AIR POLLUTION IN THE SLOVAK REPUBLIC 2023

ANNEX

AIR QUALITY ASSESSMENT IN AGGLOMERATION BRATISLAVA AND ZONE BRATISLAVA REGION

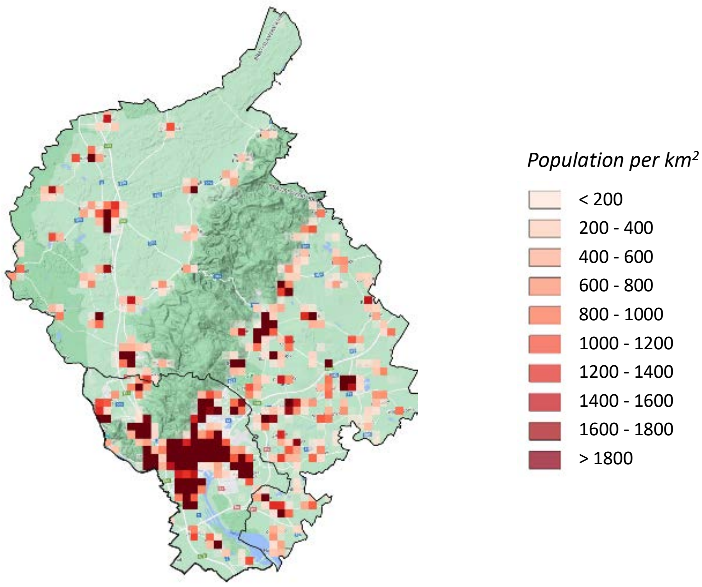
Emissions and Air Quality Division
SLOVAK HYDROMETEOROLOGICAL INSTITUTE

Bratislava, September 2024
Version 1

1 DESCRIPTION OF TERRITORY OF AGGLOMERATION BRATISLAVA AND ZONE BRATISLAVA REGION IN TERMS OF AIR QUALITY

For the purpose of air quality assessment, the territory of Slovakia is divided into zones and agglomerations (*https://www.shmu.sk/sk/?page=1&id=oko_info_az*). The territory of the Bratislava NUTS-3 region includes agglomeration Bratislava (the territory of the capital city of the Slovak Republic Bratislava) and the zone Bratislava region (the Bratislava NUTS-3 region without agglomeration Bratislava). **Fig. 1.1** shows population density in the Bratislava region.

Fig. 1.1 *Population density in the zone Bratislava region (Source: EUROSTAT, 2018).*



1.1 AGGLOMERATION BRATISLAVA (territory of the capital city of the Slovak Republic Bratislava)

Bratislava is located in a rugged terrain with altitudes ranging from 126 m (Čunovo) to 514 m (Devínska Kobyla). From southwest to northeast stretches the Little Carpathians Mountains, the western part of Bratislava lies on the Záhorie lowland, the eastern and southeastern part is occupied by the Danubian Lowland.

In the area of the Devín Gate, which separates the Hainburg Hills and the part of the Devín Carpathians, and in the area of the Lamač Gate between the Devin Carpathians and the Pezinok Carpathians, there is an orographic increase in wind speed, which has a positive effect on the ventilation of the city. The Danube River flows through Bratislava and is used for shipping.

Air pollution sources in agglomeration Bratislava

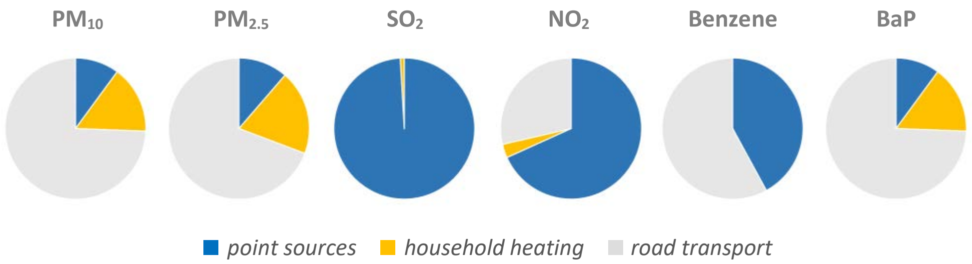
Road transport is the dominant source of air pollution in the capital. The most frequented parts of roads in Bratislava with the average number of vehicles per 24 hours based on the latest National Traffic Census in 2022 and 2023[1]:

- **D1 motorway** – south-eastern bypass of the city (Bratislava II district): 101 407 vehicles (18 284 truck/ buses (hereinafter referred to as T/B) a 82 817 cars (hereinafter referred to as C)) and in Petržalka near Incheba 74 008 vehicles (15 154 T/B, 58 639 C);
- **D2 motorway** in Petržalka behind the bridge Lafranconi: 94 387 vehicles (15 688 T/B, 78 320 C);
- **D4 motorway** southern bypass below Petržalka: 20 127 vehicles (3 533 T/B, 16 533 C);

[1] *https://www.ssc.sk/sk/cinnosti/rozvoj-cestnej-siete/dopravne-inzinierstvo/celostatne-scitanie-dopravy-v-roku-2022-a-2023.ssc*

- **road No. 2** (arrival to the city from Záhorie in front of Patrónka): 40 395 vehicles (3 694 T/B, 36 293 C);
- **road No. 61** (Bajkalská str.): 51 683 vehicles (3 382 T/B, 47 970 C);
- **road No. 572** (Šancova str. below the railway station): 34 466 vehicles (3 444 T/B, 30 744 C);
- **R7 high speed road** leading from the harbour to the south (Bratislava II district): 42 722 vehicles (5 098 T/B, 37 487 C);
- **road No. 502** (Račianska str.): 26 074 vehicles (1 512 T/B, 24 165 C);
- **road No. 63** (Bratislava II district): vehicles (1 784 T/B, 16 650 C).

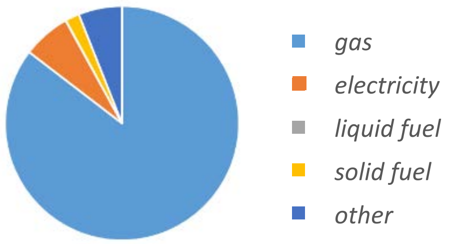
Fig. 1.2 *Share of different types of air pollution sources in total emissions in agglomeration Bratislava.*



Note: Medium and large air pollution sources registered in the NEIS database are identified for this purpose as "point sources".

Industrial sources of air pollution are less important here in terms of their contribution to local air pollution from basic pollutants. Emissions of sulphur oxides are formed almost exclusively by an industrial source – the refinery, but their values have decreased significantly over the last decades and the limit values for SO_2 concentrations in the air are not currently exceeded, as for other basic pollutants except NO_2, which, according to air quality measurements, exceeded the limit value at the AMS Trnavské mýto in 2018. The share of different types of sources in emissions in the agglomeration Bratislava is shown in **Fig. 1.2**.

Fig. 1.3 *Share of different types of fuel used for heating in family houses [2].*



According to the Population and Housing Census (PHC) 2021 data, natural gas is mainly used for heating of family houses in the agglomeration Bratislava, the share of solid fuels is the lowest compared to the other zones (this is probably mainly about fireside heating in the transitional seasons).

1.2 ZONE BRATISLAVA REGION (without agglomeration Bratislava)

The zone Bratislava region covers the area of the Bratislava NUTS-3 region without agglomeration Bratislava. The Bratislava NUTS-3 region is the smallest NUTS-3 region in Slovakia in terms of area. It includes the southern part of the Little Carpathians, the Záhorie region and the greater part of the Danubian Lowland. The surface is mostly flat. The altitude of the territory ranges from 126 m a. s. l. to 754 m a. s. l. (Vysoká Mount). The most populous towns are the district towns of Pezinok, Senec and Malacky. The average population density in the Malacky district is significantly lower than in other districts.

[2] *https://www.scitanie.sk*

Air pollution sources in zone Bratislava region

The significant source of air pollution in the zone is road transport, which concentrates mostly on motorway routes. The busiest road sections in the county with the average number of vehicles in each county per 24 hours based on the latest National Traffic Census in 2022 and 2023[1]:

Malacky district

- **D2 motorway** in the vicinity of Malacky: 32 452 vehicles (13 002 T/B, 19 350 C);
- **D4 motorway** from Volkswagen to **D2 motorway** (12 267 vehicles, 1 042 T/B, 11 173 C) and **road No. 2** to Stupava (on Stupava 16 254 vehicles, 1 585 T/B, 14 548 C);
- **road No. 503** in Malacky: 16 420 vehicles (1 345 T/B, 14 997 C) and **road No. 2:** 17 772 vehicles (1 537 T/B, 16 148 B) in the centre of Malacky;
- **road No. 2** from Malacky to Veľké Leváre: 9 378 vehicles (958 T/B, 8 331 C).

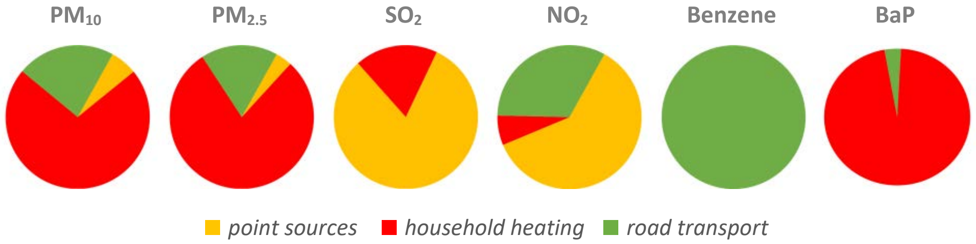
Senec district

- **D1 motorway**: 59 067 vehicles (8 968 T/B, 49 958 T/B); **R7 high speed road**: 21 236 vehicles (2 883 T/B, 18 286 C); **road No**. **503**: 19 126 vehicles (2 760 T/B, 16 247 C); **road No. 62**: 15 556 vehicles (3 137 T/B, 12 323 C); **road No 63**: 14 904 vehicles (1 456 T/B, 13 273 C); **road No. 61** in Senec: 18 365 vehicles (1 569 T/B, 16 648 C).

Pezinok district

- **road No. 502** in the vicinity of Svätý Jur: 19 439 vehicles (1 727 T/B, 17 428 C) in Pezinok: 18 776 vehicles (1 716 T/B, 16 889 C).

Fig. 1.4 *Share of different types of air pollution sources in total emissions in the zone Bratislava region.*

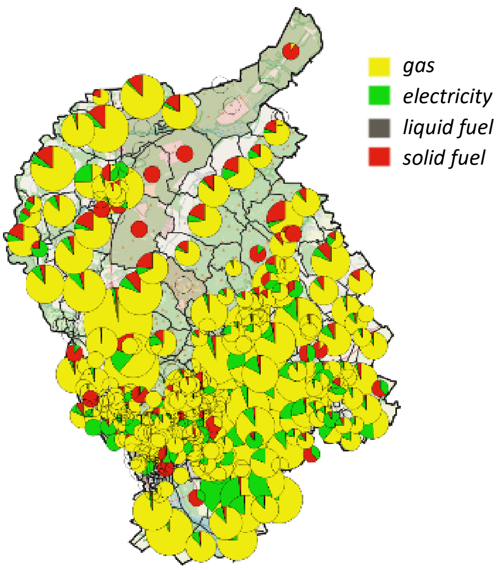


Note: Medium and large air pollution sources registered in the NEIS database are identified for this purpose as "point sources".

Industrial sources of air pollution, with the exception of cement factories (their contribution may be manifested mainly in the coarse size fraction of dust particles), are less significant in terms of their contribution to local air pollution by basic pollutants.

Fig. 1.5 shows the shares of fuel types in the heating of family houses and flats in individual municipalities (or basic settlement units) of the Bratislava region, while it can be seen that the spatial distribution of fuel types is not geographically homogeneous. However, in the total for the whole region in 2021, gas heating prevailed.[3]

Fig. 1.5 *Share of different types of fuel used for heating in the municipalities of the region.*



[3] *https://www.scitanie.sk/*

2 AIR QUALITY MONITORING STATIONS IN AGGLOMERATION BRATISLAVA AND ZONE BRATISLAVA REGION

Tab. 2.1 and **Tab. 2.3** contains information on air quality monitoring stations in agglomeration Bratislava and in the zone Bratislava region:

- international EoI code, station characteristics according to dominant sources of air pollution (traffic, background, industrial), type of monitored area (urban, suburban, rural/regional) and geographical coordinates;
- monitoring programme. Continuous monitoring instruments provide hourly average concentrations of PM_{10}, $PM_{2.5}$, nitrogen oxides, sulphur dioxide, ozone, carbon monoxide and benzene. The SHMÚ test laboratory analyses heavy metals and polycyclic aromatic hydrocarbons as part of manual monitoring, resulting in 24-hour average values.

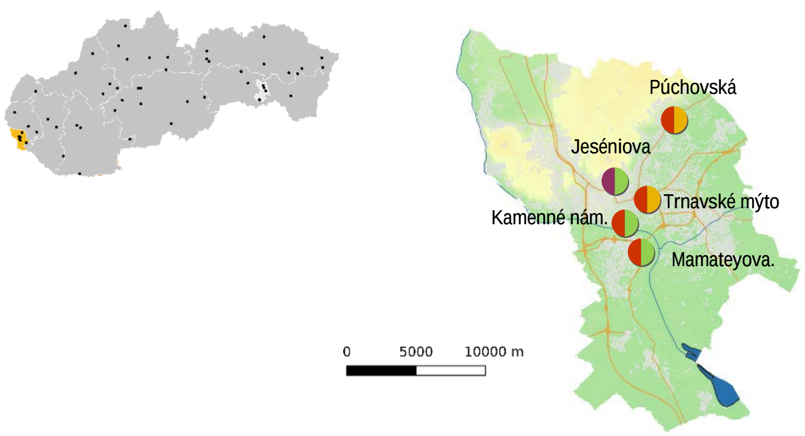
2.1 AGGLOMERATION BRATISLAVA

In agglomeration Bratislava, air quality is monitored at 5 stations. The traffic stations are located at Trnavské mýto, a location with high traffic intensity and a concentration of pedestrians in the city, another station is located in Rača on Púchovská Street.

The residential area is represented by the urban background station in Petržalka on Mamateyova street, additional monitoring stations are located in the residential area in Koliba, Jeséniova (monitors background levels of pollution in the suburban area) and in the centre of the town on Kamenné square (monitors urban background).

Tab. 2.1 Air quality monitoring programme in agglomeration Bratislava.

Agglomeration Bratislava								Monitoring programme									
								Continuously								Manually	
District	Code EoI	Station	Type of area	Type of station	Geographical longitude	Geographical latitude	Altitude [m]	PM_{10}	$PM_{2.5}$	NO, NO_2	SO_2	O_3	CO	Benzene	Hg	As, Cd, Ni, Pb	BaP
Bratislava I	SK0004A	Bratislava, Kamenné nám.	U	B	17°06'49"	48°08'41"	139	■	■								
Bratislava III	SK0002A	Bratislava, Trnavské mýto	U	T	17°07'44"	48°09'30"	136	■	■	■			■	■		■	■
Bratislava III	SK0048A	Bratislava, Jeséniova	S	B	17°06'22"	48°10'05"	287	■	■	■	■	■					■
Bratislava V	SK0001A	Bratislava, Mamateyova	U	B	17°07'31"	48°07'29"	138	■	■	■	■	■					
Bratislava III	SK0061A	Bratislava, Púchovská	U	T	17°09'29"	48°12'41"	145	■	■	■	■		■	■			■
							Total	5	5	4	3	2	2	2	0	1	3



Type of area
U – urban
S – suburban
R – regional

Type of station
T – traffic
B – background
I – industrial

In addition to air quality monitoring, precipitation quality is also analysed at the suburban background monitoring station Bratislava, Jeséniova. The monitoring programme is given in **Tab. 2.2**, the sampling period and sampling interval was two weeks.

Tab. 2.2 *Precipitation monitoring programme at monitoring station Bratislava, Jeséniova.*

	pH	Conductivity	Sulphates (SO_4^{2-})	Nitrates (NO_3^-)	Chlorides (Cl^-)	Ammonium ions ($NH4^+$)	Alkaline ions (K^+, Na^+, Ca^{2+}, Mg^{2+})	Lead (Pb)	Arsenic (As)	Cadmium (Cd)	Nickel (Ni)	Chromium (Cr)	Copper (Cu)	Zinc (Zn)
Bratislava, Jeséniova	x	x	x	x	x	x	x	x	x	x	x	x	x	x

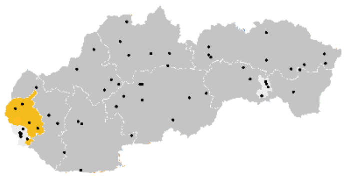
2.2 ZONE BRATISLAVA REGION

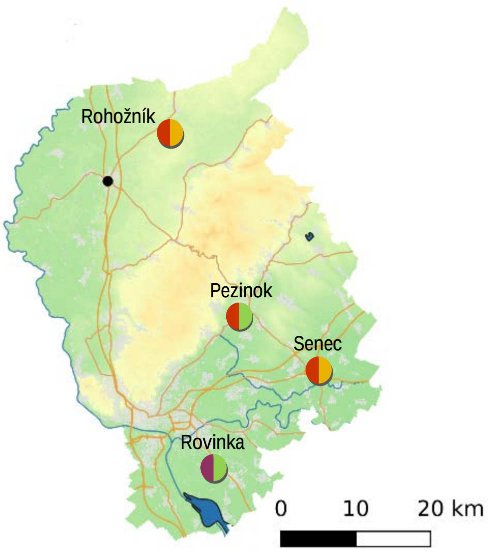
Air quality in the zone Bratislava region is monitored at four NMSKO stations, stations monitoring the impact of traffic are located in Rohožník and Senec. Both stations in the mentioned district towns are located at intersections with intensive traffic and high pedestrian traffic.

Air pollution in residential zones outside the main traffic routes is monitored by stations in the district town of Pezinok and in the village of Rovinka. Air quality monitoring in this village is also carried out due to the proximity of the Slovnaft refinery.

Tab. 2.3 Air quality monitoring programme in the zone Bratislava region.

Zone Bratislava region								Monitoring programme									
								Continuously								Manually	
District	Code EoI	Station	Type of area	Type of station	Geographical longitude	Geographical latitude	Altitude [m]	PM_{10}	$PM_{2.5}$	NO, NO_2	SO_2	O_3	CO	Benzene	Hg	As, Cd, Ni, Pb	BaP
Pezinok	SK0075A	Pezinok, Obrancov mieru.	U	B	17°15'35"	48°17'00"	150										
Rohožník	SK0077A	Rohožník, Senická cesta	U	T	17°10'17"	48°27'25"	201										
Rovinka	SK0076A	Rovinka, mobilná stanica	S	B	17°13'50"	48°05'59"	129										
Senec	SK0068A	Senec, Boldocká	U	T	17°24'16"	48°13'23"	126										
							Total	4	3	4	2	2	3	2	0	0	1





Type of area
U – urban
S – suburban
R – regional

Type of station
T – traffic
B – background
I – industrial

3 ASSESSMENT OF AIR QUALITY IN AGGLOMERATION BRATISLAVA AND ZONE BRATISLAVA REGION

This chapter contains an assessment of air quality in agglomeration Bratislava and the zone Bratislava region based on monitoring in 2023.

Tab. 3.1 *Assessment of air pollution according to limit values for protection of human health and numbers of alert threshold exceedances in the agglomeration Bratislava and the zone Bratislava region – 2023.*

AGGLOMERATION Zone		Protection of human health									IT [2]	AT [2]
	Pollutant	SO_2		NO_2		PM_{10}		$PM_{2.5}$	CO	Benzene	PM_{10}	PM_{10}
	Averaging period	1 h	24 h	1 h	1 rok	24 h	1 rok	1 rok	8 h [1]	1 rok	12 h	12 h
	Parameter	number of exceedances	number of exceedances	number of exceedances	average	number of exceedances	average	average	average	average	number of exceedances [h]	number of exceedances [h]
	Limit value [µg·m⁻³]	350	125	200	40	50	40	20	10 000	5	100	150
	Maximum number of exceedances	24	3	18		35						
BRATISLAVA	Bratislava, Kamenné nám.					0	17	11			0	0
	Bratislava, Trnavské mýto			0	30	7	21	13	1 035	0.32	0	0
	Bratislava, Jeséniova	0	0	0	8	0	15	11			0	0
	Bratislava, Mamateyova	0	0	0	16	0	14	10			0	0
	Bratislava, Púchovská	0	0	0	13	3	18	10	742	0.38	0	0
Bratislava region	Pezinok, Obrancov mieru			0	9	0	14	10			0	0
	Rohožník, Senická	0	0	0	12	3	18	12	1 383	0.59	0	0
	Rovinka	0	0	0	12	1	16		718	0.68	11	0
	Senec, Boldocká			0	19	5	20	13	1 539		22	6

≥ 90% of valid measurements

[1] *eight-hour maximum concentration*

[2] *IT, AT - duration of exceedance (in hours) of the information threshold (IT) and alert threshold (AT) for PM_{10}*

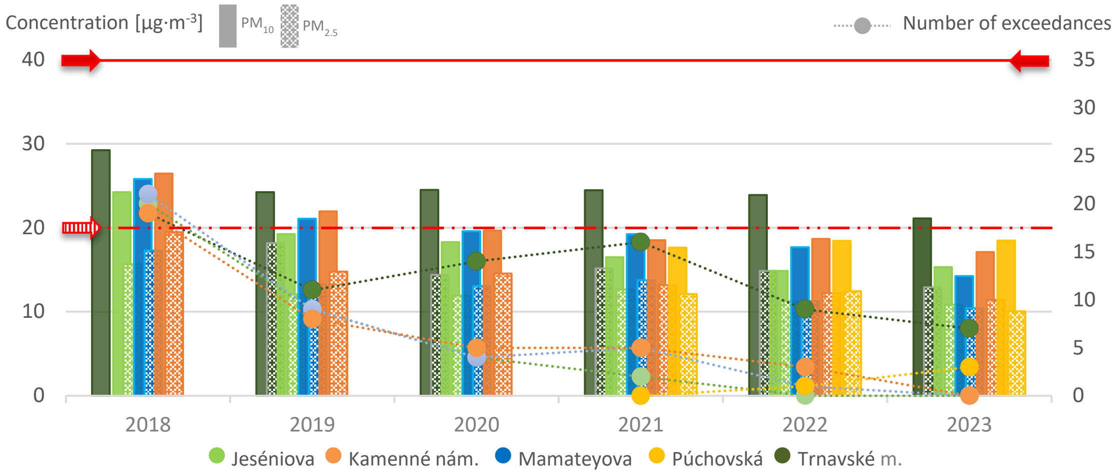
In accordance with the Decree of the Ministry of Environment of the Slovak Republic No. 250/2023 Coll. on air quality, the required proportion of valid values was observed at the monitoring stations in the Bratislava agglomeration and in the Bratislava region zone.

3.1 AGGLOMERATION BRATISLAVA

3.1.1 PM_{10} and $PM_{2.5}$

Fig. 3.1 shows the average annual concentrations of PM_{10}, $PM_{2.5}$ and the number of days with an average daily concentration of PM_{10} above 50 µg·m^{-3} according to the results of measurements at monitoring stations in Bratislava agglomeration in the years 2018 – 2023.

Fig. 3.1 Average annual concentrations of PM_{10}, $PM_{2.5}$ and the number of exceedances of the daily limit value for PM_{10}.

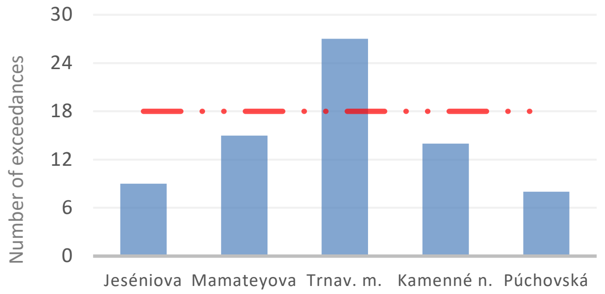


*The arrows show the limit values, **red striped** $PM_{2.5}$ (annual average concentration: 20 µg·m^{-3}); **red on the left** PM_{10} (annual average concentration: 40 µg·m^{-3}) and **red on the right** the number of exceedances (daily average PM_{10} concentration of 50 µg·m^{-3} must not be exceeded more than 35 times in a calendar year).*

The limit value for the average annual concentration of PM_{10} (40 µg·m^{-3}) and $PM_{2.5}$ (20 µg·m^{-3}) in the Bratislava agglomeration was not exceeded at any of the monitoring stations. As expected, the highest annual average concentration of PM_{10} in Bratislava (21 µg·m^{-3}) was recorded at the Trnavské Mýto traffic station, which is the lowest value measured at this station. It should be noted that in previous years PM_{10} concentrations at this station were negatively affected by demolition works on the Istropolis building. At the Púchovská traffic station, the average annual concentration was, as in 2022, 18 µg·m^{-3}. The level of PM_{10} pollution in urban background locations was lower in 2023 compared to previous years. No station exceeded the limit value for the number of exceedances (35) of the average daily concentration of PM_{10} (50 µg·m^{-3}) (**Fig. 3.1**). No exceedances of the daily limit were recorded at the Bratislava background stations and the WHO[4] recommendation (maximum 3 – 4 exceedances) was also met this year at all monitoring stations except Trnavské mýto.

As part of the European Green Deal, the European Union has developed the Zero Pollution Action Plan[5], which sets out a vision

Fig. 3.2 Number of days with average daily $PM_{2.5}$ concentration > 25 µg·m^{-3} in 2023 – evaluation in view of the newly introduced EU limit.*



** The average daily concentration of $PM_{2.5}$ > 25 µg·m^{-3} must not be exceeded more than 18 times a year. This newly introduced EU limit is to be achieved by 1 January 2030.*

[4] *WHO GLOBAL AIR QUALITY GUIDELINES, 2021. Recommendations on classical air pollutants, p. 4. https://apps.who.int/iris/bitstream/handle/10665/345334/9789240034433-eng.pdf*

[5] *https://www.consilium.europa.eu/en/press/press-releases/2024/02/20/air-quality-council-and-parliament-strike-deal-to-strengthen-standards-in-the-eu/*

for 2050. Its aim is to reduce air pollution to a level that is no longer considered harmful to health and natural ecosystems by that year. The action plan includes new EU limit and target values for many pollutants, the biggest challenge for Slovakia will be to meet the new limit values for $PM_{2.5}$. The plan for $PM_{2.5}$ introduces a daily limit value of 25 $\mu g \cdot m^{-3}$, which must not be exceeded more than 18 times per year (to be achieved by 1 January 2030). **Fig. 3.2** illustrates how many exceedances of the new EU daily limit for $PM_{2.5}$ would be achieved in 2023. In the Bratislava agglomeration, only the traffic AMS Trnavské mýto would exceed the new EU limit value. The new EU annual limit value for the annual average concentration of $PM_{2.5}$ (**Fig. 3.1**) is set at 10 $\mu g \cdot m^{-3}$. In 2023, only two stations – Mamateyova and Puchovská – would meet it. AMS Jeséniova and Kamenné námestie reached the value of 11 $\mu g \cdot m^{-3}$, which is very close to the target set for 2030. This suggests that these two stations also have a good potential to achieve it in the near future, if further measures are taken to improve air quality for the site.

Fig. 3.3 captures meteorological conditions in Bratislava in 2023, which significantly affect the concentrations of air pollutants. The coldest winter months were February and December, the least precipitation was recorded in March and very low monthly precipitation was also observed in February, June, July and September. In Bratislava, monthly PM concentrations do not have the pronounced seasonal pattern observed in other zones of Slovakia. This is mainly due to the fact that the prevalence of heating with solid fuels is low in Bratislava. Nevertheless, in February and December we recorded the highest monthly concentrations of PM_{10} and $PM_{2.5}$ at background stations, albeit with very insignificant local maxima. We can assume that during this period, people in family housing areas were also heating with fireplaces, which contributed to higher concentrations of PM_{10} and $PM_{2.5}$ in these months. Only slightly lower concentrations of PM_{10} and $PM_{2.5}$ were recorded in March when the monthly rainfall was only 10.5 mm, which may have contributed significantly to the resuspension of airborne dust.

Fig. 3.3 *Monthly precipitation totals, average and minimum temperatures (data from the climatological station BA Mlynská dolina).*

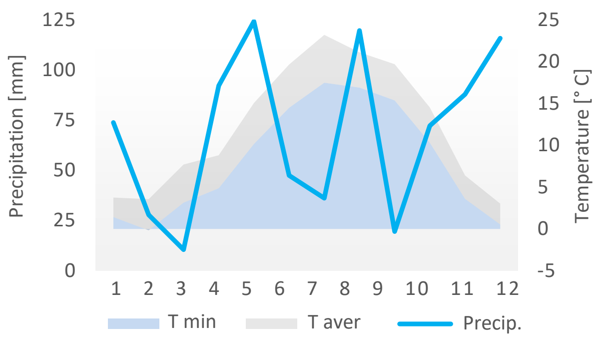
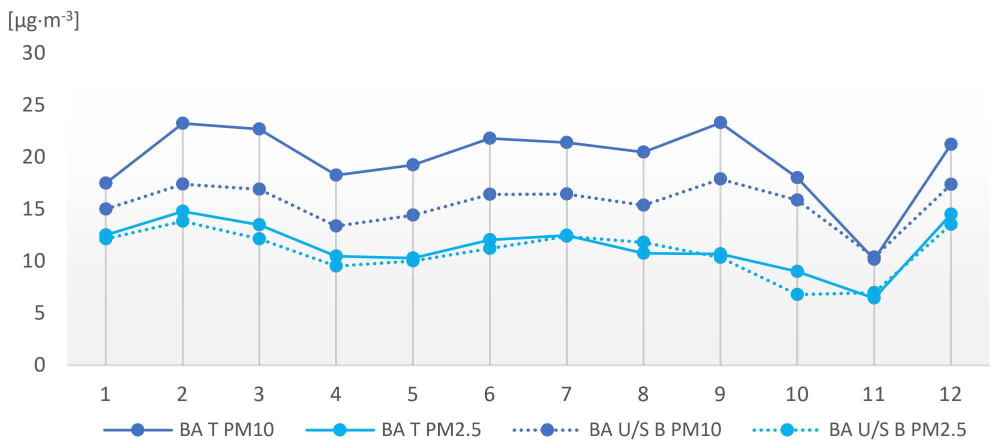


Fig. 3.4 *Average monthly concentrations of PM_{10} and $PM_{2.5}$ in agglomeration Bratislava by station type.*



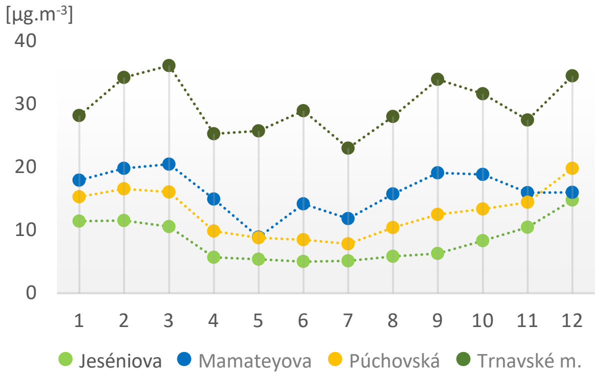
T PM10 *and* ***T PM2.5*** *– average monthly concentration of PM_{10} a $PM_{2.5}$ at the urban traffic station Trnavské mýto and Púchovská;* ***U/S B PM10*** *and* ***U/S B PM2.5*** *– average monthly concentration of PM_{10} and $PM_{2.5}$ at the urban/suburban background stations Jeséniova, Kamenné námestie and Mamateyova.*

3.1.2 Nitrogen dioxide

Nitrogen dioxide monitoring is carried out at four stations in agglomeration Bratislava, the average monthly values for each station are shown in **Fig. 3.5**.

The main source of NO_2 emissions is road traffic. At the Trnavské mýto traffic station, the second highest annual average NO_2 concentration in Slovakia (30 $\mu g \cdot m^{-3}$) was again measured in 2023, which is a consequence of the high intensity of traffic in this location. However, the limit value (40 $\mu g \cdot m^{-3}$) was not exceeded here. In other locations in Bratislava, the level of NO_2 pollution is at a much lower level, as illustrated in **Fig. 3.5**. The monthly NO_2 concentrations at the Púchovská traffic station are at a lower level than at the Mamateyova station, which is classified as a background station. The station on Jeséniova Street (the average annual NO_2 concentration here reached 8 $\mu g \cdot m^{-3}$) is the only one in Bratislava that met the WHO recommendations (10 $\mu g \cdot m^{-3}$). All background stations and the Púchovská traffic station would meet the new EU limit value (20 $\mu g \cdot m^{-3}$), valid from 2030.

Fig. 3.5 *Average monthly NO_2 concentrations in 2023.*

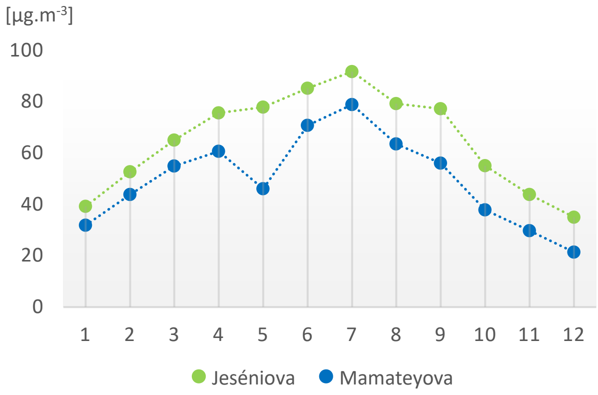


3.1.3 Ozone

Ozone monitoring is carried out in the capital at two monitoring stations, Mamateyova and Jeséniova. The latter is located at a higher altitude in Koliba, at the foothills of the Little Carphatians. Higher concentrations are measured at this station than at Mamateyova street in Petržalka.

The highest concentrations of ground-level ozone generally occur in warm months with high sunshine intensity (**Fig. 3.6**). Large differences in ground-level ozone concentrations are also observed in warm and cold seasons. The number of days with exceedances of the ground-level ozone target value is shown in **Tab. 3.2**.

Fig. 3.6 *Average monthly O_3 concentrations in 2023.*



Tab. 3.2 *Number of days with exceedances of the ground-level ozone target value for the protection of human health.*

Station	2021	2022	2023	Average 2021 – 2023
Bratislava, Jeséniova	23	37	23	28
Bratislava, Mamateyova	15	25	18	19

≥ 90% requested valid data *Exceedance of the target value is marked in red.*

Note: The target value for the protection of human health for ground-level ozone is set by Regulation of MoE SR No. 250/ 2023 Coll. on air quality: "The highest daily 8-hour mean concentration shall not exceed 120 $\mu g \cdot m^{-3}$ for more than 25 days per calendar year on average for three years".

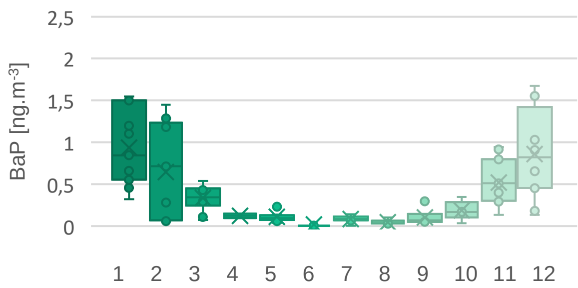
Ground-level O_3 is formed in the atmosphere in the presence of solar (UV-B) radiation by the chemical reaction of nitrogen oxides (NO, NO_2) and volatile organic compounds or carbon monoxide. The source of nitrogen oxides are combustion processes, in urban agglomeration conditions mainly road traffic, in the case of Bratislava also refinery. Road traffic is also a source of emissions of volatile organic compounds, but also industrial sources and, in the warm half of the year, vegetation is an important source. However, ground-level O_3 is also decomposed by reaction with NO at certain concentrations (so-called ozone titration), therefore O_3 concentrations are lower in areas with higher NO.

The target value for the protection of human health for ozone was exceeded in the assessment years 2021-2023 in the Bratislava agglomeration at the monitoring station Bratislava, Jeséniova (**Fig. 3.6**). The reason for the lower ground-level ozone values in Mamateyova Street compared to Jeséniova Street is probably the above-mentioned titration of ozone by nitric oxide, which occurs in higher concentrations in the vicinity of Mamateyova Street than in Jeséniova Street, due to the influence of road traffic and the refinery, which is a source of emissions of volatile organic compounds (VOCs).

3.1.4 Benzo(a)pyrene

The pollutant benzo(a)pyrene is monitored at three monitoring stations in the Bratislava agglomeration – at Jeséniova Street, Trnavské mýto and Púchovská Street. None of the stations exceeded the target value for the annual average concentration (1 ng·m⁻³). Concentrations in the period from May to September were low at all stations, with a monthly average of up to 0.1 ng·m⁻³.

Fig. 3.7 *Average monthly concentrations of BaP in 2023 at MS Púchovská.*



Tab. 3.3 *Average annual concentrations of BaP in 2019 – 2023.*

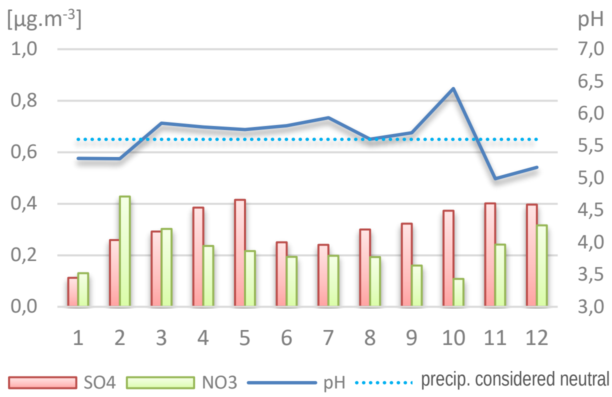
	2019	2020	2021	2022	2023
Target value [ng·m⁻³]	1.0	1.0	1.0	1.0	1.0
Bratislava, Jeséniova	0.2	0.2	0.2	0.3	*0.3
Bratislava, Trnavské Mýto	0.4	0.5	0.5	0.5	0.3
Bratislava, Púchovská			0.9	0.4	0.4

*≥ 90% requested valid data; *60% valid data*

3.1.5 Chemical composition of precipitation

The quality of precipitation in Bratislava is monitored at the Jeséniova station in Koliba. In 2023, the amount of precipitation was very unevenly distributed in individual months, with below-average precipitation in March, April and July (data from MS Jeséniova). The wet deposition of NO_3^- was 0.18 g/m²/year, SO_4^{2-} 0.22 g/m²/year. Wet deposition of lead was at the level of 3 mg/m²/year. The annual average pH value was 6.0 (**Fig. 3.8**)[6]. Detailed monitoring results are presented in Chapter 3.4 Regional Monitoring of *Air pollution in the Slovak Republic 2023 Report*.

Fig. 3.8 *Monthly concentration values SO_4^{2-} NO_3^- and pH in Bratislava in 2023.*



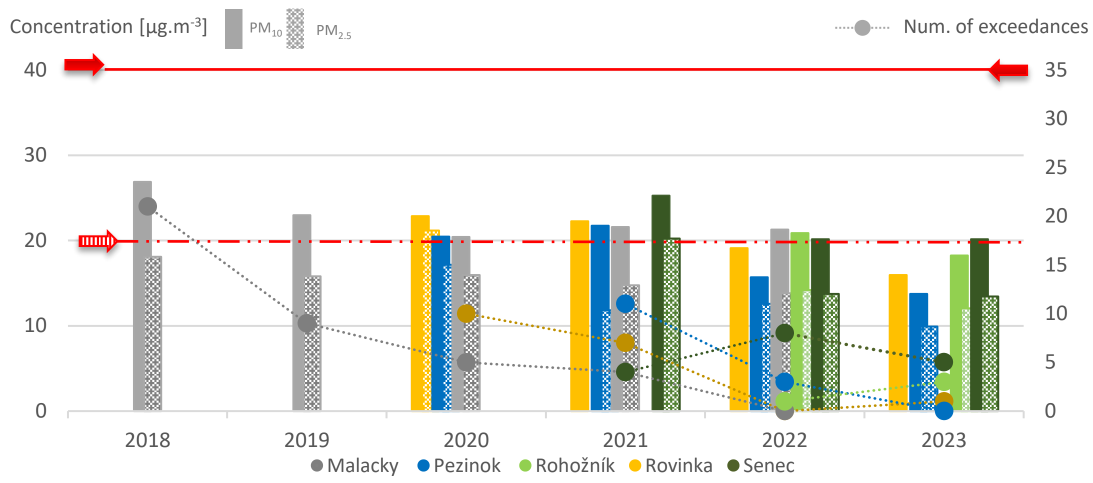
[6] *Neutral water has a pH of 7. Rain absorbs carbon dioxide from the atmosphere and produces carbonic acid, which is slightly acidic, so the normal pH of atmospheric precipitations is 5.6. Acid rain has a typical pH of 4.2 to 4.4.*

3.2 ZONE BRATISLAVA REGION

3.2.1 PM_{10} and $PM_{2.5}$

Fig. 3.9 shows the average annual concentrations of PM_{10}, $PM_{2.5}$ and the number of days with average daily concentrations above 50 µg·m^{-3} according to the results of measurements at monitoring stations in the zone Bratislava region in years 2018 – 2023.

Fig. 3.9 *Average annual concentrations of PM_{10}, $PM_{2.5}$ and the number of exceedances of the daily limit value for PM_{10}.*



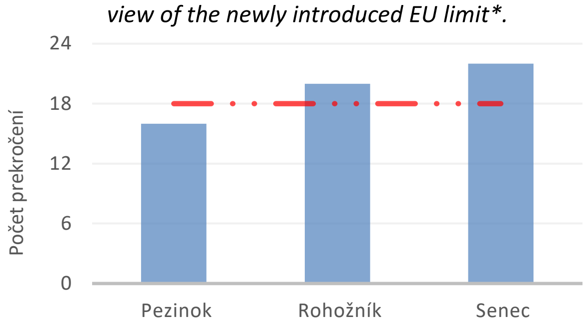
*The arrows show the limit values, **red striped** $PM_{2.5}$ (annual average concentration: 20 µg·m^{-3}); **red on the left** PM_{10} (annual average concentration: 40 µg·m^{-3}) and **red on the right** the number of exceedances (daily average PM_{10} concentration of 50 µg·m^{-3} must not be exceeded more than 35 times in a calendar year).*

The NMSKO station in Senec, Boldocká has been in operation since September 2021. The NMSKO station in Malacky ceased operation in April 2022 and was replaced by the NMSKO station in Rohožník (started operation in June 2022). Therefore, the average value and number of air pollution exceedances in Malacky and Rohožník do not reflect the situation for the whole year 2022.

The zone Bratislava region was monitored by only one monitoring station in Malacky until 2020, then the monitoring network began to expand. Stations were added in Rovinka and Senec. The last change took place in 2022 – it was the transfer of the traffic station from Malacky to Rohožník. In the zone Bratislava region, we have longer-term measurements only for the monitoring station in Rovinka, both PM_{10} concentrations and the number of exceedances of the daily limit value for PM_{10} have a decreasing trend at this station. In 2023, the limit value for the average annual concentration of PM_{10} (40 µg·m^{-3}) and $PM_{2.5}$ (20 µg·m^{-3}) as well as the daily limit value for PM_{10} (max. 35 exceedances) were not exceeded (**Fig. 3.9**).

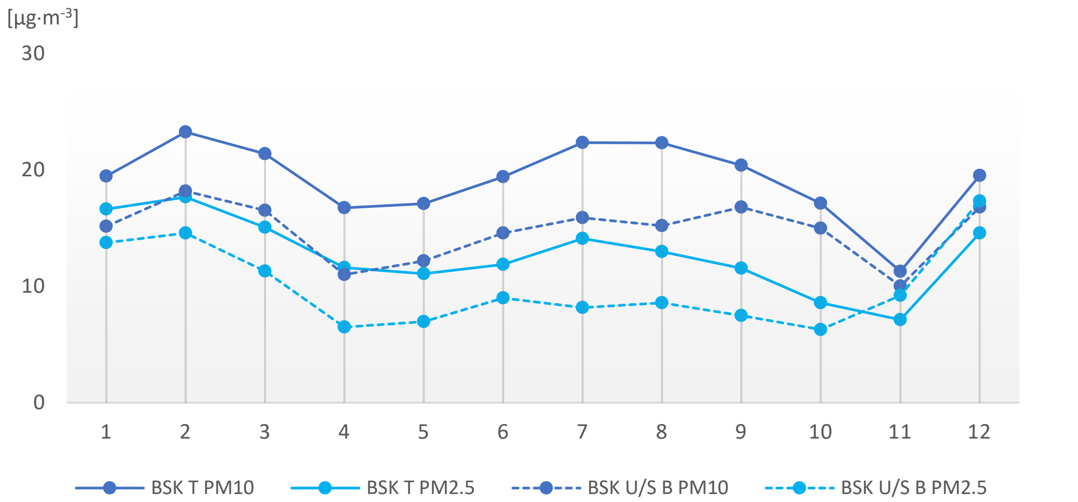
In Pezinok, no exceedances of the daily PM_{10} limit (50 µg·m^{-3}) were recorded in 2023. All stations met the WHO recommendation for the daily number of exceedances (maximally 3 – 4 exceedances of the daily limit of 45 µg·m^{-3} for PM_{10}), except for the traffic station in Senec (5 exceedances). Only the monitoring station in Pezinok would meet the new EU daily limit for $PM_{2.5}$ (to be achieved by 1 January 2030) (**Fig. 3.10**).

Fig. 3.10 *Number of days with average daily $PM_{2.5}$ concentration > 25 µg·m^{-3} in 2023 – evaluation in view of the newly introduced EU limit*.*



** The average daily concentration of $PM_{2.5}$ > 25 µg·m^{-3} must not be exceeded more than 18 times a year. This newly introduced EU limit is to be reached by 1. 1. 2030.*

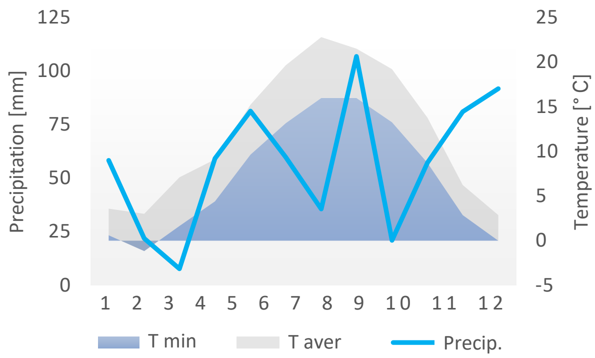
Fig. 3.11 Average monthly concentrations of PM_{10} and $PM_{2.5}$ in the zone by station type.



***T PM10** and **T PM2.5** – average monthly concentrations of PM_{10} and $PM_{2.5}$ at the traffic stations Rohožník and Senec (the Rohožník station started measuring in June 2022); **U/S B PM10** and **U/S B PM2.5** – average monthly concentrations of PM_{10} and $PM_{2.5}$ at the urban/suburban background stations Pezinok and Rovinka;*

The course of monthly average PM_{10} and $PM_{2.5}$ concentrations in 2023 is shown in **Fig. 3.11**. The most pronounced seasonal course of $PM_{2.5}$ concentrations can be observed at urban and suburban background stations, in the winter period, when they capture the contribution of household heating with solid fuels. It can be assumed that this is additional heating in fireplaces, since in the zone Bratislava region gas is the predominant method of household heating (**Fig. 1.5**). The highest $PM_{2.5}$ concentrations at the sub/urban background stations occurred in the coldest months of February and December (**Fig. 3.12**). To illustrate the meteorological conditions, we selected the climatological station in Kráľová pri Senci, which is located close to several of our monitoring stations, and we can assume that the differences in monthly temperatures were not significant in the zone (**Fig. 3.12**). For the monitoring station in Rohožník we can assume lower monthly temperatures. Even in this zone, the mean annual concentration at all monitoring stations is higher than the WHO recommendation (5 µg·m^{-3}). This recommendation has not been met in any month of the year, including summer, when $PM_{2.5}$ concentrations tend to be lowest.

Fig. 3.12 Monthly precipitation totals, average and minimum temperatures (data from climatological station Kráľová pri Senci).

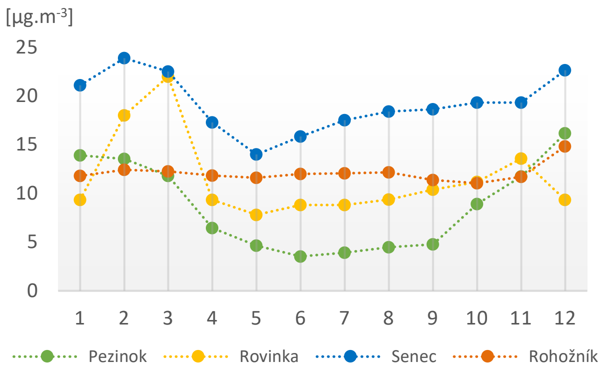


3.2.2 Nitrogen dioxide

The average monthly nitrogen dioxide values for each station are shown in **Fig. 3.13**. In the zone Bratislava region, the limit value (40 µg·m^{-3}) for the annual average NO_2 concentration was not exceeded at any station. The main source of NO_2 emissions is road traffic. The highest concentrations for this reason are recorded at the traffic station in Senec (19 µg·m^{-3}). This station is located in a place with a higher traffic frequency than the traffic station in Rohožník. The higher NO_2 concentrations in February and March at the monitoring station in Rovinka may have been influenced by the refinery located close to the station.

NO_2 concentrations are relatively low in the zone Bratislava region, the WHO recommendation (10 µg·m^{-3}) for the average annual NO_2 pollution level was met by the station in Pezinok (9 µg·m^{-3}) as well as previous year. These WHO recommendations take more account of the impact of pollution on health. The EU's ambition is to move closer to the WHO recommendations through the Zero Pollution Action Plan, which includes new EU limit values for a number of pollutants, including NO_2 (20 µg·m^{-3}), which will enter into force in 2030.

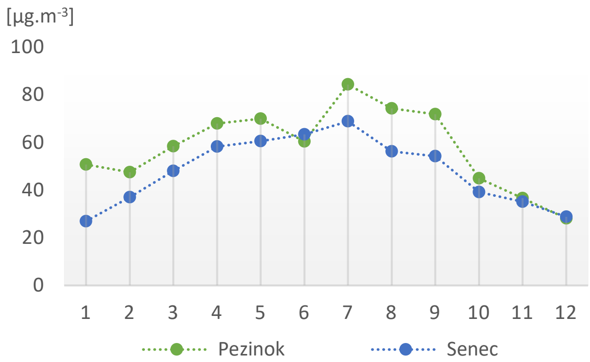
Fig. 3.13 *Average monthly NO_2 concentrations in 2023.*



3.2.3 Ozone

Ozone monitoring (**Fig. 3.14**) is carried out at monitoring stations in Senec and Pezinok. The highest concentrations were recorded in July, when the highest monthly mean temperatures were measured at the nearby climatological station in Kráľová pri Senci (**Fig. 3.12**). Slightly lower concentrations occurred in August due to the fact that more days with precipitation occurred in this month.

Fig. 3.14 *Average monthly O_3 concentrations in 2023.*

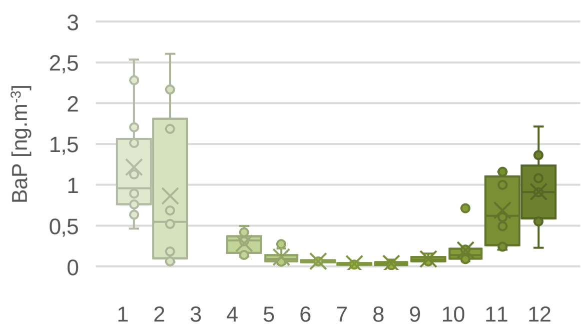


Ground-level ozone concentrations have a pronounced diurnal and monthly pattern, rising with sunrise, peaking around midday and gradually decreasing in the evening to a minimum that occurs in the morning. Large differences in ground-level ozone concentrations are also observed in the warm and cold seasons.

3.2.4 Benzo(a)pyrene

The average annual concentration at the monitoring station in Rovinka in 2023 was 0.4 ng·m^{-3}, thus not exceeding the target value (1 ng·m^{-3}), but the required number of valid measurements of 90 % was not achieved. The highest monthly concentrations of this pollutant were recorded in the winter months with a maximum of 1.1 ng·m^{-3} in January (**Fig. 3.15**). This is a reflection of worsened dispersion conditions and probably increased use of solid fuels in houses, where people tend to use fireplaces and stoves as an additional source of heating.

Fig. 3.15 *Average monthly concentrations of BaP in 2023.*



Tab. 3.4 *Average annual concentrations of benzo(a)pyrene in 2020 – 2023.*

	2020	2021	2022	2023
Target value [ng·m-3]	1.0	1.0	1.0	1.0
Rovinka	0.4	0.6	0.5	*0.4

≥ 90% requested valid data ** 81% valid data*

4 AIR QUALITY MODELLING

Fig. 4.1 and **Fig. 4.2** show results of PM_{10} modelling calculated using the RIO model in combination with IDW-R (a more detailed description of the method is in Chapter 4 of *Air Pollution in the Slovak Republic 2023 Report*).

Fig. 4.1 *Average annual concentration of PM_{10} in 2023 according to RIO model output, IDW-R.*

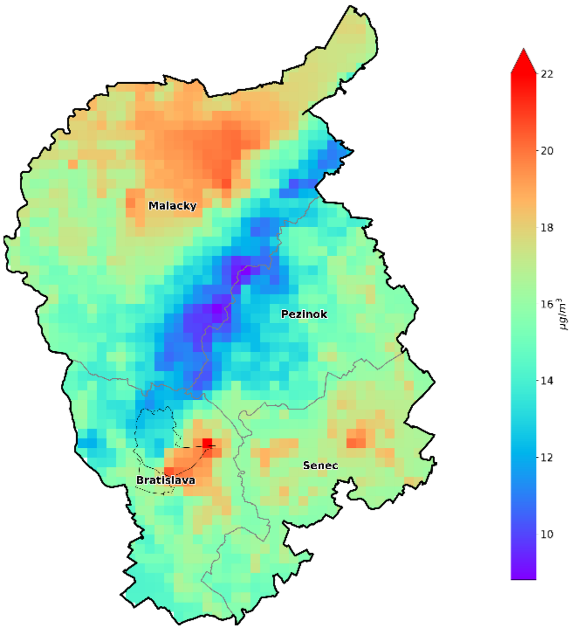


Fig. 4.2 *Number of exceedances of the PM_{10} daily limit value in 2023. Only areas for which the number of exceedances was non-zero are shown.*

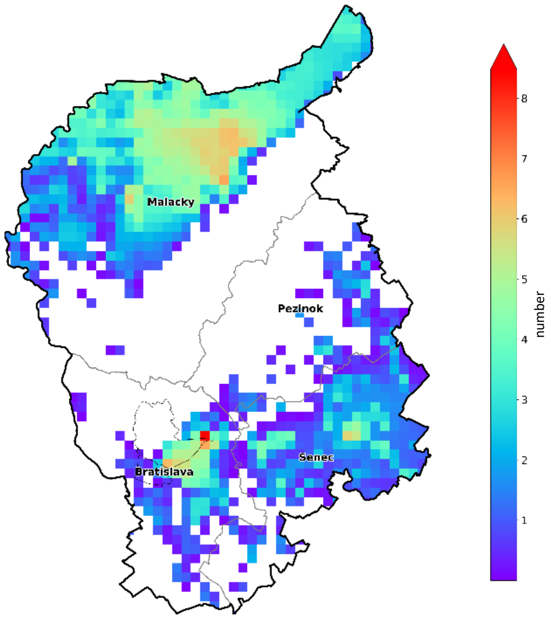


Fig. 4.3 *Average annual concentration of $PM_{2.5}$ in 2023 according to RIO model output, IDW-R.*

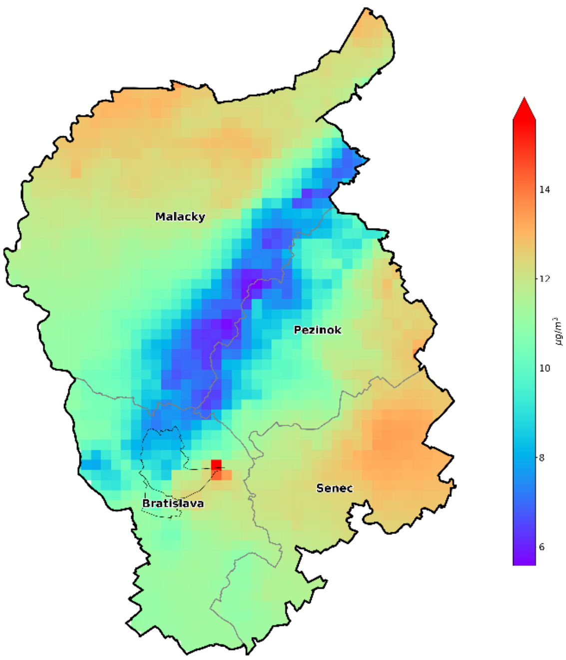
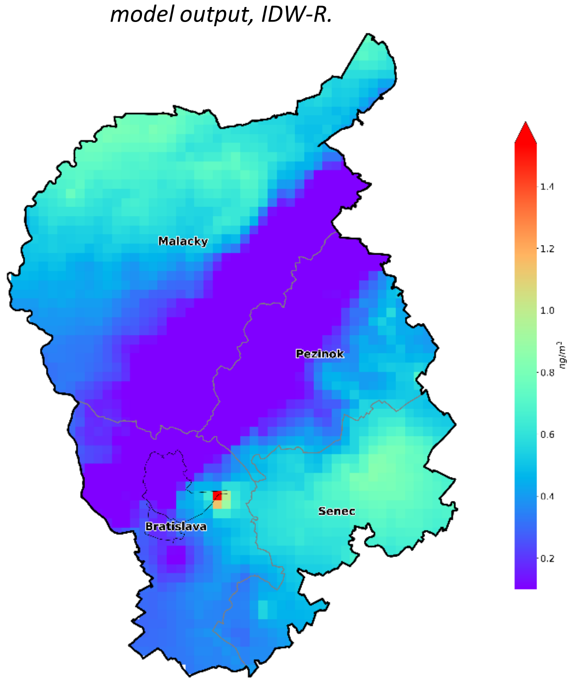


Fig. 4.4 *Average annual concentration of benzo(a)pyrene in 2023 according to RIO model output, IDW-R.*



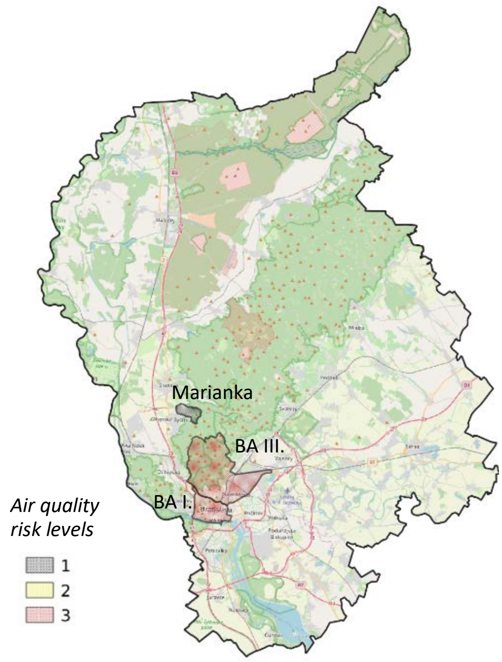
The map in **Fig. 4.3** shows the spatial distribution of annual mean $PM_{2.5}$ concentrations according to the output of the RIO model combined with the IDW-R model. According to the model output, the annual mean $PM_{2.5}$ concentration across the zone was higher than the WHO recommended limit value (the WHO limit values are more stringent than the EU limit). The highest concentrations are likely to be located in the area of the Danubian Plain and the Záhorie region. In Bratislava, the highest concentrations are around busy roads in road canyons.

The map of the spatial distribution of annual average benzo(a)pyrene concentrations according to the output of the RIO, IWD-R model (**Fig. 4.4**) shows the possible occurrence of higher concentrations in Most pri Bratislave. However, future high-resolution modelling would be required for more accurate information.

4.1 Risk municipalities

Fig. 4.5 shows the municipalities at risk of poor air quality, identified by the Integrated Municipal Assessment Method[7]. In the Bratislava region (zone and agglomeration), based on the outputs of the CMAQ chemical-transport model, the RIO interpolation model and the results of the CALPUFF high-resolution modelling, two areas with risk level 3 were identified – Bratislava I and Bratislava III, due to the risk of high NO_2 concentrations around busy roads in these Bratislava districts. And due to the risk of high concentrations of $PM_{2.5}$ due to the high number of local heating plants, one area with risk level 1 – Marianka – was identified.

__Fig. 4.5__ Risk municipalities in zone Bratislava region and Bratislava agglomeration.



The municipalities where the limit value for PM, NO_2 or the target value for BaP was exceeded according to modelling with high spatial resolution were automatically assigned a risk level 3. Similarly to municipalities where exceedances of the limit or target value were detected by measurement. The list of municipalities and their risk levels is published on the SHMÚ website[8].

Zones and agglomerations containing at least one municipality with risk level 3 shall draw up an Air Quality Plan. In this sense, municipalities with risk level 3 shall respond to *air quality management areas*. However, emission reduction measures must be implemented in the zone and agglomeration in all municipalities with a risk level of 2 or 3, ideally also in municipalities with a risk level of 1.

The assessment using the Integrated Municipal Assessment Method aims to identify areas where measures to improve air quality need to be targeted. Taking into account the distribution of air pollution sources and the microclimatic characteristics of the area, it is likely that the level of pollution in the risk area varies from one location to another. An idea of the spatial distribution of air pollution is provided by the results of high-resolution modelling, which are progressively added to the SHMÚ website[9].

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[7] *Štefánik, D., Krajčovičová, J.: Metóda integrovaného posúdenia obcí vzhľadom na riziko nepriaznivej kvality ovzdušia, SHMÚ, 2023, available at https://www.shmu.sk/sk/?page=996*

[8] *https://www.shmu.sk/sk/?page=2768*

[9] *https://www.shmu.sk/sk/?page=2699*

5 SUMMARY

According to the monitoring results, no limit value for any pollutant was exceeded in 2023 in the Bratislava agglomeration or in the zone Bratislava region. The target value for O_3 was exceeded at the suburban background monitoring station Bratislava, Jeséniova. The long-term trends of PM (**Fig. 3.1**) and NO_2 pollution are decreasing in this agglomeration and zone.

Based on the outputs of the RIO, IDW-R model, we can conclude that in the Bratislava region (zone and agglomeration), there is a risk of higher concentrations of PM and NO_2 than the values measured at the traffic station at Trnavské mýto in the vicinity of busy canyon-type road connections in the Bratislava I and III districts. Marianka has been identified as a risk level 1 municipality for higher concentrations of $PM_{2.5}$. If we were to assess the fulfilment of the requirements resulting from the new Air Quality Directive adopted by the European Parliament in April 2024, which sets stricter limit values (which will come into force from 1 January 2030), the biggest problem in the Bratislava agglomeration and the zone Bratislava region would be not to exceed the new limit values for $PM_{2.5}$ and NO_2 at the Trnavské mýto traffic station. The other stations in the zone and agglomeration, although they do not currently meet several of the stricter requirements of the new Air Quality Directive, are not far from meeting them. Pollution levels are showing a downward trend and if this continues, we can assume that by 2030 AMS in the zone and agglomeration will meet the more stringent limit values of the new directive. In order to comply with this directive, additional measures will need to be implemented at the Trnavské mýto traffic station to help reduce pollution to the required level.

If we were to assess air quality according to the WHO[10] recommendations, no station in the zone Bratislava region and agglomeration Bratislava would meet the concentration values for the pollutants. The ambition of the Zero Pollution Action Plan[11] is to achieve air quality according to these recommendations by 2050.

The Bratislava region (both, zone and agglomeration) is the least problematic area in Slovakia in terms of air quality.

[10] *WHO GLOBAL AIR QUALITY GUIDELINES, 2021. Recommendations on classical air pollutants, p. 4. https://apps.who.int/iris/bitstream/handle/10665/345334/9789240034433-eng.pdf*

[11] *https://www.consilium.europa.eu/en/press/press-releases/2024/02/20/air-quality-council-and-parliament-strike-deal-to-strengthen-standards-in-the-eu/*