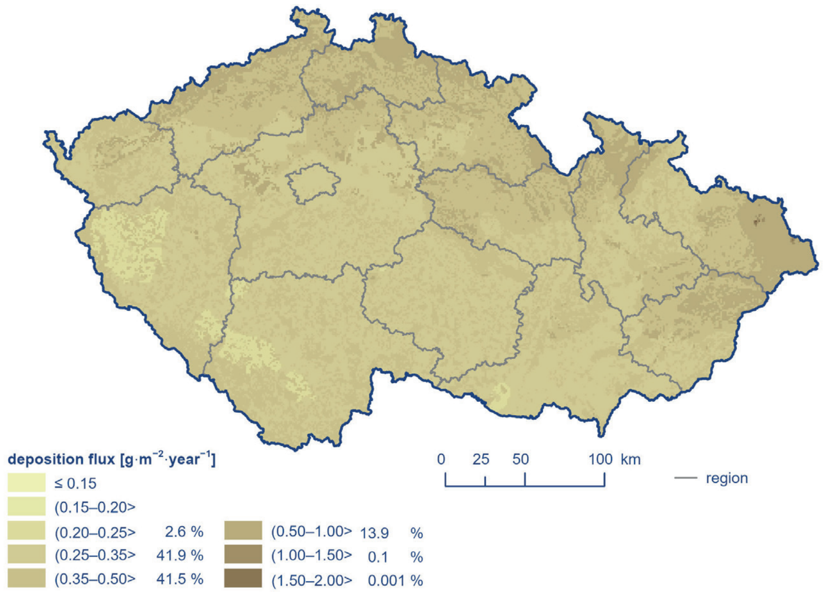

Fig. IX.2 Field of annual total deposition of sulphur, 2021

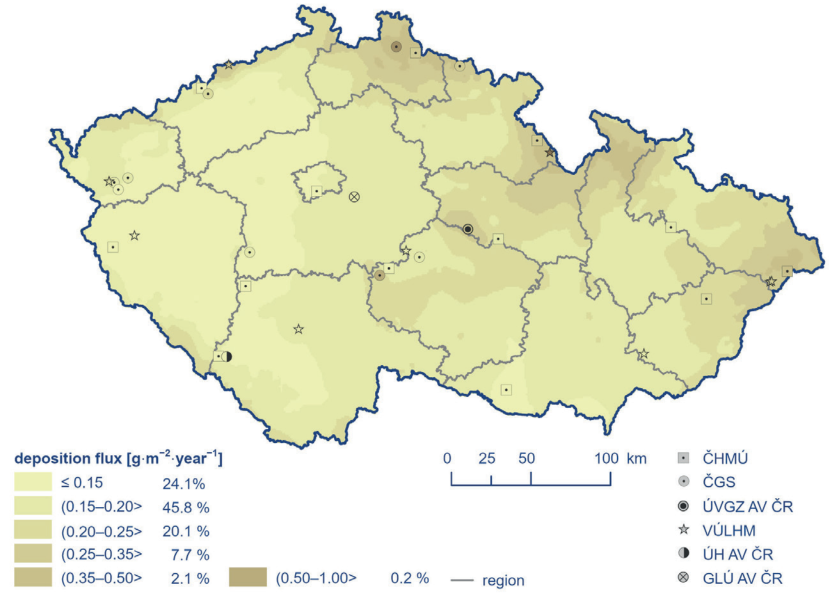

Fig. IX.3 Field of annual wet deposition of sulphur (S_SO_4^{2-}), 2021

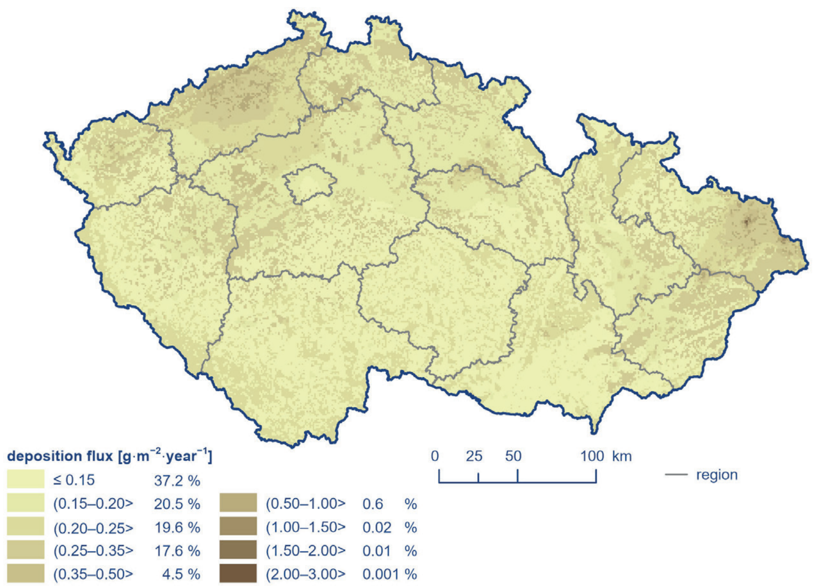

Fig. IX.4 Field of annual dry deposition of sulphur (S_SO_2), 2021

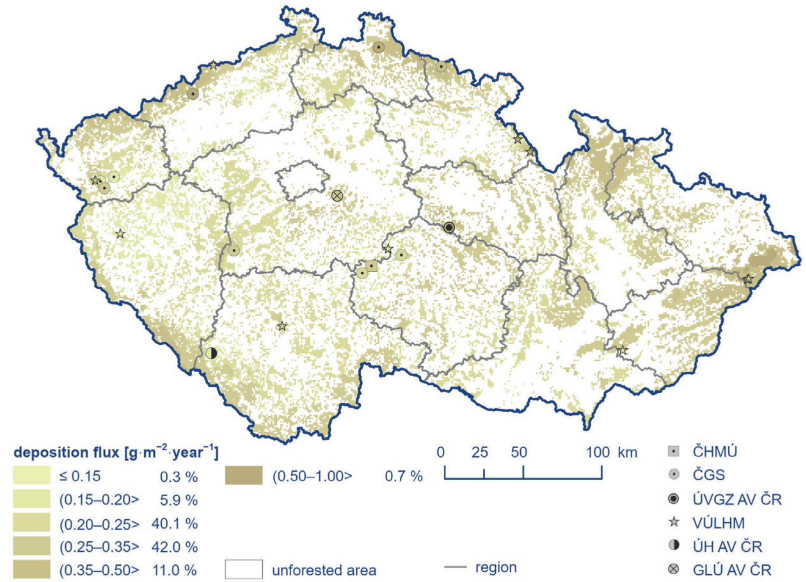

Fig. IX.5 Field of annual throughfall deposition of sulphur, 2021

Deposition of nitrogen

The average nitrogen deposition flux in 2021 was 0.702 $g \cdot m^{-2} \cdot year^{-1}$ (Table IX.1). Compared to 2020 (0.715 $g \cdot m^{-2} \cdot year^{-1}$), this is a decrease of 2 %.

The total nitrogen deposition on the area of the CR in 2021 amounted to 55 383 t (Tab. IX.2). Compared to 2020 (56 396 t), this is a decrease of 2 %. In 2021, the value of the total nitrogen deposition flux was lower than 0.75 $g \cdot m^{-2} \cdot year^{-1}$ on 67 % of the CR area. Higher values occurred in the areas of Jizerské hory, Orlické hory, and Jeseníky (Fig. IX.6).

On the contrary, the deposition of oxidized forms of nitrogen ($N\_NO_3^-$) reached higher value, namely 33 451 t in 2021, while in 2020 the value was 27 779 t (an increase of 20 %). The wet component of the deposition amounted to 18 876 t, which is an increase of 31 % compared to 2020 (14 382 t), and the dry component to 14 575 t, making an increase of 9 % compared to 2020 (13 397 t). Wet deposition of reduced forms ($N\_NH_4^+$) decreased in 2021, same as total nitrogen deposition, to a value of 21 932 t, and compared to 2020, when the value was 28 617 t it is a decrease of 23 %. The total wet deposition of nitrogen (sum of wet deposition of $N\_NO_3^-$ and $N\_NH_4^+$) amounted to 40 808 t in 2021, which is a decrease of 5 % compared to 2020 (42 999 t).

The highest values of wet deposition of oxidized forms of nitrogen (above 0.75 $g \cdot m^{-2} \cdot year^{-1}$) are recorded in the Jizerské hory, Orlické hory and Jeseníky, representing 0.9 % of the territory of the CR (Fig. IX.7). Wet deposition of reduced forms of nitrogen shows the highest values in the Jjizerské hory (0.102 % of the area of the CR, Fig. IX.8). The total wet deposition covers namely the Jizerské hory, Krkonoše, Orlické hory, and Jeseníky (8.901 % of the area of the CR, Fig. IX.9). Higher values of total dry deposition are observed locally within the entire CR, amounting to 0.41 % of the total territory (Fig. IX.10).

Table IX.2 Estimate of the total annual deposition in the Czech Republic (78 841 sq. km) in tonnes, 2021

	Deposition [t]		
	wet	dry	total
S	14 786	15 549	30 335
N (ox)	18 876	14 575	33 451
N (red)	21 932		
N (ox + red)	40 808		55 383
H^+	219	2 013	2 232
Cd	2.2	0.9	
Pb	34	19	

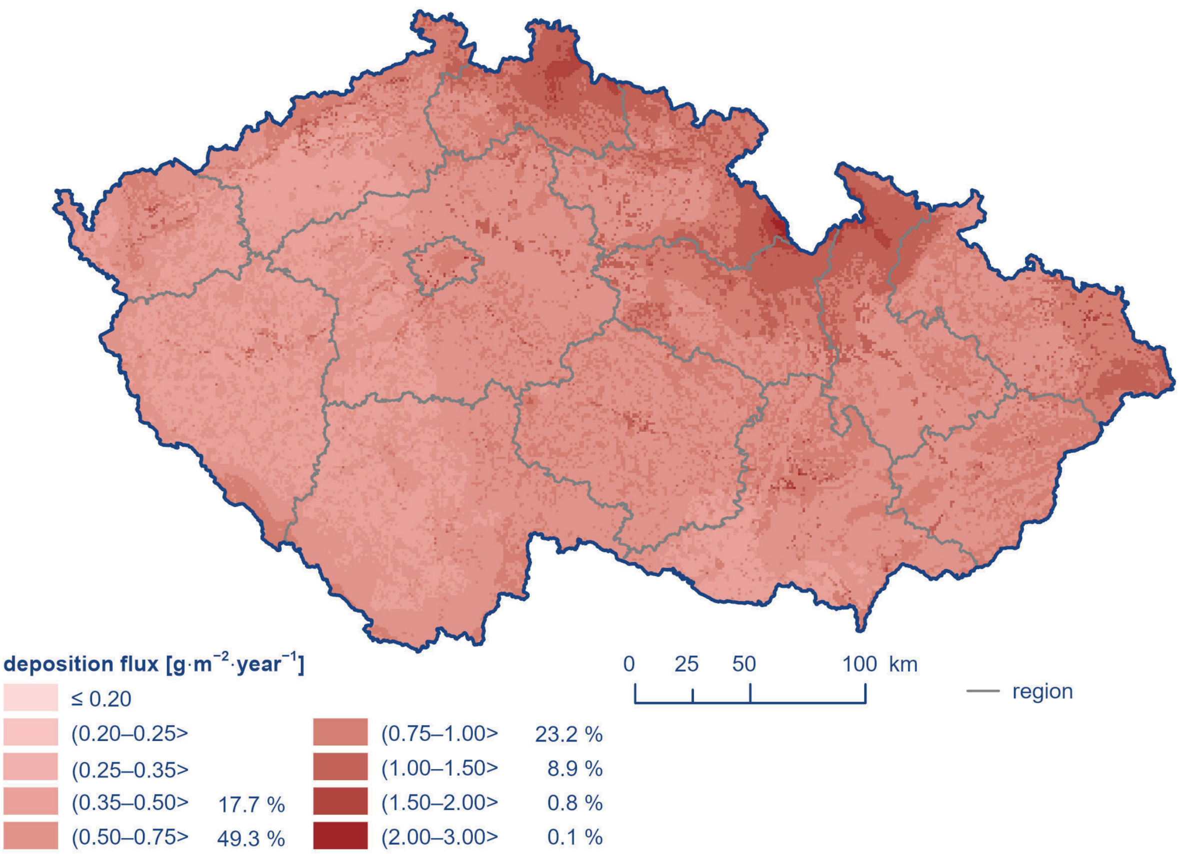

Fig. IX.6 Field of annual total deposition of nitrogen, 2021

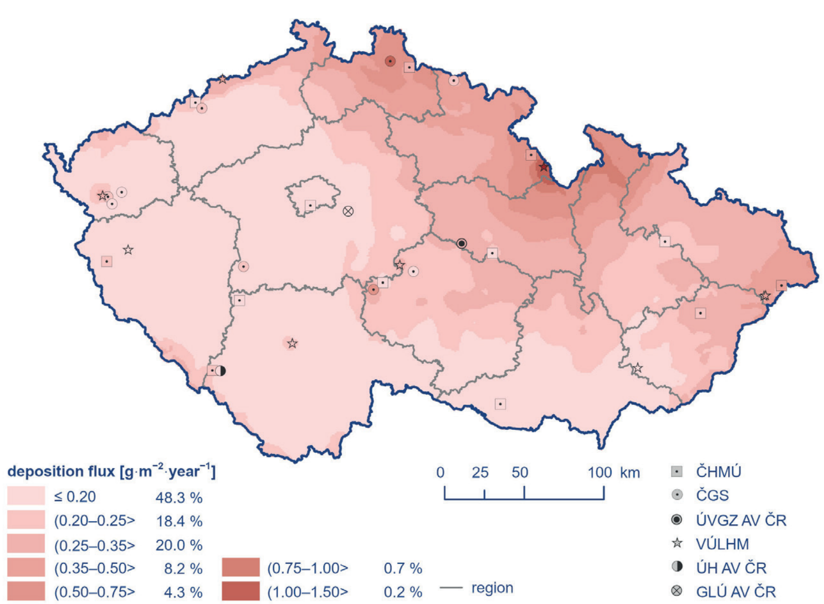

Fig. IX.7 Field of annual wet deposition of nitrogen (N_NO$_3^-$), 2021

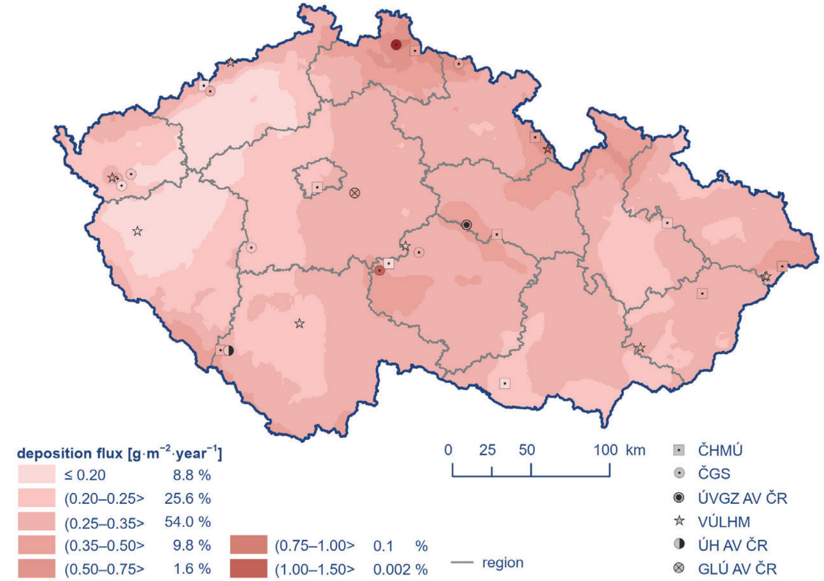

Fig. IX.8 Field of annual wet deposition of nitrogen (N_NH$_4^+$), 2021

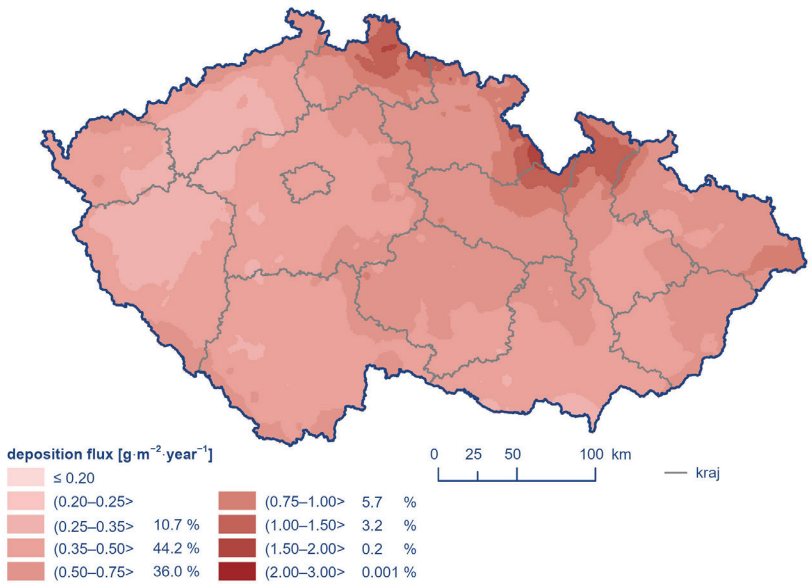

Fig. IX.9 Field of annual total wet deposition of nitrogen, 2021

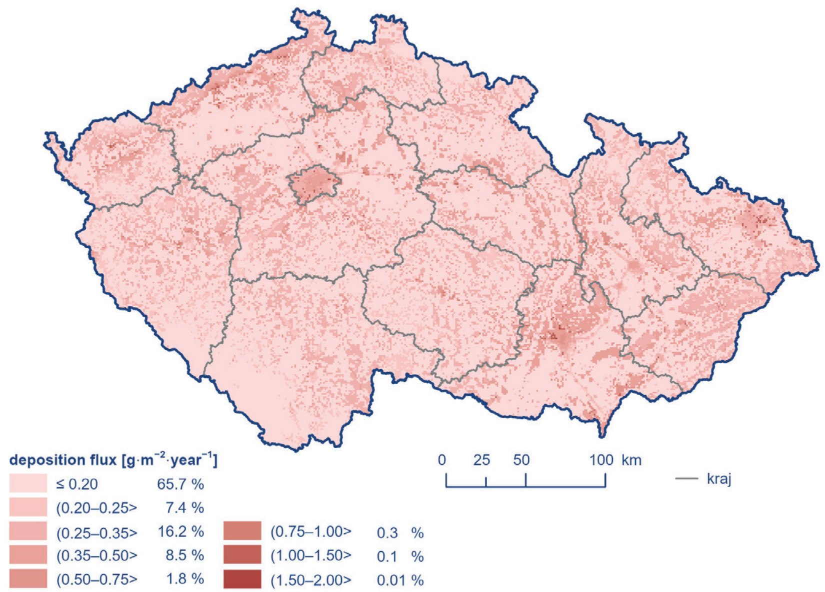

Fig. IX.10 Field of annual dry deposition of nitrogen (N_NO$_x$), 2021

Deposition of hydrogen ions

The average value of the hydrogen deposition flux in 2021 was, as in 2020, 28 mg·m^{-2}·year^{-1} (Tab. IX.1).

The total deposition of hydrogen ions on the area of the CR in 2021 was 2 232 t (Table IX.2). The year 2021 is thus comparable to the year 2020, when the value was 2 224 t. The partial components of hydrogen ion deposition are also comparable. The wet component reached 219 t in 2021, compared to 218 t in 2020, and the dry component was 2 013 t in 2021, compared to 2 006 t in 2020.

The total deposition of hydrogen ions in most of the CR territory (99.8 %) reaches values between 10 and 100 mg·m^{-2}·year^{-1}. Higher values are observed in the Krušné hory, the Ostrava area, and locally in the Brno area (Fig. IX.11). Wet deposition amounts to a maximum of 10 mg·m^{-2}·year^{-1}, while the highest values above 5 mg·m^{-2}·year^{-1} are recorded in the upper parts of the Krušné hory, Jizerské hory, Krkonoše, Jeseníky and Moravian-Silesia Beskydy (4.6 % of the CR; Fig. IX.12). Dry deposition is comparable to total deposition (Fig. IX.13).

Deposition of cadmium, lead, nickel and chloride ions

Wet deposition of cadmium reached 2.2 t in 2021, which is comparable to 2020 (2.0 t). Dry deposition in 2021 (0.9 t) was the same as in 2020 (Tab. IX.2). The highest values (above 0.05 mg·m^{-2}·year^{-1}) have been reached by cadmium deposition in the Jablonec area, Orlické hory, and Moravian-Silesia Beskydy (4.8 % of the CR area; Fig. IX.14). Dry deposition has reached values higher than 0.05 mg·m^{-2}·year^{-1} almost exclusively in the Liberec region, in the Krkonoše mountain area and Krkonoše foothills, and partly in the Ostrava area (0.8 % of the CR; Fig. IX.15).

Wet deposition of lead in 2021 (34 t) was comparable to 2020 (31 t). Dry deposition was also comparable, reaching a value of 19 t in 2021, while it was 17 t in 2020 (Tab. IX.2). The highest values of led wet deposition (over 0.7 mg·m^{-2}·year^{-1}) have been reached in the upper parts of the Jizerské hory, Orlické hory, and the Moravian-Silesia Beskydy (4.7 % of the CR; Fig. IX.16). The highest values of dry deposition have then been reached in the Příbram and Ostrava areas (3.5 % of the CR; Fig. IX.17).

Wet deposition of chloride ions, similar to other monitored substances, acquires higher values (above 0.5 mg·m^{-2}·year^{-1}) within the CR primarily in mountainous areas, especially in the Jizerské hory and Orlické hory (0.5 % of the CR; Fig. IX.18).

The annual wet deposition of nickel ions reaches the highest values at the locations Uhlířská, Salačova Lhota, Červík (Fig. IX.19).

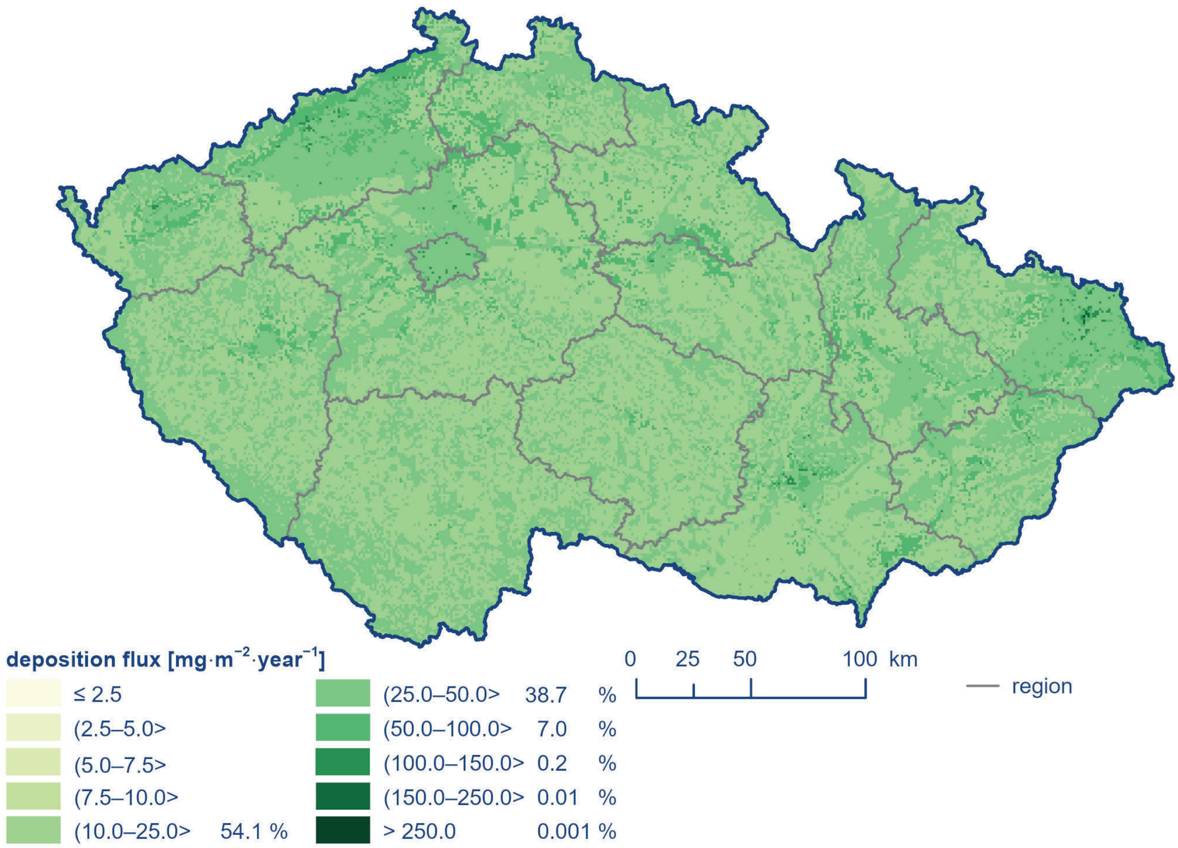

Fig. IX.11 Field of annual total deposition of hydrogen ions, 2021

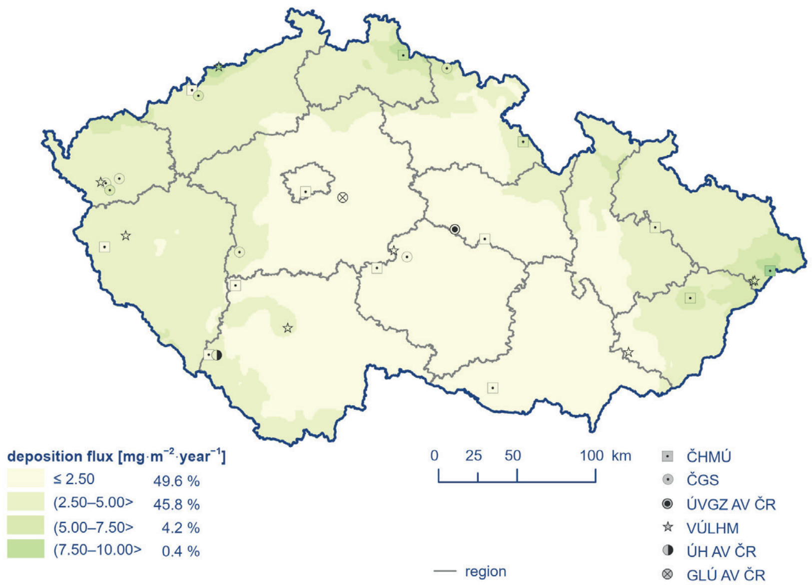

Fig. IX.12 Field of annual wet deposition of hydrogen ions, 2021

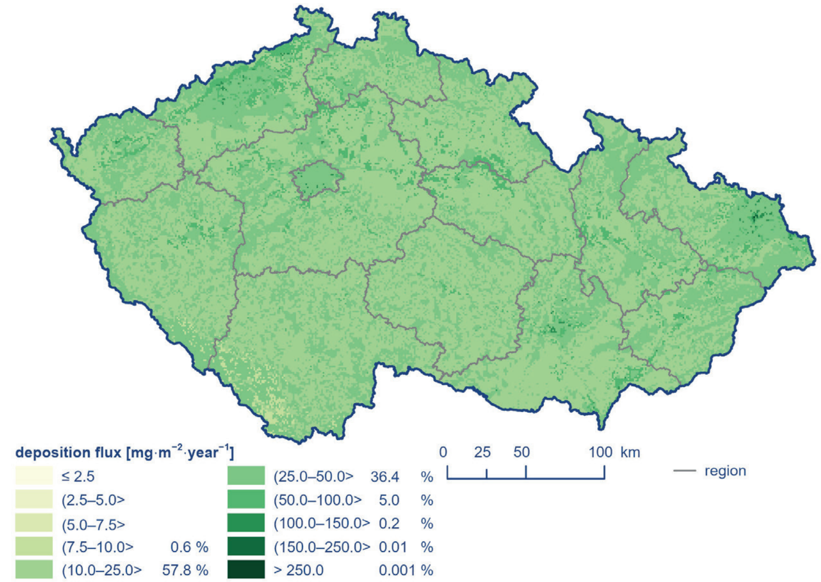

Fig. IX.13 Field of annual dry deposition of hydrogen ions corresponding to SO_2 and NO_x gas deposition, 2021

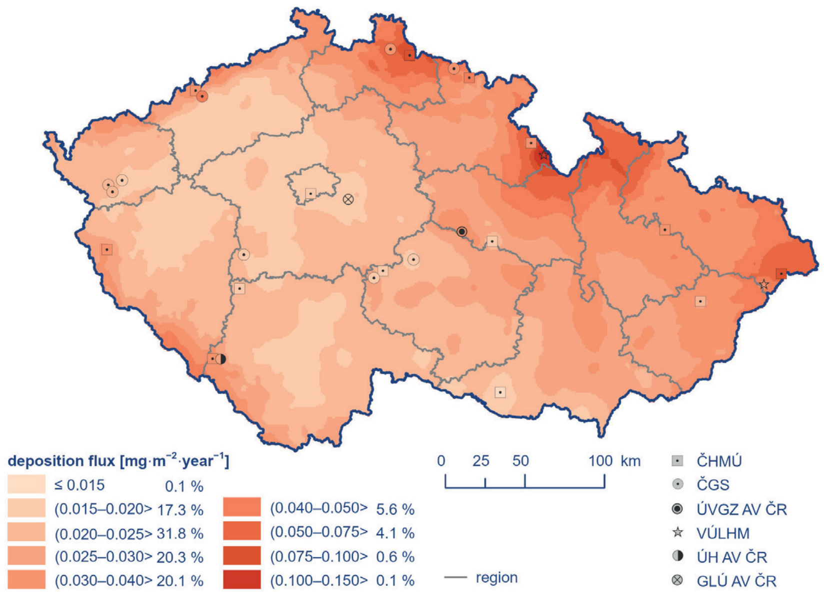

Fig. IX.14 Field of annual wet deposition of cadmium ions, 2021

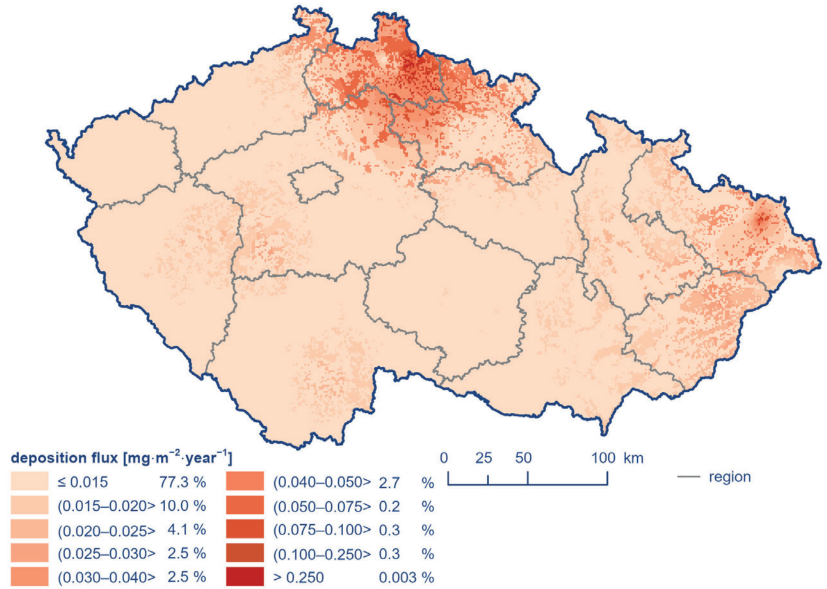

Fig. IX.15 Field of annual dry deposition of cadmium, 2021

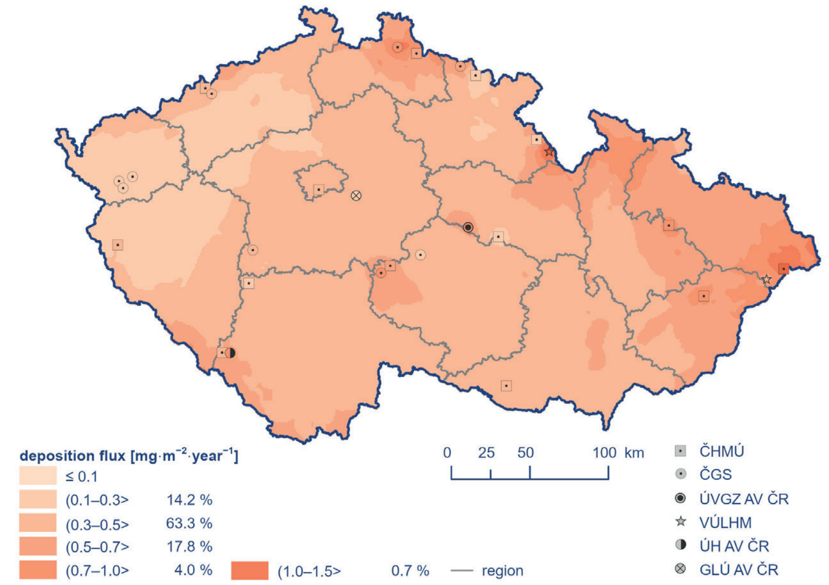

Fig. IX.16 Field of annual wet deposition of lead ions, 2021

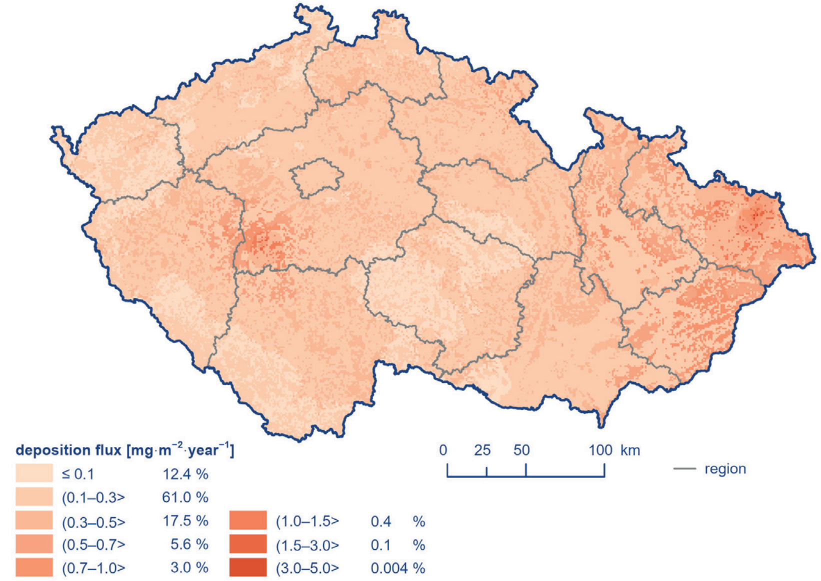

Fig. IX.17 Field of annual dry deposition of lead, 2021

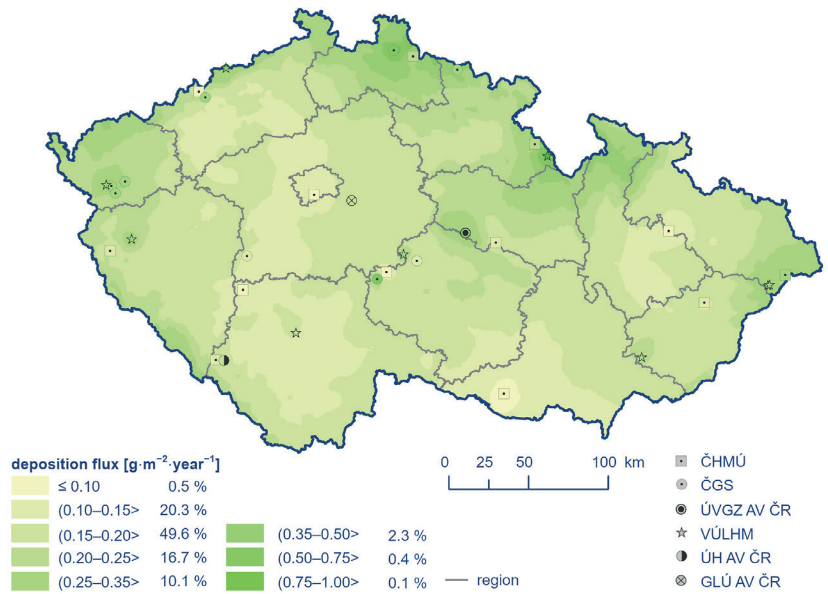

Fig. IX.18 Field of annual wet deposition of chloride ions, 2021

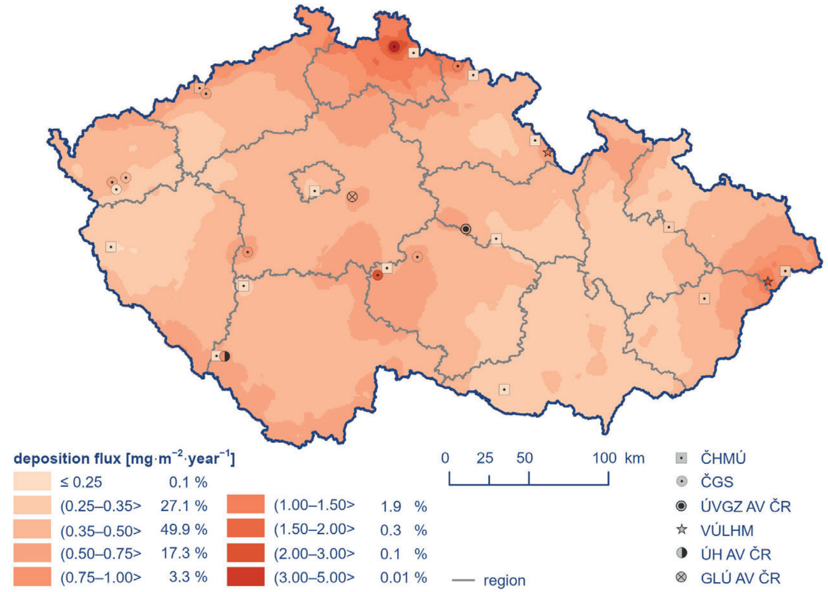

Fig. IX.19 Field of annual wet deposition of nickel ions, 2021

Trends in deposition

Since 2002, a decrease in the total annual sulphur deposition can be observed (Fig. IX.20). In the years 2002–2006, the total deposition was higher than 65 000 t, except for 2003 (51 510 t), the year significantly below normal in terms of precipitation (516 mm, i.e., 77 % of the long-term normal). Since 2015, the total deposition has been below 40 000 t over the area of the CR with constant or slightly decreasing values, corresponding to the level of SO_2 concentration in the ground layer of the atmosphere. In 2021, the lowest value of total annual sulphur deposition was reached in the period from 2002. In comparing the wet and dry components of deposition, the wet component prevailed until 2009, again except for 2003. Since 2010, the dry component has slightly prevailed. The exceptions are the years 2011 and 2021, when the ratio is balanced.

Since 2002, the annual deposition of sulphur on the forested surface of the CR (26 428 km^2), as well as the throughfall deposition of sulphur, have shown a decrease with considerable fluctuations (Tab. IX.3). In 2021, the total deposition on the forested surface of the CR reached the second lowest value since 2002, while the lower deposition was only in 2016. The throughfall deposition of sulphur reached, in 2021, the lowest value since 2002. Until 2016, the values of throughfall deposition are higher than total deposition values, except for 2014, and since 2017, the total deposition has been higher. In the long term, higher values of throughfall deposition are observed especially in some mountainous areas, which can be attributed to the contribution of deposition from fog, low cloud cover and rime frost (horizontal deposition). Total sulphur deposition is calculated as a sum of vertical wet and dry deposition from SO_2, while horizontal wet deposition is not included in the total deposition due to uncertainties.

The total annual deposition of nitrogen in the years 2002–2013 ranged from 40 000 to 50 000 t (Fig. IX.21). A slight decrease can be observed since 2012, with occasional fluctuations in 2017 and 2021. The value of total annual nitrogen deposition in 2021 was the third lowest since 2002, with lower values recorded in 2019 and 2020, corresponding to NO_X concentrations. Until 2010, the wet component of oxidized forms of nitrogen prevailed. Since 2011, the dry component has slightly prevailed, except for 2013 and 2016 with both components balanced. Since 2017, the wet component of deposition has again prevailed, but only very slightly.

Together with the variation of deposition of nitrogen and sulphur (Hůnová et al. 2014), variation can be seen in the mutual ratio of these two elements in atmospheric precipitation, related to trends in emissions of particular compounds. A slight, although not steady, increase in the ratio of nitrates to sulphates could have been observed at selected CHMI stations (wet-only) since 2000 (Hůnová et al., 2017). In 2002 and 2003, sulphates dominated

Table IX.3 Estimate of the total annual deposition of sulphur on the forested part of the Czech Republic (26 428 sq. km) in tonnes, 2001–2021

	deposition [t]	
	total	**troughfall**
2001	27 894	36 899
2002	25 984	31 011
2003	21 306	26 818
2004	23 247	32 835
2005	22 855	26 461
2006	21 975	25 660
2007	17 445	29 279
2008	15 528	30 197
2009	16 590	26 193
2010	17 621	27 944
2011	15 118	18 691
2012	15 311	19 079
2013	16 530	19 723
2014	16 810	12 836
2015	13 294	16 044
2016	12 625	19 724
2017	14 621	12 608
2018	14 870	14 002
2019	13 133	10 707
2020	13 057	7 492
2021	12 757	7 174

atmospheric precipitation. Until 2011, the ratio was quite even, except for 2009, and since 2012 nitrates have clearly predominated. In 2021, the second highest value of the ratio (1.46) was reached since 2002, while the highest value (1.58) occurred in 2017 (Fig. IX.22).

The total deposition of hydrogen ions has been ranging between 2 500 and 5 000 t since 2012. Since 2013, a decreasing trend of the deposition is evident, with the second lowest value recorded in 2021, after 2020. The dry component significantly dominates the deposition of hydrogen ions, while the proportion of the wet component has been decreasing since 2007 (Fig. IX.23).

The total deposition of cadmium ions has been ranging from 6 to 12 t since 2013, except for 2011. There is a noticeable decrease in deposition from 2014, followed again by an increase from 2019. In 2021, the fifth lowest value of total deposition was reached, with the lowest value recorded in 2018. The wet component predominates in the deposition of cadmium ions, with a ratio of about 70:10. The only exception is 2018, when both components had equal proportion (Fig. IX.24).

The total deposition of lead ions ranged between 150 and 200 t until 2006. Since 2007, a slight decrease in deposition is noticeable with deviations in 2012 and 2015. In 2021, the third lowest annual value since 2002 was reached, with lower values occurring in 2019 and 2020 only. As with the deposition of cadmium ions, the wet component prevails in a ratio of approx. 70:10. The exception is 2012, when the proportion of both components is similar (Fig. IX.25).

Trends in wet deposition at selected CHMI stations

For the assessment of wet deposition, five CHMI stations were selected, with “wet-only” sampling. These are the Praha-Libuš, Svratouch, Košetice, Souš, and Přimda stations. Wet deposition is largely affected by meteorological and climatic conditions and emission sources, therefore deposition values are highly variable from year to year. When evaluating the aforementioned stations, it can be observed that the highest wet deposition values are reached at the Souš station, while the lowest at the Košetice station.

Since 2002, a decrease in wet deposition of sulphate ions (SO_4^{2-}) has been observed, with deviations depending on meteorological conditions. Compared to 2020, the Souš and Svratouch stations show a significant increase in 2021, while the Košetice and Přimda stations show a decrease. The deposition at the Praha-Libuš station remains the same (Fig. IX.26). As with the deposition of SO_4^{2-}, a decrease with significant fluctuations is observed for the deposition of nitrate ions (NO_3^-). Compared to 2020, the Souš, Přimda and Praha-Libuš stations show an increase in 2021, while the Košetice station, on the contrary, shows a decrease. Deposition at the Svratouch station remains the same (Fig. IX.27). The trend of the deposition of ammonium ions (NH_4^+) in the years 2002–2021 is highly variable depending on meteorological conditions and the amount of emission sources. Compared to 2020, the deposition at the Souš station in 2021 remains at the same level, while it decreases slightly at the other stations, except for the Košetice station, where the decrease is significant (Fig. IX.28). The development of hydrogen ion deposition is highly variable, however, a decreasing trend can be identified, particularly at the Souš station. Compared to 2020, the Souš and Přimda stations showed an increase in 2021, while the values at the Praha-Libuš, Svratouch, and Košetice stations decreased (Fig. IX.29).

The deposition of cadmium ions decreased until 2013, and then stagnated at values below 0.2 $mg \cdot m^{-2}$ from 2014. The higher cadmium deposition at the Souš station corresponds to the long-term high pollution burden of this area. Compared to 2020, deposition values are comparable in 2021, except for the Přimda station, where there is a slight increase, and the Souš station, where, on the contrary, there is a decrease (Fig. IX.30). In 2016, the lead ion deposition values showed a significant increase in wet deposition at all stations, up to a value of 7 $mg \cdot m^{-2}$ at the Souš and Svratouch stations. Since 2014, deposition values have stagnated below 1 $mg \cdot m^{-2}$. Compared to 2020, deposition values in 2021 are comparable at the Praha-Libuš and Souš stations, lower at the Svratouch station and, conversely, higher at the Košetice and Přimda stations (Fig. IX.31).

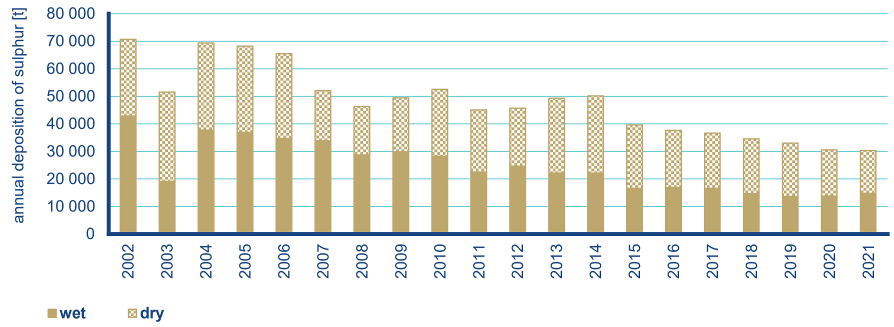

Fig. IX.20 Annual deposition of sulphur (S_SO$_4^{2-}$, S_SO$_2$) on the area of the Czech Republic, 2002–2021

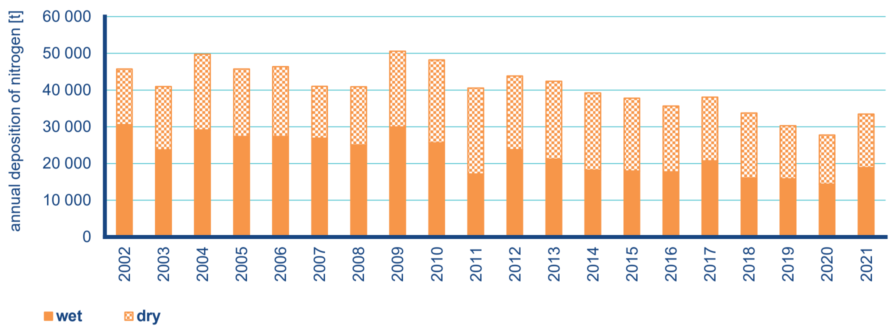

Fig. IX.21 Annual deposition of oxidized forms of nitrogen (N_NO$_3^-$, N_NO$_x$) on the area of the Czech Republic, 2002–2021

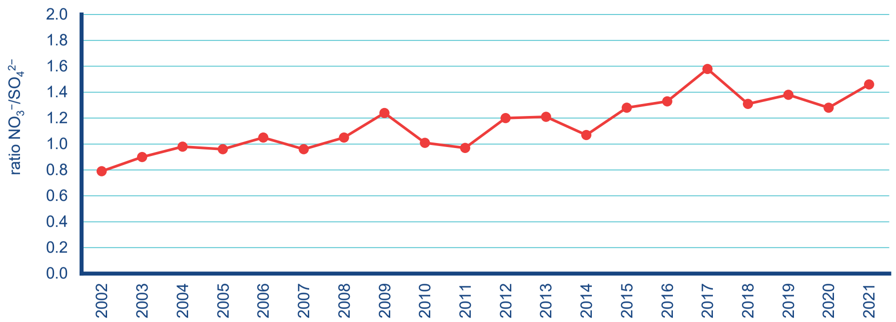

Fig. IX.22 Ratio of nitrate to sulphate concentrations in atmospheric deposition (expressed as μeq·l^{-1}) at the CHMI localities, 2002–2021

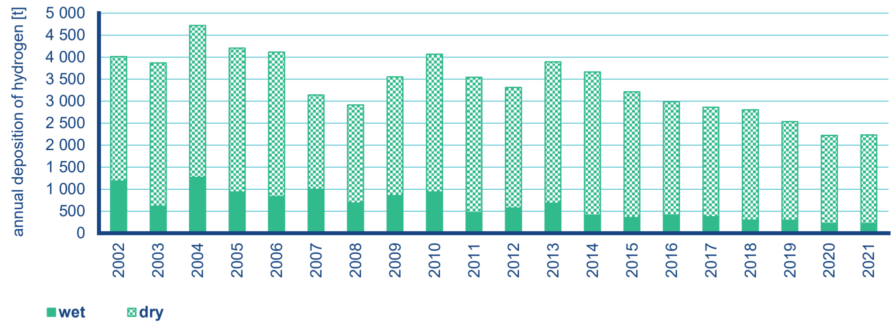

Fig. IX.23 Annual deposition of H$^+$ on the area of the Czech Republic, 2002–2021

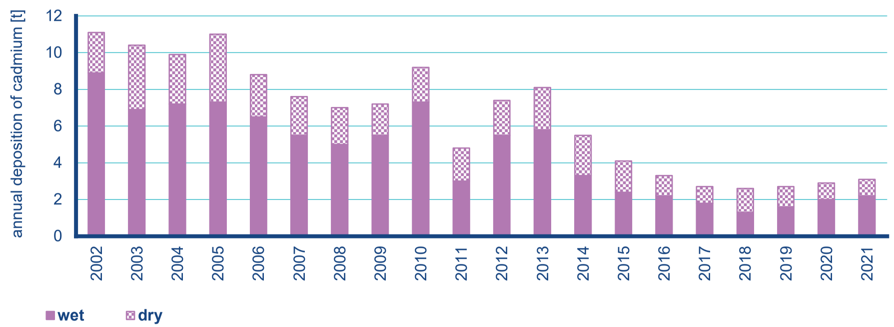

Fig. IX.24 Annual deposition of Cd^{2+} on the area of the Czech Republic, 2002–2021

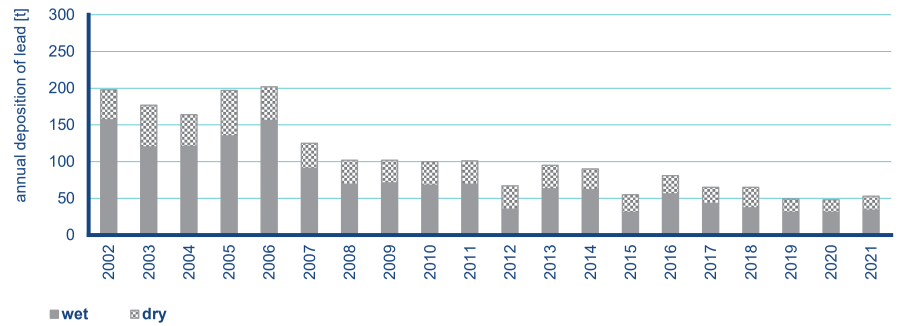

Fig. IX.25 Annual deposition of Pb^{2+} on the area of the Czech Republic, 2002–2021

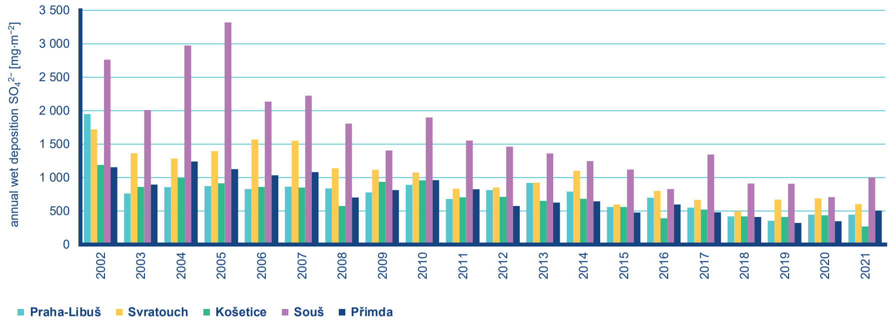

Fig. IX.26 Annual wet deposition of SO_4^{2-} at selected stations, 2002–2021

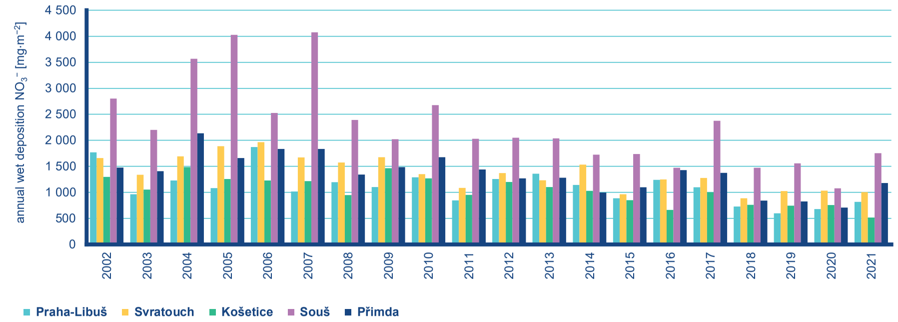

Fig. IX.27 Annual wet deposition of NO_3^- at selected stations, 2002–2021

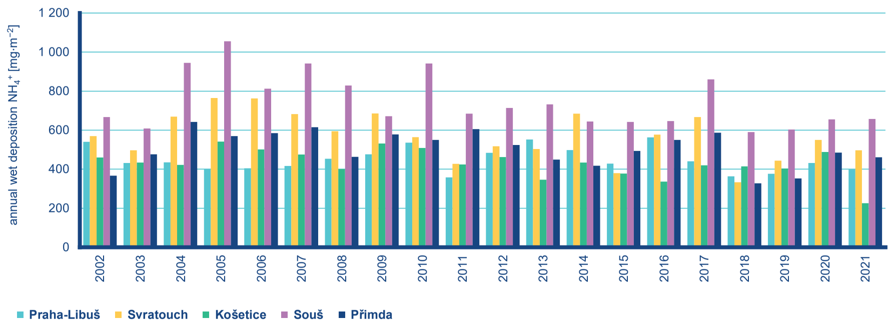

Fig. IX.28 Annual wet deposition of NH_4^+ at selected stations, 2002–2021

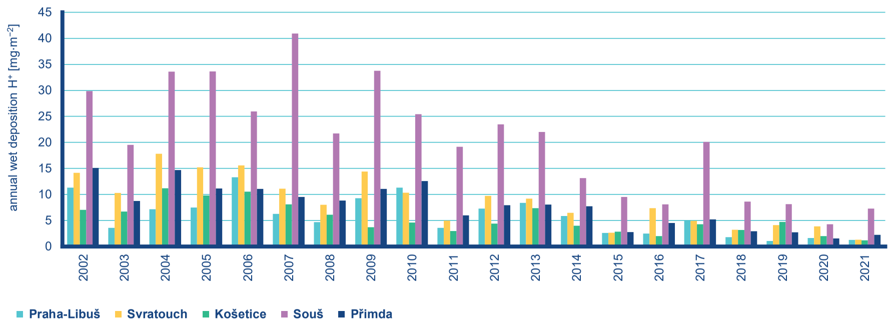

Fig. IX.29 Annual wet deposition of H^+ at selected stations, 2002–2021

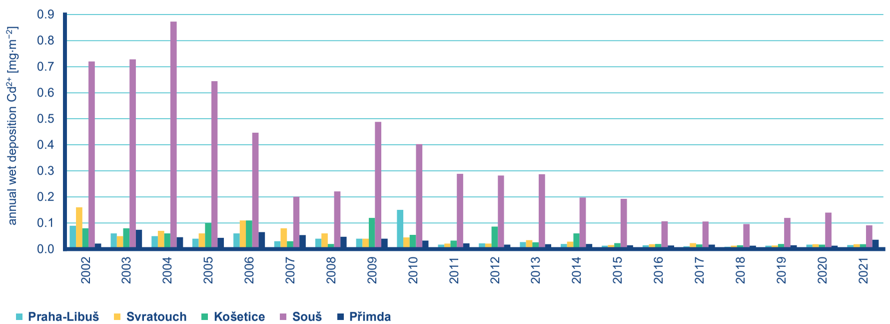

Fig. IX.30 Annual wet deposition of Cd^{2+} at selected stations, 2002–2021

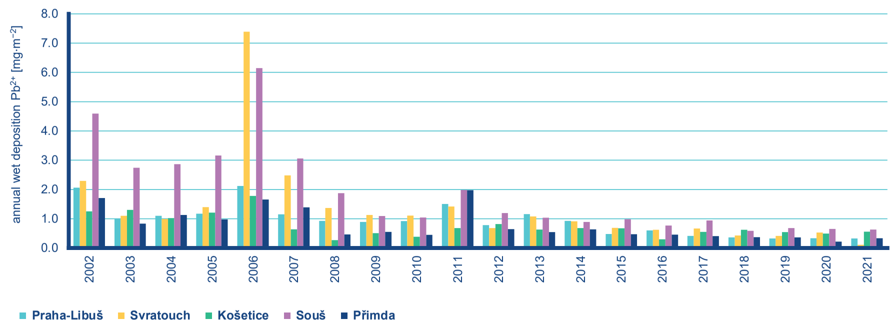

Fig. IX.31 Annual wet deposition of Pb^{2+} at selected stations, 2002–2021