AIR POLLUTION IN THE SLOVAK REPUBLIC 2024

ANNEX

AIR QUALITY ASSESSMENT IN AGGLOMERATION BRATISLAVA AND ZONE BRATISLAVA REGION

Emissions and Air Quality Division
SLOVAK HYDROMETEOROLOGICAL INSTITUTE

Bratislava, September 2025
Version 1

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

For the purposes of air quality assessment, the territory of Slovakia is divided into zones and agglomerations[1]. 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).

According to the Statistical Office of the Slovak Republic, as of March 31, 2025, the **Bratislava Region** had the highest population density of all regions in Slovakia, at **358 inhabitants per km².** The **highest** density is reported by the **Bratislava I district** with 4,954 inhabitants per km², while the **Malacky district** has the **lowest density** in the region with 84 inhabitants per km². The Slovak Republic has an average population density of 111inhabitants per km².

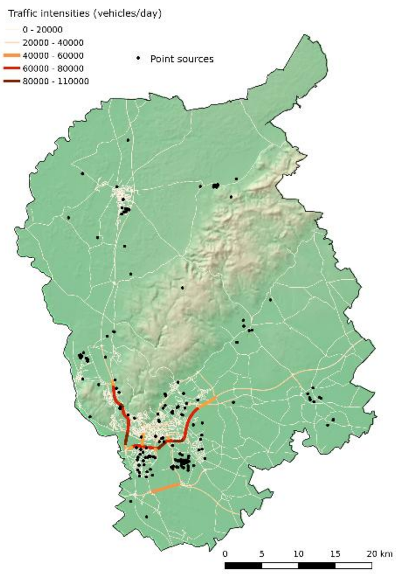
1.1 AGGLOMERATION BRATISLAVA (territory of the capital city of the Slovak Republic Bratislava)

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

The dominant source of air pollution in the capital is road transport. Significant industrial sources of emissions in Bratislava include the Slovnaft refinery, which is one of the largest point sources in the region. The most frequented road sections in Bratislava with the average number of vehicles per 24 hours based on the latest National Transport Census in 2022 and 2023[2]:

Fig. 1.1 *Road traffic intensity in the Bratislava region. Source: CDV*



Tab. 1.1 *Number of vehicles on the most frequented roads of the agglomeration*

Highway/road	Number of vehicles	Trucks	Passenger cars
D1 SE bypass BA II	101 407	18 284	82 817
D1 BA V. Incheba	74 008	15 154	58 639
D2 BA V. Lanfranconi	94 387	15 688	78 320
D4 bypass Jarovce	20 127	3 533	16 533
2 Patrónka	40 395	3 694	36 293
61 Bajkalská street	51 683	3 382	47 970
572 Šancova street	34 466	3 444	30 744
R7 od prístavu na juh	42 722	5 098	37 487
502 Račianska	26 074	1 512	24 165
63 BA II	18434	1 784	16 650

Tab. 1.1 contains the traffic intensity on major roads in agglomeration according to the national transport census in 2022 and 2023). The map in **Fig. 1.1** shows roads with higher traffic intensity, which were processed by the Transport Research Center (Centrum dopravního výzkumu, CDV) for

[1] www.shmu.sk/sk/?page=1&id=oko_info_az

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

the year 2024. The map also shows the locations of point sources.

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.

Air pollution sources in zone Bratislava region

A significant source of air emissions in the Bratislava Region is road transport, which is concentrated to the greatest extent on motorways. The most frequented road sections in the zone with the average number of vehicles in individual districts per 24 hours based on the latest national transport census in 2022 and 2023 is in **Tab. 1.2**[1]:

Tab. 1.2 *Number of vehicles on the most frequented roads of the zone Bratislava*

District	Highway/road	Number of vehicles	Trucks	Passenger cars
Malacky	**D2** Malacky	32 452	13 002	19 350
	D4 Stupava	12 267	1 042	11 173
	2 Stupava	16 254	1 585	14 548
	503 Malacky	16 420	1 345	14 997
	2 Veľké Leváre	14 997	3 382	47 970
Senec	**D1** Senec	59 067	8 968	49958
	R7 Senec	21 236	2 883	18286
	503 Senec	19 126	2 760	16247
	62 Senec	15 556	3 137	12323
	63 Senec	14 904	1 456	13273
	61 Senec	18 365	1 569	16648
Pezinok	**502** Svätý Jur	19 439	1 727	17428
	502 Pezinok	18 776	1 716	16889

Industrial sources of air pollution, with the exception of cement factories (which contribute 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. 1.2 Share of different types of fuels in heating in the municipalities of the region

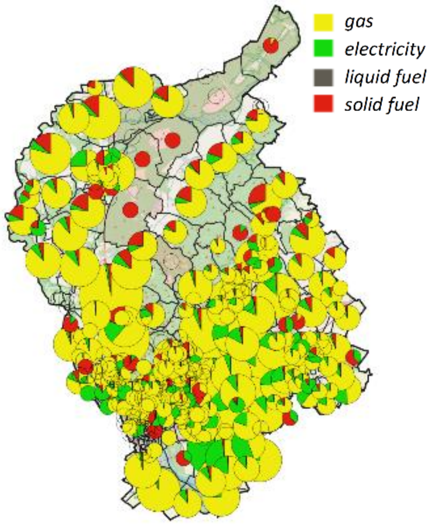


Fig. 1.2. shows the shares of fuel types used for heating family houses in municipalities (or basic settlement units) of the Bratislava Region. The map shows that the spatial distribution of fuels used is not geographically homogeneous - in many areas, heating with gas and electricity dominates. However, in the northern and northeastern part of the region, especially in smaller and rural municipalities of the Malacky and Pezinok districts, a higher share of heating with solid fuels is visible. In summary, for the entire Bratislava Region in 2021, heating with natural gas prevailed.[3]

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

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

Tab. 2.1 and **Tab. 2.2** contain information on air quality monitoring stations in the agglomeration Bratislava and the zone Bratislava region:

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

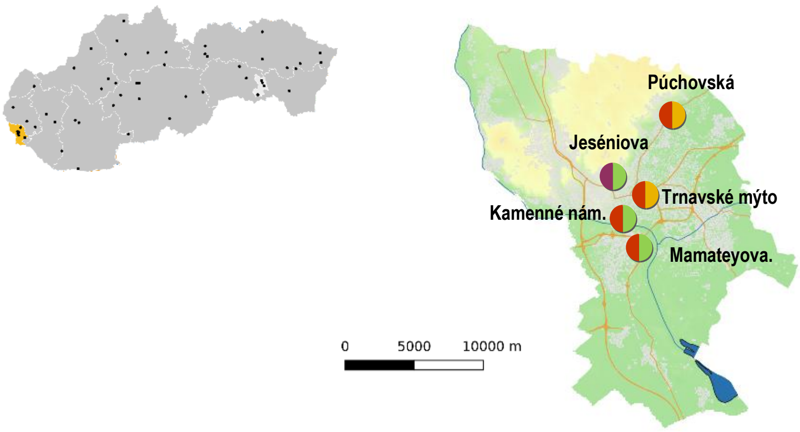
2.1 AGGLOMERATION BRATISLAVA

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	EoI code	Station	Type: area	Type: station	Geographical: longitude	Geographical: latitude	altitudee [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 – rural (regional)

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

At the suburban background monitoring station Bratislava, Jeséniova, in addition to air quality monitoring, precipitation quality is also analyzed. The monitoring program of this station is presented in **Tab. 2.2**, the sampling period and sampling interval was 2 weeks.

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

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

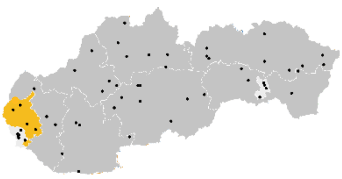
2.2 ZONE BRATISLAVA REGION (without agglomeration Bratislava)

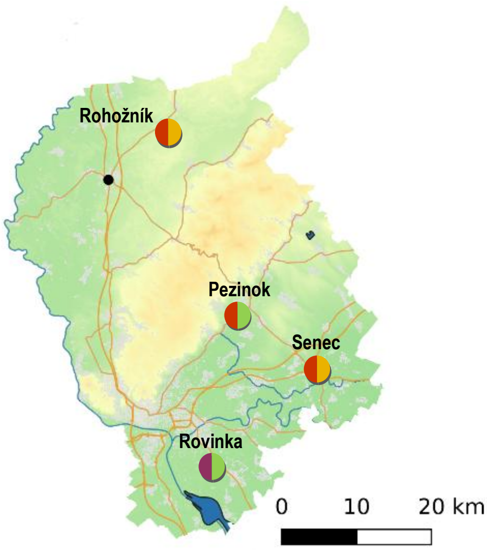
Air quality in the zone Bratislava region is monitored at four NMSKO stations, stations monitoring the impact of traffic are located in **Rohožník** and **Senec**. Both stations in the mentioned district towns are located at intersections with intensive traffic and high pedestrian traffic.

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. 2.1 Air quality monitoring programme in zone Bratislava region.

Zone Bratislava region (without agglomeration Bratislava)								Monitoring programme									
								Continuously								Manually	
District	EoI code	Station	Type		Geographical		Altitude [m]	PM_{10}	$PM_{2,5}$	NO, NO_2	SO_2	O_3	CO	Benzene	Hg	As, Cd, Ni, Pb	BaP
			area	station	longitude	latitude											
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 – rural (regional)

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

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

This chapter focuses on a detailed analysis of air quality assessment based on the monitoring results in the agglomeration Bratislava and the zone Bratislava region in 2024.

Tab. 3.1 *Assessment of air pollution according to limit values for protection of human health and smog warning system for PM_{10} in the Bratislava agglomeration and in the zone Bratislava – 2024.*

AGGLOMERATION Zone		Type	Protection of human health									IT[2)]	AT[2)]
	Pollutant		SO_2		NO_2		PM_{10}		$PM_{2,5}$	CO	Benzén	PM_{10}	PM_{10}
	Averaging period	Area/station	1 h	24 h	1 h	1 year	24 h	1 year	1 year	8 h[1)]	1 year	12 h	12 h
	Parameter		number of exceedances	number of exceedances	number of exceedances	average	number of exceedances	average	average	average	average	Duration of exceedance [h]	Duration of exceedance [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.	UB					6	19	12			19	2
	Bratislava, Trnavské mýto	UT			0	28	12	22	13	1146	0.3	13	2
	Bratislava, Jeséniova	SB	0	0	0	7	7	18	12			7	0
	Bratislava, Mamateyova	UB	1	0	0	15	3	18	1			15	5
	Bratislava, Púchovská	UT	0	0	0	12	13	21	11	844	0.2	19	2
Bratislava region	Pezinok, Obrancov mieru	UB			0	9	0	14	10			14	4
	Rohožník, Senická	UT	0	0	0	11	7	21	11	1687	0.4	21	0
	Rovinka	SB	0	0	0	11	4	17		1146	0.7	24	11
	Senec, Boldocká	UT			0	18	8	20	12	1200		15	4

≥ 90 % 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}*

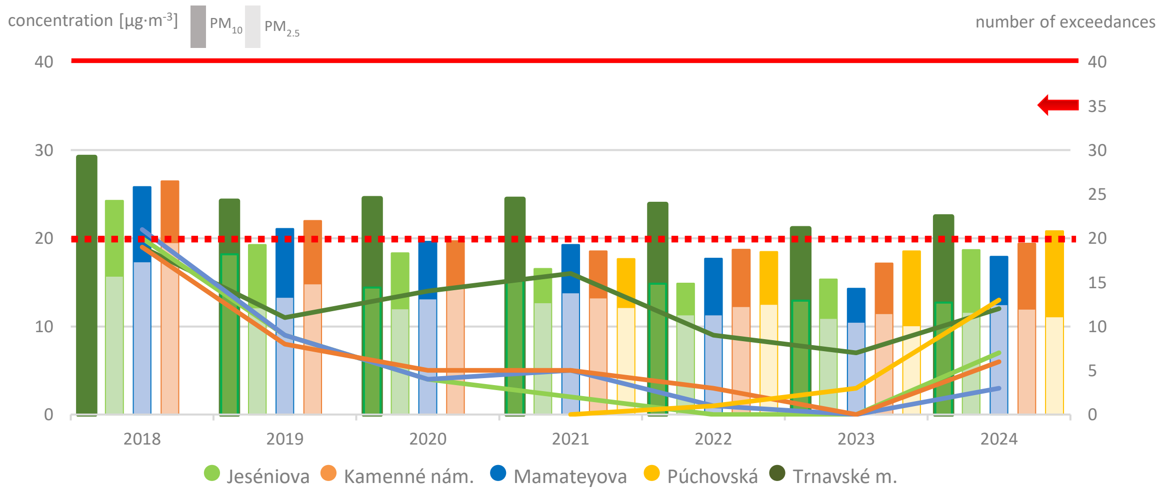
In accordance with the Decree of the Ministry of Environment of the Slovak Republic No. 250/2023 Coll. on air quality, the required proportion of valid values was observed at the monitoring stations.

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 average daily PM_{10} concentrations above 50 µg·m^{-3} according to the results of measurements at monitoring stations in the agglomeration Bratislava in 2018 – 2024.

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}.*

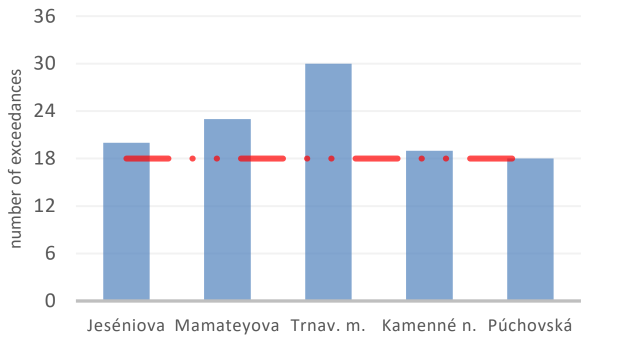


*PM_{10} dark column color, $PM_{2.5}$ – light column color; **number of exceedances** – solid broken lines*
Horizontal lines show limit values (LV), red solid PM_{10} (average annual concentration: 40 µg·m^{-3});
red striped $PM_{2.5}$ (average annual concentration: 20 µg·m^{-3}); red solid arrow – LV number of exceedances
(average daily PM_{10} concentration 50 µg·m^{-3} max. number of exceedances 35/calendar year

The limit values for the annual average concentrations of PM_{10} (40 µg·m^{-3}) and $PM_{2.5}$ (20 µg·m^{-3}) were not exceeded at any monitoring station in the Bratislava agglomeration. The highest annual average PM_{10} concentration in Bratislava, 22 µg·m^{-3}, was recorded at the Trnavské Mýto traffic station, representing the second lowest value measured at this location since monitoring began. It should be noted that in 2021 and 2022, PM_{10} concentrations at this station were negatively influenced by demolition works on the Istropolis building.

At the Púchovská traffic station, the annual average PM_{10} concentration reached 21 µg·m^{-3}, which is 3 µg·m^{-3} higher than in previous year. In urban background locations, PM_{10} levels in 2024 were higher than in the preceding two years.

Fig. 3.2 *Number of days with average daily $PM_{2.5}$ concentration > 25 µg·m^{-3} in 2024 – evaluation with respect to the newly introduced EU limit*.*



** Under the new EU limit, which will come into force on 1 January 2030, the average daily concentration of $PM_{2.5}$ must not exceed 25 µg·m^{-3} more than 18 times a year..*

The limit value for the number of exceedances (35) of the daily average PM_{10} concentration (50 µg·m^{-3}) was not exceeded at any station. However, an increase in the number of exceedances was observed compared to the previous two years (**Fig. 3.1**). The WHO guideline (allowing a maximum of 3–4 exceedances per year) would have been met only by the AMS station on Mamateyova Street.

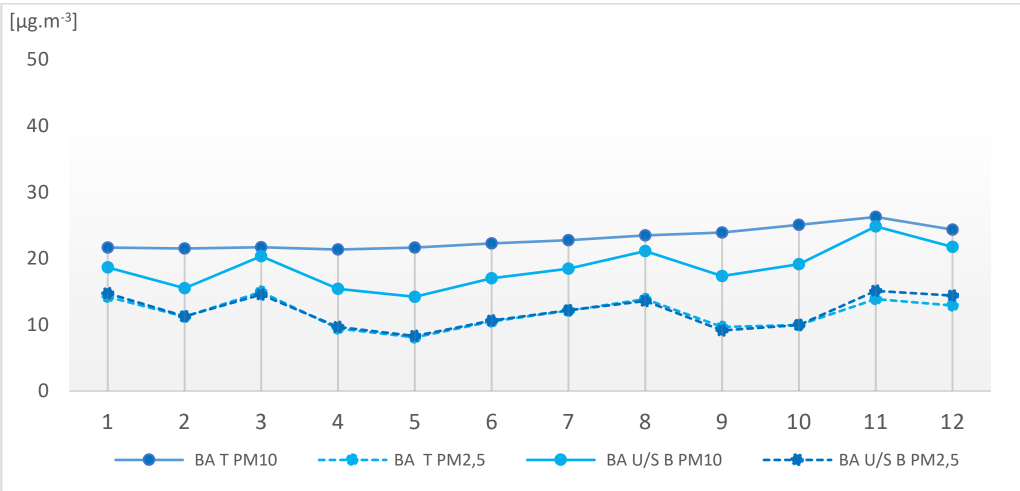
The European Union, as part of the European Green Deal, has developed a Zero Pollution Action Plan, which sets out a vision for 2050. Its aim is to reduce air pollution to levels that are no longer considered harmful to health and natural ecosystems by this year. The action plan includes new EU limit and target values for many pollutants, the biggest challenge for Slovakia will be meeting the new limit values for $PM_{2.5}$. The plan for $PM_{2.5}$ introduces a daily limit value of 25 µg·m^{-3}, which must not be exceeded more than 18 times per year (this is to be achieved by 1 January 2030).

Air quality in 2024 was negatively affected by long-term persistent adverse dispersion conditions at the end of the year and a significant episode of desert dust transport at the turn of March and April. It has been shown that in the event of adverse meteorological factors, it will also be difficult for the Bratislava agglomeration to meet the tightened limits of the new EU Directive 2881/2024 by 2030, therefore it is necessary to take effective measures to improve air quality to reduce emissions of PM_{10} and $PM_{2.5}$.

Fig. 3.2 The figure illustrates how many exceedances of the new EU daily limit for $PM_{2.5}$ would be reached in 2024. In the Bratislava agglomeration, all AMS would exceed the new EU limit value except for AMS Púchovská, which would narrowly meet the permitted number of exceedances; in 2023, all AMS would meet this limit except for AMS at Trnavské Mýto. The new EU annual limit value for the average annual concentration of $PM_{2.5}$ (**Fig. 3.1**) is set at 10 µg·m^{-3}; in 2024, no AMS would meet it. In 2023, two stations – Mamateyova and Púchovská – met this limit value. Measurements at AMS Jeséniova were affected in 2024 by construction work in the close vicinity of AMS; increased dustiness negatively affected PM_{10} concentrations in particular.

The share of solid fuel heating in Bratislava is low, but during periods of unfavorable dispersion conditions it can negatively affect the air quality in the city. In winter, people in localities with family buildings tend to heat themselves in fireplaces, which contributes to higher concentrations of PM_{10} and $PM_{2.5}$ in these months.

Fig. 3.3 *Average monthly concentrations of PM_{10} and $PM_{2,5}$ in zone Bratislava region by station type.*



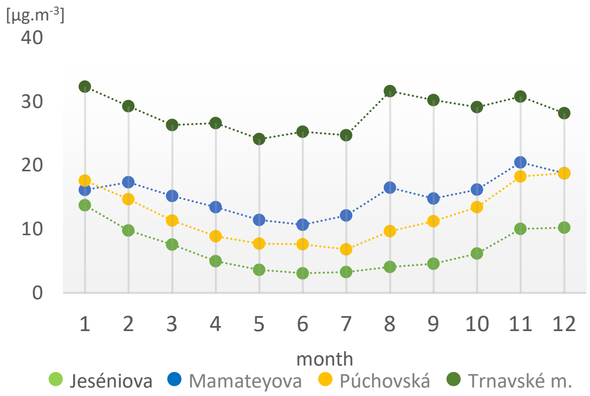
__T PM10__ and __T PM2.5__ – average of monthly concentrations of PM_{10} and $PM_{2,5}$ at traffic stations Trnavské mýto and Púchovská; __U/S B PM10__ and __U/S B PM2.5__ – average of monthly concentrations of PM_{10} and $PM_{2,5}$ at urban/suburban background Jeséniova, Kamenné námestie a Mamateyova.

3.1.2 Nitrogen dioxide

Nitrogen dioxide monitoring is carried out in the Bratislava agglomeration at four stations. The average monthly values for individual stations are shown in **Fig. 3.4**.

The main source of NO_2 emissions is road transport. The second highest average annual NO_2 concentration in Slovakia (28 µg·m^{-3}) was again measured at the Trnavské mýto transport station in 2024, which is a consequence of the high intensity of traffic in this location; the limit value (40 µg·m^{-3}) was not exceeded. In other locations in Bratislava, the level of NO_2 pollution is much lower, as illustrated in **Fig. 3.4**. Monthly NO_2 concentrations at the Púchovská transport station are lower than at the urban background Mamateyova station. The station on Jeséniova Street (the average annual NO_2 concentration here reached 7 µg·m^{-3}) is the only one in Bratislava that met the WHO recommendations (10 µg·m^{-3}). All suburban/urban background stations and the Púchovská transport station would meet the new EU limit value (20 µg·m^{-3}), valid from 2030.

Fig. 3.4 *Average monthly NO_2 concentrations in 2024.*

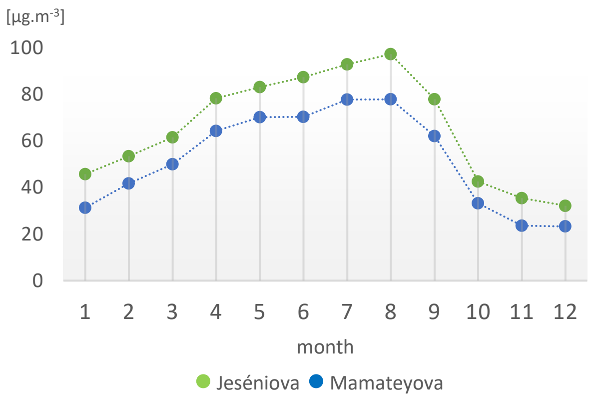


3.1.3 Ozone

Ozone monitoring is carried out in Bratislava at two monitoring stations, Mamateyova and Jeséniova. The second of them is located at a higher altitude on Koliba, at the foot of the Malé Karpaty Mountains. Higher concentrations are measured at this station than at Mamateyova Street in Petržalka.

The highest monthly concentration of ground-level ozone was recorded in an above-average warm August at the Jeséniova AMS (**Fig. 3.5**). Ground-level ozone concentrations have a significant annual trend, with the highest occurring in the summer months. The number of days with exceeding the target value of ground-level ozone is given in **Tab. 3.2**.

Fig. 3.5 *Average monthly O_3 concentrations in 2024.*



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

Stanica	2022	2023	2024	Priemer 2022 – 2024
Bratislava, Jeséniova	37	23	26	29
Bratislava, Mamateyova	25	18	18	20

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

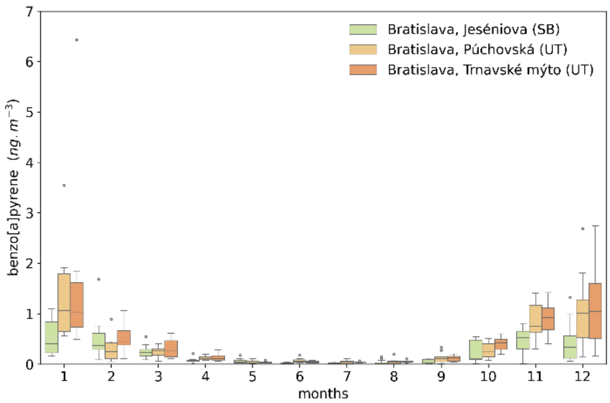
Note: The target value for the protection of human health for ground-level ozone is set as follows according to the Decree of the Ministry of the Environment of the Slovak Republic No. 250/2023 Coll. on air quality: The highest daily 8-hour average concentration shall not exceed 120 µg.m^{-3} for more than 25 days per calendar year on average over three years.

Ground-level O_3 is formed in the atmosphere in the presence of solar (UV) radiation by a chemical reaction of nitrogen oxides and volatile organic compounds or carbon monoxide. The source of nitrogen oxides is combustion processes, in urban agglomeration conditions mainly road transport, and in the case of Bratislava also a refinery. The source of emissions of volatile organic compounds is also road transport, but also industrial sources, and in the warm half of the year vegetation is a significant source. However, ground-level O_3 also decomposes by reaction with NO at certain concentrations (so-called ozone titration), which is why O_3 concentrations are lower in areas with higher NO (transport hot spots).The target value for the protection of human health for ozone was exceeded in the Bratislava agglomeration at the Bratislava, Jeséniova monitoring station in the assessed years 2022–2024 (**Fig. 3.5**). The cause of the lower ground-level ozone values on Mamateyova Street compared to Jeséniová Street is the aforementioned titration of ozone with nitric oxide, which occurs in higher concentrations in the vicinity of Mamateyova Street than on Jeséniova Street due to the impact of road traffic and the refinery, which is a source of volatile organic compound emissions..

3.1.4 Benzo(a)pyrene

The pollutant benzo(a)pyrene is monitored in the Bratislava agglomeration at three monitoring stations – on Jeséniová Street, Trnavské mýto and Púchovská Street (**Fig. 3.6**). None of the stations exceeded the target value for the average annual concentration (1 ng·m^{-3}). Concentrations in the period from May to September reached low values at all stations, the maximum concentration > 6 ng·m^{-3} was recorded at the AMS Trnavské mýto in January.

Fig. 3.6 Concentrations of B(a)P in 2024.



Tab. 3.1 Average annual concentration of benzo(a)pyrene in 2018 – 2024.

	2020	2021	2022	2023	2024
Target value [ng·m^{-3}]	1,0	1,0	1,0	1,0	1,0
Bratislava, Jeséniova	0,2	0,3	0,3	0,3*	0,2
Bratislava, Trnavské Mýto	0,5	0,5	0,5	0,3	0,5
Bratislava, Púchovská		0,9	0,4	0,4	0,4

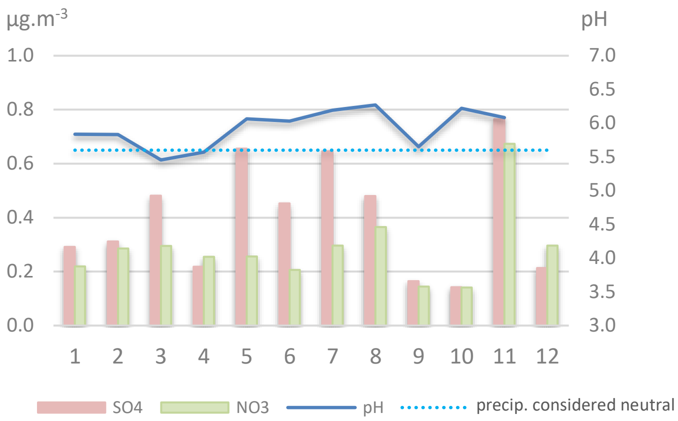
*≥ 90 % valid measurements; *60 % valid measurements*

3.1.5 Chemical composition of precipitation

The quality of precipitation in Bratislava is monitored at the Jeséniova station in Koliba. In 2024, the amount of precipitation was unevenly distributed in individual months, with below-average precipitation in the months of January to March, July, November and December (data from the Jeséniova AMS).

Wet deposition of NO_3^- was 0.15 g/m^2/year, SO_4^{2-} 0.23 g/m^2/year. Wet deposition of lead was at the level of 4.8 g/ha/year. The annual weighted average pH value was 5.8 (**Fig. 3.7**). Detailed monitoring results are presented in Chapter 3.4 Regional Monitoring of the report *Air Pollution SR. 2024.*

Fig. 3.7 *Average monthly concentrations of SO_4^{2-} NO_3^- a pH in precipitations in 2024 at AMS Bratislava, Jeséniova.*

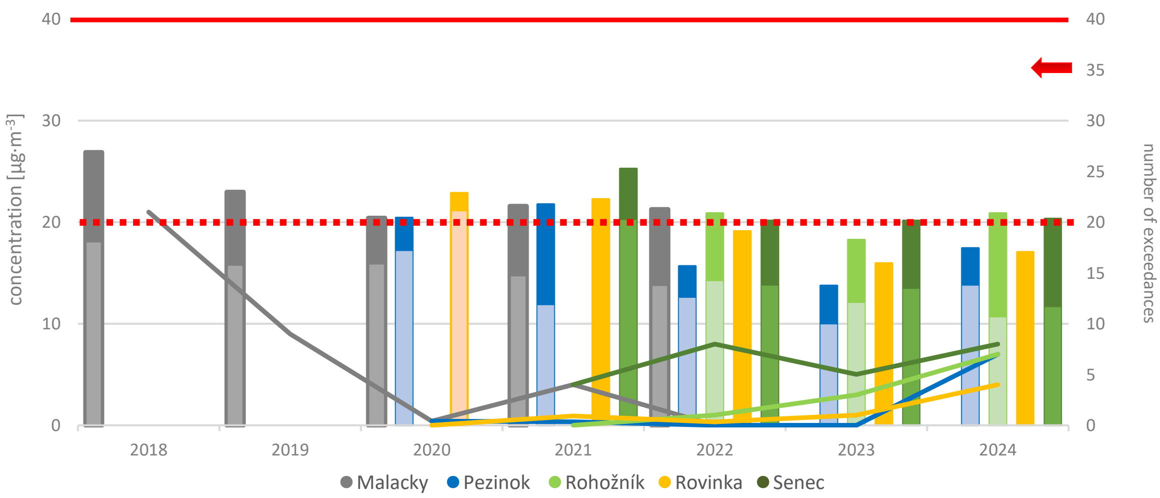


3.2 ZONE BRATISLAVA REGION

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

Fig. 3.8 shows the average annual concentrations of PM_{10}, $PM_{2.5}$ and the number of days with average daily PM_{10} concentrations above 50 µg·m^{-3} according to the results of measurements at monitoring stations in the zone Bratislava region in 2018 – 2024.

Fig. 3.8 *Average annual concentrations of PM_{10}, $PM_{2.5}$ and the number of exceedances of the daily limit value for PM_{10}.*

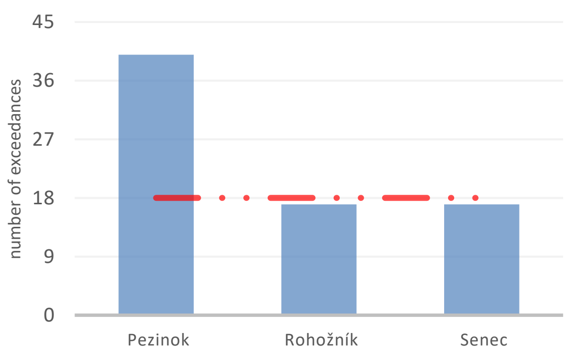


PM_{10} *dark column color,* ***$PM_{2.5}$*** *– light column color;* ***number of exceedances*** *– solid broken lines*
Horizontal lines show limit values (LV), red solid PM_{10} (average annual concentration: 40 µg·m^{-3});
red striped $PM_{2.5}$ (average annual concentration: 20 µg·m^{-3}); red solid arrow – LV number of exceedances
(average daily PM_{10} concentration 50 µg·m^{-3} max. number of exceedances 35/calendar year).

The Bratislava Region zone was covered by only one monitoring station in Malacky until 2020, then the monitoring network began to expand. Stations were added in Rovinka, Pezinok and Senec. The last change took place in 2022 - it was the transfer of the traffic station from Malacky to Rohožník. In the Bratislava Region, we have longer-term measurements only for the monitoring station in Rovinka, PM_{10} concentrations there have a decreasing trend. In 2024, the limit value for the average annual concentration of PM_{10} (40 µg·m^{-3}) and $PM_{2.5}$, as well as the daily limit value of PM_{10} (max. 35 exceedances) was not exceeded (**Fig. 3.8**).

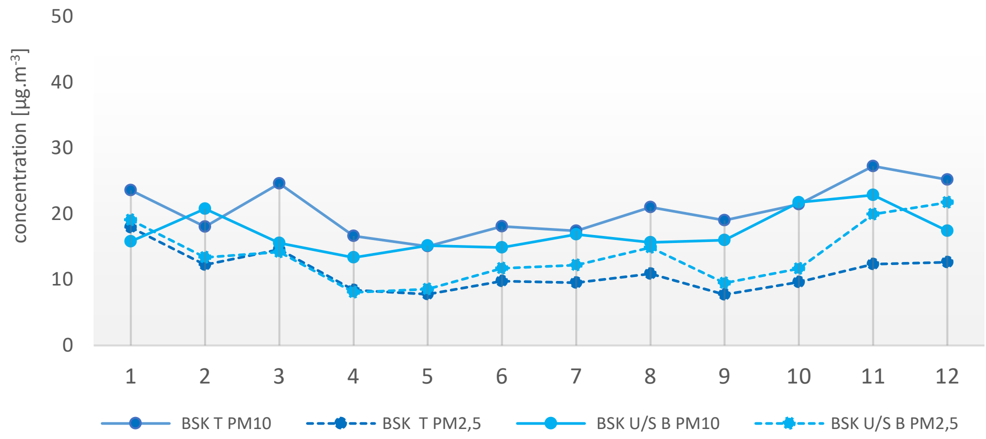
In 2024, all AMS in the zone recorded a slight increase in exceedances of the daily PM_{10} limit (50 µg·m^{-3}) and no station met the WHO recommendations for the daily number of exceedances. The new EU daily limit for $PM_{2.5}$ (to be achieved by 1 January 2030) would not be met by the AMS in Pezinok with 40 exceedances of the daily limit, the other stations would barely meet this limit (**Fig. 3.9**).

Fig. 3.9 *Number of days with average daily $PM_{2.5}$ concentration > 25 µg·m^{-3} in 2024 – evaluation with respect to the newly introduced EU limit*.*



** Under the new EU limit, which will come into force on 1 January 2030, the average daily concentration of $PM_{2.5}$ must not exceed 25 µg·m^{-3} more than 18 times a year.*

Fig. 3.10 Average monthly concentrations of PM_{10} and $PM_{2,5}$ in zone Bratislava region by station type.



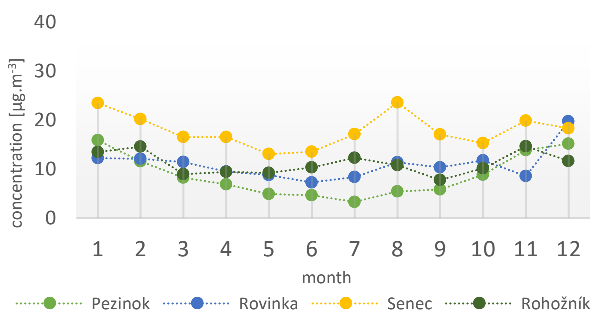
***T PM10** a **T PM2.5** – average of monthly concentrations PM_{10} and $PM_{2,5}$ at traffic stations (Rohožník and Senec); **U/S B PM10** a **U/S B PM2.5** – average of monthly concentrations PM_{10} and $PM_{2,5}$ at urban/suburban background stations (Pezinok a Rovinka);*

The course of average monthly PM_{10} and $PM_{2.5}$ concentrations in 2024 is shown in **Fig. 3.10**. The most pronounced seasonal course of $PM_{2.5}$ concentrations can be observed at urban and suburban background stations at the end of the year, when $PM_{2.5}$ concentrations were significantly higher than at traffic AMS and captured the impact of household heating with solid fuel in combination with long-term poor dispersion conditions. We can assume that this is additional heating in fireplaces, since in the Bratislava Region gas is the majority method of household heating (**Fig. 1.2**). Even in this zone, the average annual concentration at all monitoring stations is higher than the WHO recommendation (5 $\mu g \cdot m^{-3}$). This recommendation was not met in any month of the year, including summer, when $PM_{2.5}$ concentrations are lowest.

3.2.2 Nitrogen dioxide

The average monthly values of nitrogen dioxide for individual stations are shown in **Fig. 3.11**. In the Bratislava Region zone, the limit value for the annual average concentration of NO_2 was not exceeded at any station (40 $\mu g \cdot m^{-3}$). The main source of NO_2 emissions is road transport. For this reason, the highest concentrations are recorded at the transport station in Senec (18 $\mu g.m^{-3}$), this transport station is located in a place with a higher frequency of traffic than the transport station in Rohožník.

Fig. 3.11 Average monthly NO_2 concentrations in 2024.



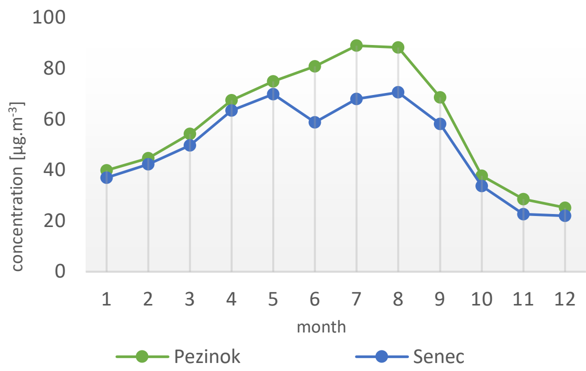
NO_2 concentrations are at a relatively low level in the Bratislava Region zone, the WHO recommendation (10 $\mu g \cdot m^{-3}$) for the average annual level of NO_2 pollution was met by the station in Pezinok (9 $\mu g.m^{-3}$), just like last year. These WHO recommendations more closely reflect the impact of pollution on health. The EU's ambition is to move closer to WHO recommendations through the Zero Pollution Action Plan, which includes new EU limit values for several pollutants, including NO_2 (20 $\mu g \cdot m^{-3}$), which will enter into force in 2030.

3.2.3 Ozone

Ozone monitoring (**Fig. 3.12**) is carried out at the monitoring stations in Senec and Pezinok. The highest concentrations were recorded in July and August, the warmest months of the year. September was above average cold and rainy, which was reflected in a significant decrease in ozone concentrations compared to the summer months.

Ground-level ozone concentrations have a significant daily and monthly trend, rising with sunrise, reaching a peak around noon and gradually decreasing in the evening to a minimum that occurs in the early morning. Large differences in ground-level ozone concentrations are also recorded in the warm and cold seasons.

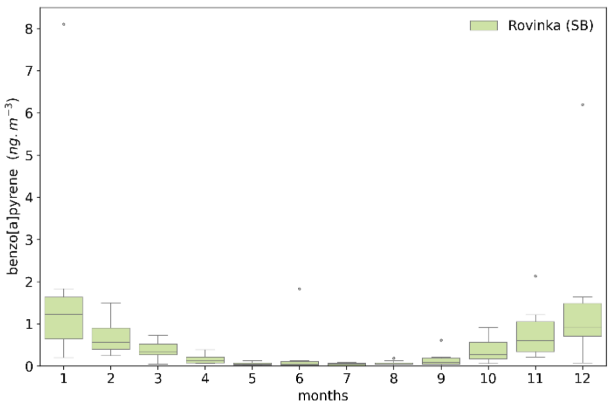
Fig. 3.12 Average monthly O_3 concentrations in 2024.



3.2.4 Benzo(a)pyrene

The average annual concentration at the Rovinka in 2024 was 0.5 ng m^{-3}, thus not exceeding the target value of 1 ng·m^{-3}. The highest monthly concentrations of this substance were recorded in the winter months, with a maximum in December, and the highest measurement above 8 ng.m^{-3} was recorded in January (**Fig. 3.13**). This is a reflection of the increased use of solid fuels in family houses, where people tend to use fireplace inserts and stoves as an additional source of heating.

Fig. 3.13 Concentrations of B(a)P in 2024. .



Tab. 3.2 Average annual concentration of benzo(a)pyrene in 2018 – 2024.

		2020	2021	2022	2023	2024
Target value	[ng·m-3]	1,0	1,0	1,0	1,0	1,0
Rovinka		0,4	0,6	0,5	*0,4	0,5

≥ 90 % valid measurements ** 81 % valid measurements*

4 AIR QUALITY MODELLING

Fig. 4.1 and **Fig. 4.2** show the outputs of the RIO model in combination with IDW-R for PM_{10} in the Bratislava Region zone including Bratislava (a more detailed description of the method is in Chapter 4 of the Report on Air Quality in the Slovak Republic in 2024).

Fig. 4.1 *Annual average PM_{10} concentration in 2024. Output of model RIO/IDW-R.*

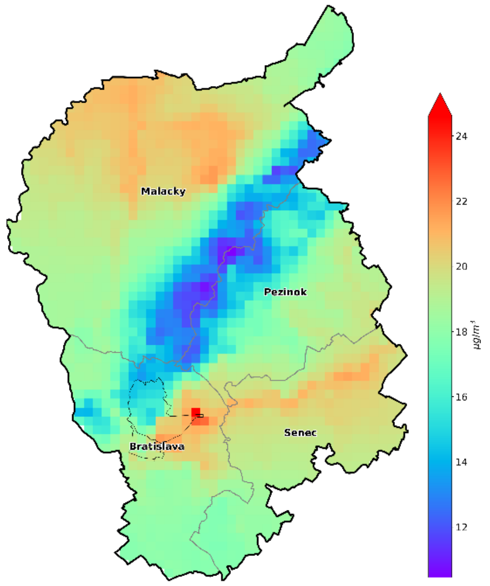


Fig. 4.2 *Number of exceedances of the PM_{10} daily limit value in 2024. Only areas for which the number of exceedances was non-zero are shown.*

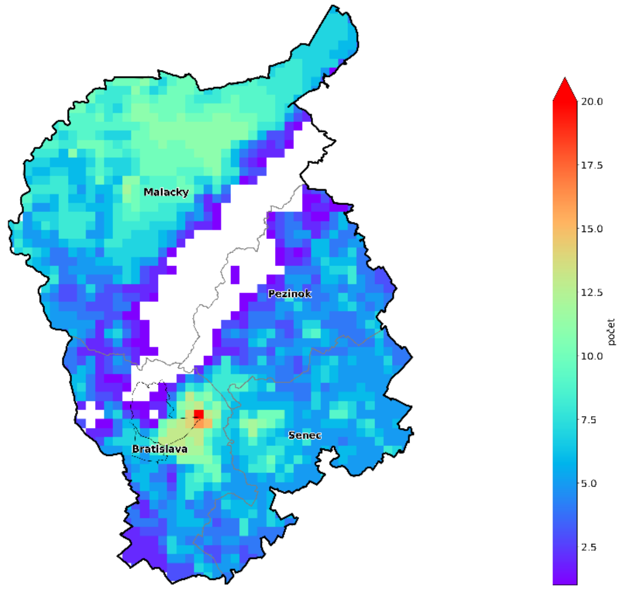


Fig. 4.3 *Annual average $PM_{2.5}$ concentration in 2024. Output of model RIO/IDW-R.*

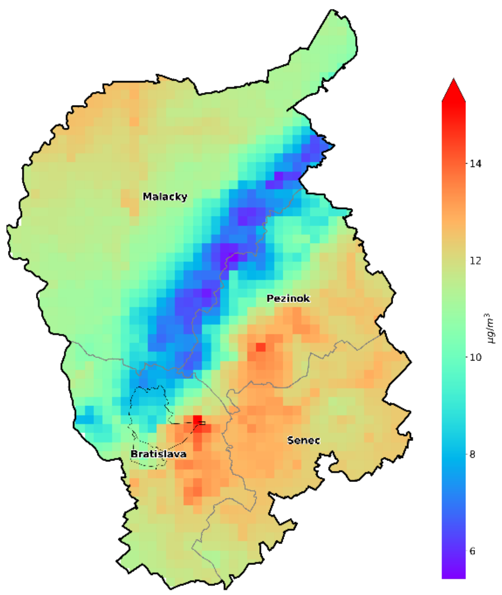
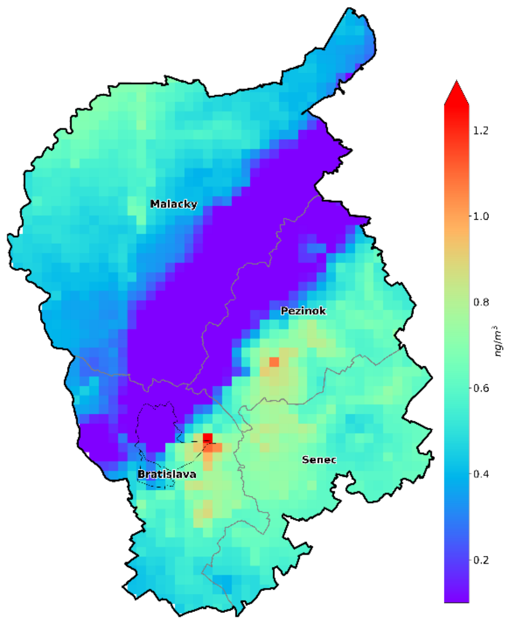


Fig. 4.4 *Annual average benzo(a)pyrene concentration in 2024. Output of model RIO/IDW-R.*



The map in **Fig. 4.3** shows the spatial distribution of average annual $PM_{2.5}$ concentrations according to the output of the RIO model in combination with the IDW-R model. According to the model outputs, the average annual $PM_{2.5}$ concentration in the entire area of the zone was higher than the limit value recommended by WHO (WHO limit values are stricter than the EU limit). The highest concentrations are localized in the Danube Plain and in Záhorie. In Bratislava, the highest concentrations are around busy roads in road canyons.

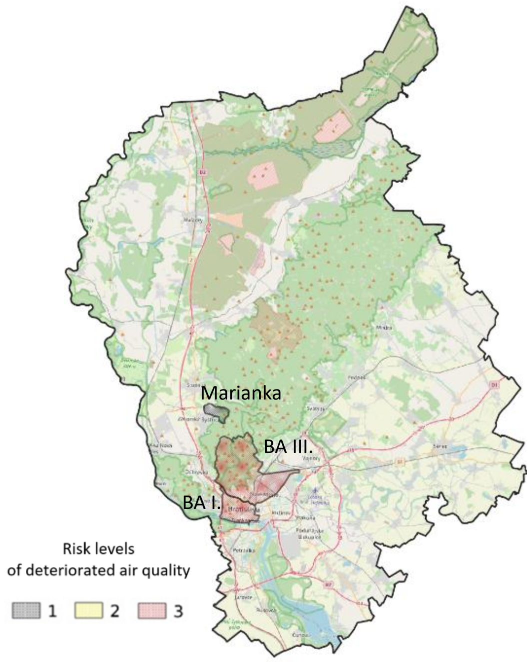
The map of the spatial distribution of average annual benzo(a)pyrene concentrations according to the output of the RIO, IWD-R model (**Fig. 4.4**) shows the possible occurrence of higher concentrations in some municipalities located east and northeast of Bratislava. However, for more accurate information, high-resolution modeling would be necessary in the future.

4.1 Risk municilalities

Fig. 4.5 shows the municipalities at risk of poor air quality, identified by the Integrated Municipal Assessment Method[4]. 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.

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 website8.[5]

Fig. 4.5 Risk municipalities in zone Bratislava region and Bratislava agglomeration.



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 [6].

[4] *Štefánik, D., Krajčovičová, J.: Metóda integrovaného posúdenia obcí vzhľadom na riziko nepriaznivej kvality ovzdušia, Slovenský hydrometeorologický ústav, 2023, dostupné na https://www.shmu.sk/sk/?page=996*

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

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

5 SUMMARY

According to the monitoring results, the limit value for no pollutant was exceeded in the Bratislava agglomeration or in the Bratislava Region zone in 2024. The target value for O_3 was exceeded at the suburban background monitoring station Bratislava, Jeséniova. Long-term trends in PM (**Fig. 3.9**) and NO_2 particle pollution are decreasing in this agglomeration and zone.

Based on the outputs from *high spatial resolution modelling*, we can conclude that in the Bratislava agglomeration, elevated concentrations of NO_2 and PM may occur near busy canyon-type road sections in the Bratislava I and III districts. In the Bratislava Region zone, the municipality (Marianka) has, based on the integrated methodology, risk level I.

The year 2024 was adversely affected by persistently deteriorated dispersion conditions at the end of the year and a significant episode of saharian dust transport at the turn of March and April. Meteorological conditions were not as favorable as in 2022 and 2023, which clearly showed that with deteriorated dispersion factors it may be difficult for the Bratislava agglomeration to meet the tightened limits of the upcoming European legislation by 2030. For this reason, it is necessary to take effective measures to improve air quality, primarily aimed at reducing emissions of PM_{10} and $PM_{2.5}$ particulate matter, as well as nitrogen oxides (NO_2), especially in areas with high traffic load.

If we were to assess the fulfillment of the requirements resulting from the new Air Quality Directive (EU) 2024/2881, which sets stricter limit values valid from 1 January 2030, the biggest problems with achieving them in the Bratislava agglomeration and the Bratislava Region zone would arise at the Trnavské mýto monitoring station - for the pollutants $PM_{2.5}$ and NO_2.

If we were to evaluate air quality according to WHO[7] recommendations, no station in the Bratislava zone and agglomeration would meet the values of the established concentrations for pollutants. The ambition of the Zero Pollution Action Plan is to achieve air quality according to these recommendations by 2050. Despite the previous conclusions, the Bratislava Region Zone and the Bratislava agglomeration are the least problematic areas of Slovakia in terms of air quality.

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