AIR POLLUTION IN THE SLOVAK REPUBLIC 2021

ANNEX

AIR QUALITY ASSESSMENT IN AGGLOMERATION BRATISLAVA AND ZONE BRATISLAVA REGION

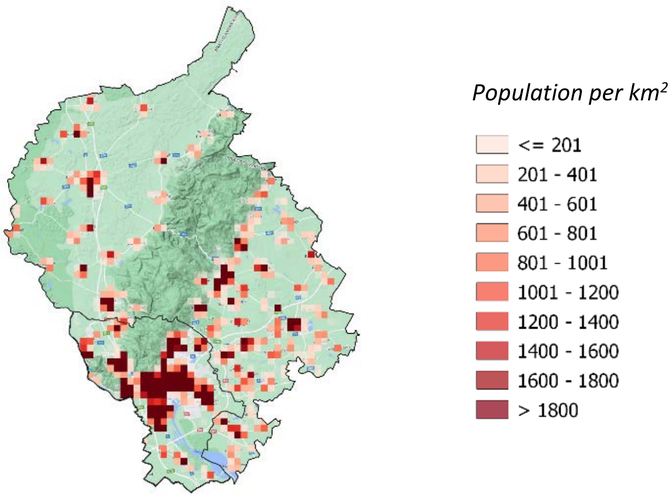
Air quality monitoring department
SLOVAK HYDROMETEOROLOGICAL INSTITUTE

Bratislava, November 2023
Version 2

1 DESCRIPTION OF AGGLOMERATION BRATISLAVA AND ZONE BRATISLAVA REGION TERRITORY 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 region includes agglomeration Bratislava (the territory of the capital city of the Slovak Republic Bratislava) and the zone of the Bratislava region (the Bratislava 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 mountain of the Small Carpathians, the western part of Bratislava lies on the Záhorie lowland, the eastern and southeastern part is occupied by the Danubian lowland.

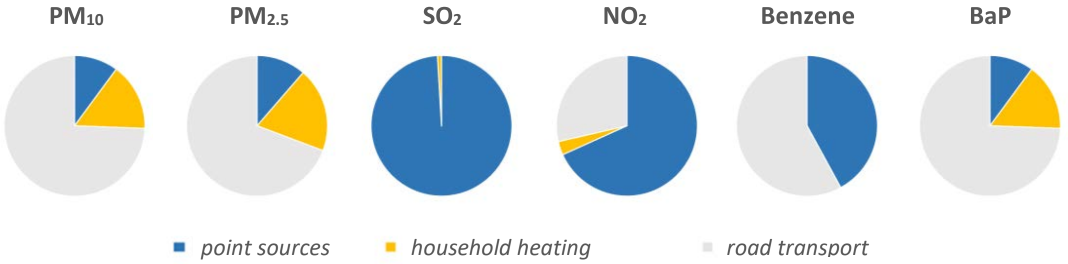
In the area of the Devín Gate, which separates the Hainburg Hills and the part of the Devín Carpathians, and in the area of the Lamač gate between the the Devin Carpathians and the Pezinok Carpathians, there is an orographic increase in wind speed, which has a positive effect on the ventilation of the 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 city is road transport. The highest number of cars in Bratislava passes the D1 motorway bypass from the Harbour bridge in the direction to Žilina (on the most frequented section it is 93 344 vehicles on average daily, (12 762 trucks and 80 058 cars), the D2 motorway bypass from the Lafranconi in the direction of Austria and Hungary (82 646 vehicles, 11 913 trucks and 70 519 cars), the road No. 2 (59 121 vehicles, 3 273 trucks and 55 545 cars) running parallel to the R1 high speed road in Petržalka, road No 61 (Trnavská cesta – 48 720 vehicles, 3 420 trucks and 45 141 cars) and by road of 2^{nd} class No 572 in the direction to Most pri Bratislave (35 051 vehicles, 2 915 trucks and 31 984 cars)[1].

[1] *https://www.ssc.sk/files/documents/dopravne-inzinierstvo/csd_2015/ba/scitanie_tabulka_ba_2015.pdf*

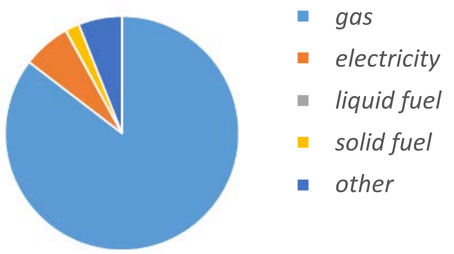
Fig. 1.2 *Share of different types of air pollution sources in total emissions in agglomeration Bratislava.*



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 SO2 concentrations in the air are not currently exceeded, as for other basic pollutants except NO2, 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 in family houses in the zone, 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 region without agglomeration Bratislava. The Bratislava region is the smallest 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 Danube Lowland. The surface is mostly flat. The altitude of the territory ranges from 126 m a. s. l. to 754 m a. s. l. (mount Vysoká). 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

The significant source of air pollution in the Bratislava region is road transport, which concentrates mostly on motorway routes. The results of the national traffic census in 2015 show that the D1 motorway leading to Senec reaches a daily intensity of 62 652 vehicles on average (10 385 trucks and 52 260 cars), while the D2 motorway leading from Bratislava to Malacky and Brno in the section near Stupava 32 968 vehicles (9 787 trucks and 23 132 cars).[3]

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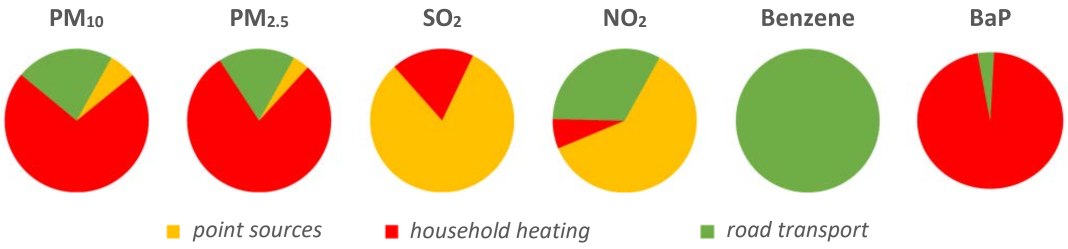
[2] *https://www.scitanie.sk*

[3] *https://www.ssc.sk/sk/cinnosti/rozvoj-cestnej-siete/dopravne-inzinierstvo/celostatne-scitanie-dopravy-v-roku-2015/bratislavsky-kraj.ssc*

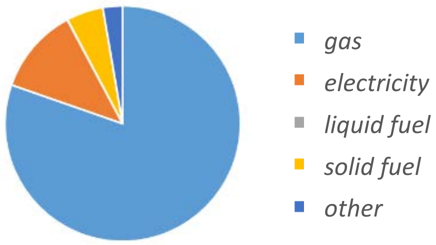
Fig. 1.4 *Share of different types of air pollution sources in total emissions in the zone Bratislava region.*



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 (whose contribution may be reflected 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 *Share of different types of fuel used for heating in family houses [4].*



According to the Population and Housing Census (PHC) 2021 data, natural gas is mainly used for heating in family houses in the zone, although to a lesser extent in comparison with agglomeration Bratislava. Solid fuels are more likely to be used in rural settlements with good availability of firewood.

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

Tab. 2.1 a **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.

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

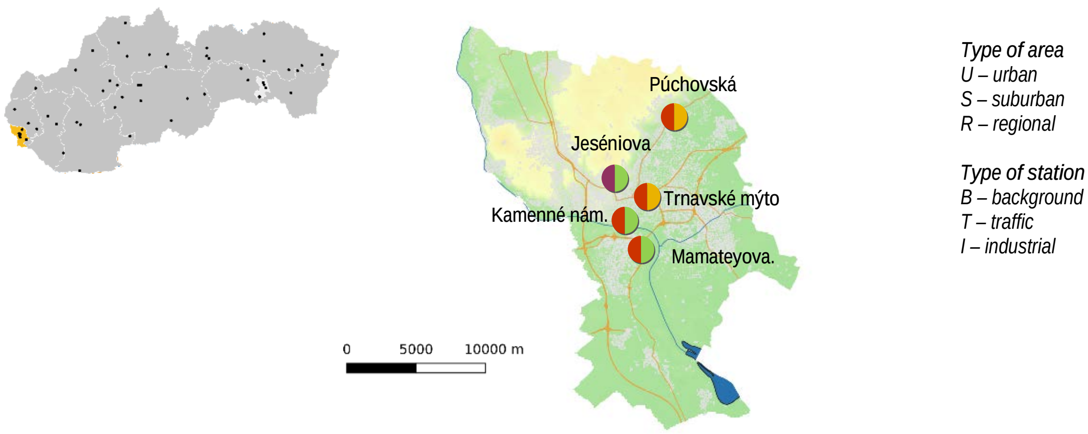
2.1 **AGGLOMERATION BRATISLAVA** (territory of the capital city of the Slovak Republic Bratislava)

In agglomeration Bratislava, air quality is monitored at 5 stations. In addition to the traffic station at Trnavske mýto, which is one of the locations with the highest traffic intensity and the highest concentration of pedestrians in the city, in 2021 a new monitoring station in Rača, Púchovská started to operate.

Housing estate 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								Measurement programme									
								Continuously								Manually	
District	Code EoI	Name of 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



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 one month.

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

	pH	Conductivity	Sulphates (SO_4^{2-})	Nitrates (NO_3^-)	Chlorides (Cl^-)	Ammonium ions (NH_4^+)	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

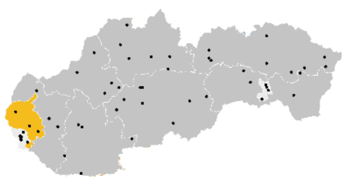
2.2 ZONE BRATISLAVA REGION (without agglomeration Bratislava)

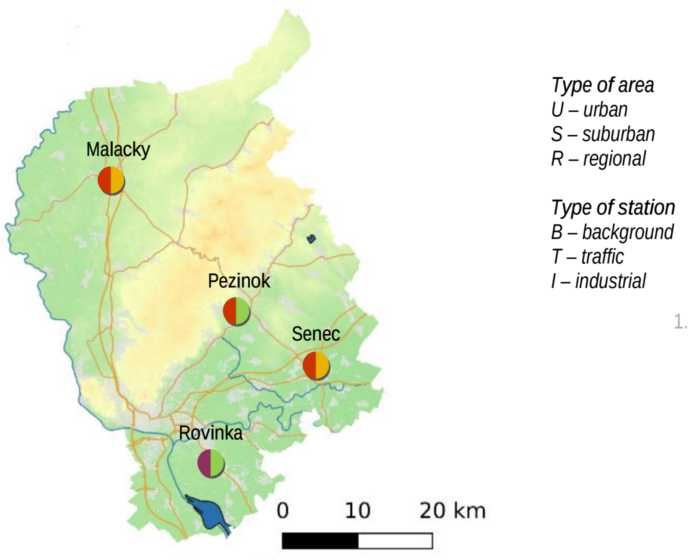
In the Bratislava region, air quality is monitored at 4 stations. Station monitoring the impact of traffic is located in the centre of Malacky and a new monitoring station has been added in Senec since 2021. Both stations in the above-mentioned district towns are located at intersections with heavy traffic and large numbers of pedestrians.

Air pollution in residential zones outside the main traffic routes is monitored by stations in the district town of Pezinok and the village of Rovinka. Air quality monitoring Rovinka is also carried out due to the proximity of the Slovnaft refinery. The NMSKO station in Pezinok is one of the new stations added as part of the latest extension of the NMSKO network.

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

Zone Bratislava region (without agglomeration Bratislava)								Measurement programme									
								Continuously								Manually	
District	Code EoI	Name of 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	Benzén	Hg	As, Cd, Ni, Pb	BaP
Malacky	SK0407A	Malacky, Mierové nám.	U	T	17°01'09"	48°26'13"	162										
Pezinok	SK0075A	Pezinok, Obrancov mieru.	U	B	17°15'35"	48°17'00"	150										
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	1	4	2	0	0	1





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.

Tab. 3.1 *Assessment of air pollution according to limit values for protection of human health and numbers of alert threshold exceedances in agglomeration Bratislava and zone Bratislava region – 2021.*

AGGLOMERATION Zone		Protection of human health									AT [2)]	
	Pollutant	SO_2		NO_2		PM_{10}		$PM_{2.5}$	CO	Benzene	SO_2	NO_2
	Averaging period	1 h	24 h	1 h	1 year	24 h	1 year	1 year	8 h [1)]	1 year	3 h in a row	3 h in a row
	Parameter	number of exceedances	number of exceedances	number of exceedances	average	number of exceedances	average	average	average	average	number of exceedances	number of exceedances
	Limit value [$\mu g \cdot m^{-3}$]	350	125	200	40	50	40	20	10 000	5	500	400
	Maximum number of exceedances	24	3	18		35						
BRATISLAVA	Bratislava, Kamenné nám.					5	18	13				
	Bratislava, Trnavské mýto			0	33	16	24	15	928	0.74		0
	Bratislava, Jeséniova	0	0	0	9	2	16	13			0	0
	Bratislava, Mamateyova	0	0	0	17	5	19	14			0	0
	Bratislava, Púchovská*	0	0	0	13	0	18	12	781	0.80	0	0
Bratislava region	Malacky, Mierové nám.	0	0	0	16	4	21	15	1 248	0.59	0	0
	Pezinok			0	16	11	22	12	1 113			0
	Rovinka	1	0	0	12	7	22		665	0.93	0	0
	Senec, Boldocká*			0	23	4	25	20	1 070			0

≥ 90% of valid measurements

[1)] *eight-hour maximum concentration* [2)] *limit values for alert thresholds*

* *measurements started during 2021, there are not enough valid measurements to assess the exceedance of limit values on a yearly basis*

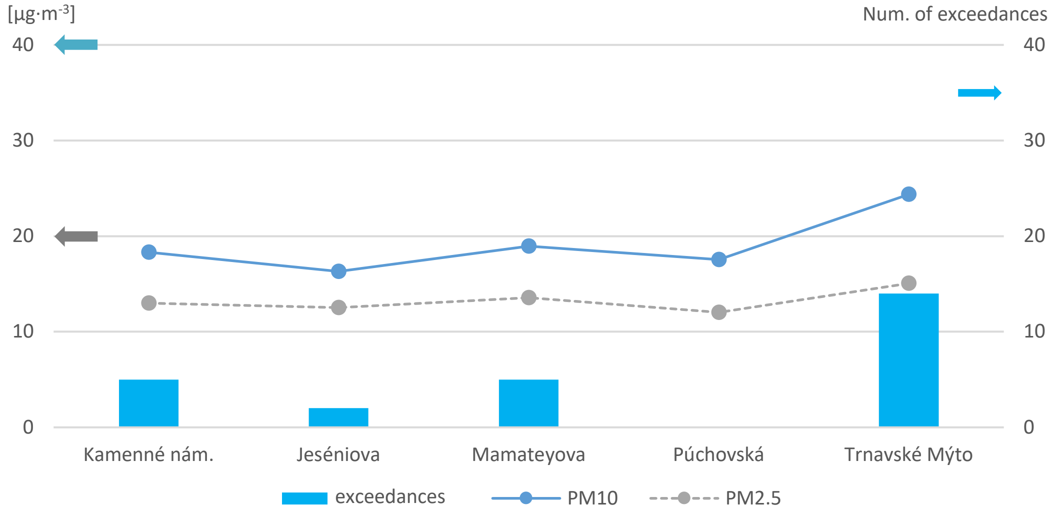
With the exception of the new monitoring stations Bratislava, Púchovská (started to measure on 26 May 2021) and Senec, Boldocká (to measure started on 22 September 2021), in accordance with the Regulation of the Ministry of Environment of the Slovak Republic No. 244/2016 Coll. of Acts on air quality, as amended, the required proportion of valid values was met at the other 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 2021.

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}.*



Number of exceedances - daily average concentrations higher than 50 µg·m^{-3}; the Púchovská station does not reflect air pollution for the whole year (started measuring during the year 2021).

The arrows show the limit values, ***grey arrow*** *$PM_{2.5}$ (average annual concentration: 20 µg·m^{-3});* ***blue left arrow*** *PM_{10} (average annual concentration: 40 µg·m^{-3});* ***blue right arrow*** *number of exceedances (average daily 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 annual average concentration of PM_{10} (40 µg·m^{-3}) in agglomeration Bratislava region was not exceeded. The limit value for the number of exceedances (35) of the average daily limit concentration of PM_{10} (50 µg·m^{-3}) was not exceeded by any station (**Fig. 3.2**). The traffic station Trnavské Mýto recorded the highest annual average concentration of PM_{10} 24 µg·m^{-3}, number of daily exceedances increased from 14 to 16 compared to the previous year. At urban background stations, we observed very little variation in measured annual concentrations in 2021. The PM_{10} concentration was slightly lower at the suburban background station Jeséniova. **Fig. 3.2** shows the number of exceedances of the average daily limit concentration of PM_{10} for each months of the year in agglomeration Bratislava. A total of 28 exceedances occurred for the whole year. Such number of exceedances in some zones is recorded by one station. One exceedance at Trnava Mýto was recorded in June, which is unusual. This was probably due to an episode of long-distance transport of dust from arid areas.

Fig. 3.2 *Number of PM_{10} daily limit value exceedances per month in 2021.*

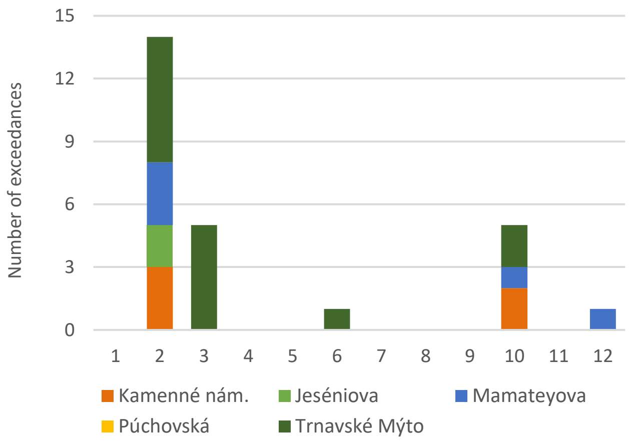
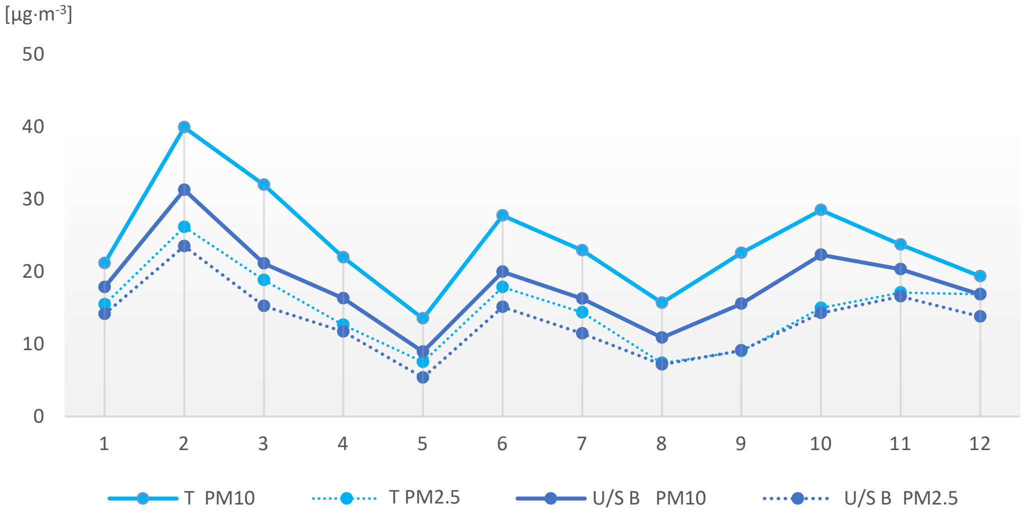


Fig. 3.3 *Average monthly concentrations of PM_{10} and $PM_{2.5}$ in agglomeration Bratislava by station type.*



T PM10 *and* ***T PM2.5*** *– average monthly concentration of PM_{10} a $PM_{2.5}$ at the urban traffic station Trnavské mýto and Púchovska;* ***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 station Jeséniova, Kamenné námestie, Mamateyova.*

Compared to other zones, monthly concentrations (**Fig. 3.3**) show the smallest differences in PM_{10} concentrations between colder and warmer months. This is because central heating of households prevails in Bratislava having much lower emissions of particulate matter. The higher values in February were probably due to a combination of several factors – the presence of an anticyclone in the zone, relatively low temperatures and an episode of long-distance transport of Saharan dust. Dust transport episodes from remote arid regions occurred several times in 2021, one of which was likely the cause of the unusual exceedance 50 $\mu g \cdot m^{-3}$ at the average daily PM_{10} concentration in June, as mentioned above.

In **Fig. 3.3** $PM_{2.5}$ concentrations are shown by the dashed line. Like PM_{10}, $PM_{2.5}$ does not have such a noticeable seasonal pattern as other monitoring stations in Slovakia. Also in Bratislava, the average annual concentration at all monitoring stations is higher than WHO recommendations (5 $\mu g \cdot m^{-3}$). This recommendation was not met in any month of the year, including summer, when $PM_{2.5}$ concentrations tend to be lowest.

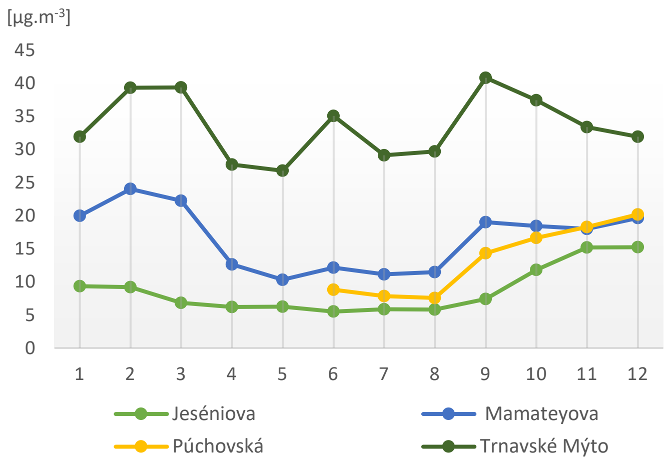
High average concentrations of $PM_{2.5}$ are at risk because of their unfavourable effects on health.

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. 3.4**.

The main source of NO_2 emissions is road transport. The highest concentrations for this reason are recorded at the traffic station Trnavské Mýto. However, the annual average value (33 $\mu g \cdot m^{-3}$) did not exceed the limit value (40 $\mu g \cdot m^{-3}$) even here. NO_2 concentrations at suburban background station Jeséniova maintain a relatively constant level throughout the year

Fig. 3.4 *Average monthly NO_2 concentrations.*



without seasonal fluctuations, which is charakteristic of a location with no significant impact from road traffic or industrial sources. Other stations recorded a relatively insignificant minimum in the summer, as illustrated in **Fig. 3.4**. The highest values are measured at the traffic station at Trnavské Mýto due to higher traffic intensity. However, the limit value for the annual average NO_2 concentration in Bratislava has not been exceeded since 2018. Local maximum at Trnavské mýto in June 2021 is probably the result of poor dispersion conditions. Average annual concentrations at background stations reached values up to 20 μg·m^{-3}. Only Jeséniova station in Bratislava closely meet WHO recommendations (10 μg·m^{-3}) which are significantly stricter than the EU limit values.

3.1.3 Ozone

Ozone monitoring is carried out in Bratislava at two monitoring stations, Mamateyova and Jeséniova. The latter is located at a higher altitude on a hill above the city. The influence of altitude and type of station (suburban) where ozone titration occurs to a lesser extent is reflected in the measured higher concentrations.

The highest concentrations of ground-level ozone generally occur in warm months with high sunshine intensity (**Fig. 3.5**). **Fig. 3.6** and **Fig. 3.7** show the so-called daily course of O_3 concentration. It shows that concentrations increase with sunrise, peaking around midday and gradually decreasing in the evening to a minimum, which occurs early in the morning. Large differences in ground-level ozone concentrations are also observed in the warm and cold seasons.

Fig. 3.5 *Average monthly O_3 concentrations.*

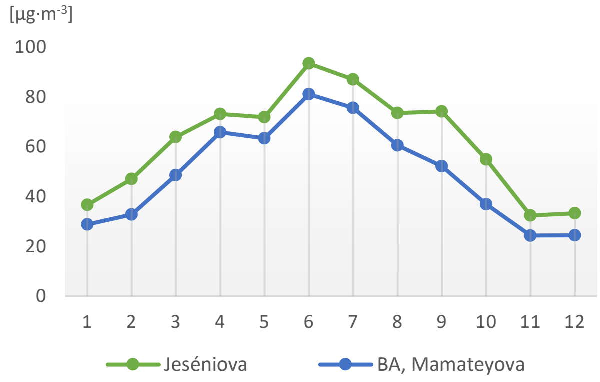


Fig. 3.6 *Daily O_3 concentration in January 2021.*

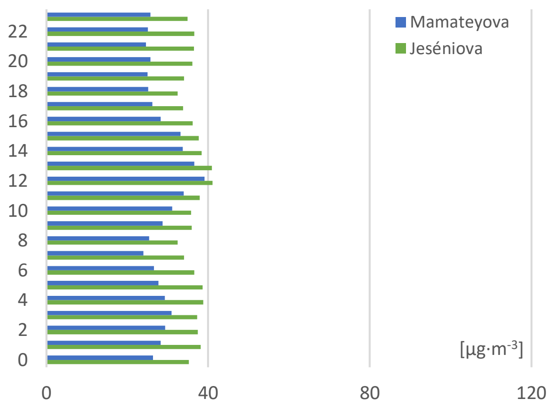
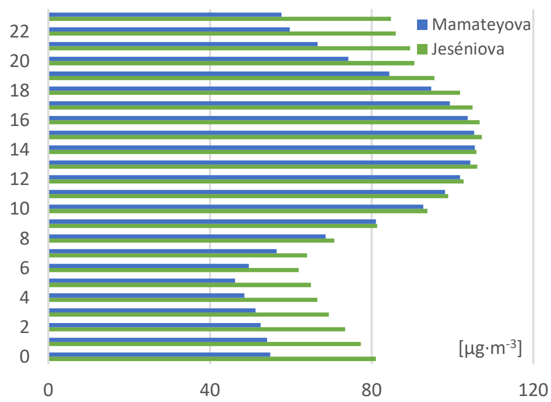


Fig. 3.7 *Daily O_3 concentration in July 2021.*



The number of days with exceedances of the ground-level ozone target value shows **Tab. 3.2**

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

Station	2019	2020	2021	Average 2019 – 2021
Bratislava, Jeséniova	40	17	23	27
Bratislava, Mamateyova	32	12	15	20

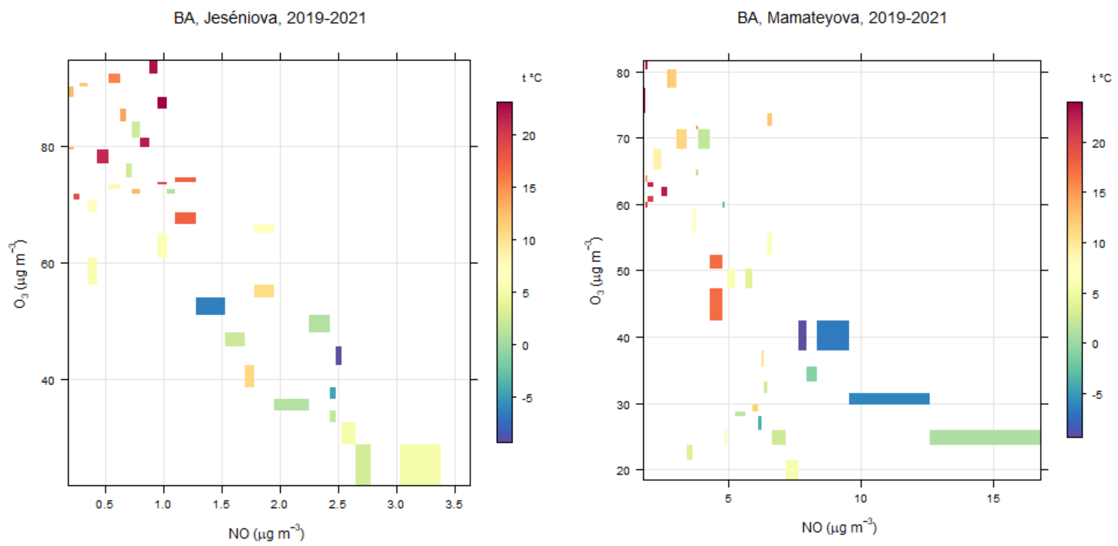
≥ 90% requested valid data *Exceedance of the target value is marked in red.*

Note: The target value for the protection of human health for ground-level ozone is set by Regulation of MoE SR No. 244/2016 Coll. of Acts on air quality, as amended: "The highest daily 8-hour mean concentration shall not exceed 120 μg·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 transport, in the case of Bratislava also refinery. Road transport 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 Bratislava agglomeration at the monitoring station Bratislava, Jeséniova in the assessment years 2019-2021. The reason for the lower values of ground-level ozone 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 both the refinery and road traffic (**Fig. 3.8**).

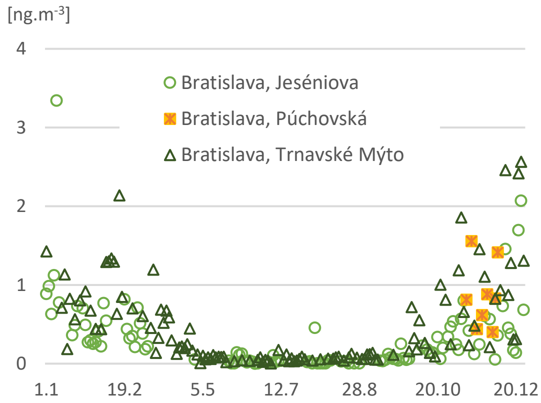
Fig. 3.8 *The relationship of monthly mean O_3 concentrations and NO and temperature.*



3.1.4 Benzo(a)pyrene

Benzo(a)pyrene is monitored at three monitoring stations in agglomeration Bratislava – on Jeséniova Street, Trnavské mýto and Púchovská Street. None of the stations that measured throughout the year did not exceed the target value for the annual average concentration (1 ng·m^{-3}). Monitoring of benzo(a)pyrene at the new traffic station at Púchovská Street was carried out during November, in December there was a failure of measurements due to a technical problem. The measured values corresponded approximately to the values measured at Trnavske mýto in the same period.

Fig. 3.9 *Results of benzo(a)pyrene measurements in agglomeration Bratislava in 2021.*



Higher levels of benzo(a)pyrene were measured at stations in Bratislava in the colder months of the year, more frequently at the traffic station on Trnavske mýto and episodically also on Jeséniova Street (**Fig. 3.9**).

Tab. 3.3 *Assessment of benzo(a)pyrene air pollution.*

	2017	2018	2019	2020	2021
Target value [ng·m^{-3}]	1.0	1.0	1.0	1.0	1.0
Bratislava, Jeséniova			0.2	0.2	0.3
Bratislava, Trnavské Mýto	0.4	0.9	0.4	0.5	0.5
Bratislava, Púchovská					*0.9

≥ 90% requested valid data   ** There are not enough valid measurements for a full year assessment*

3.1.5 Chemical composition of precipitation

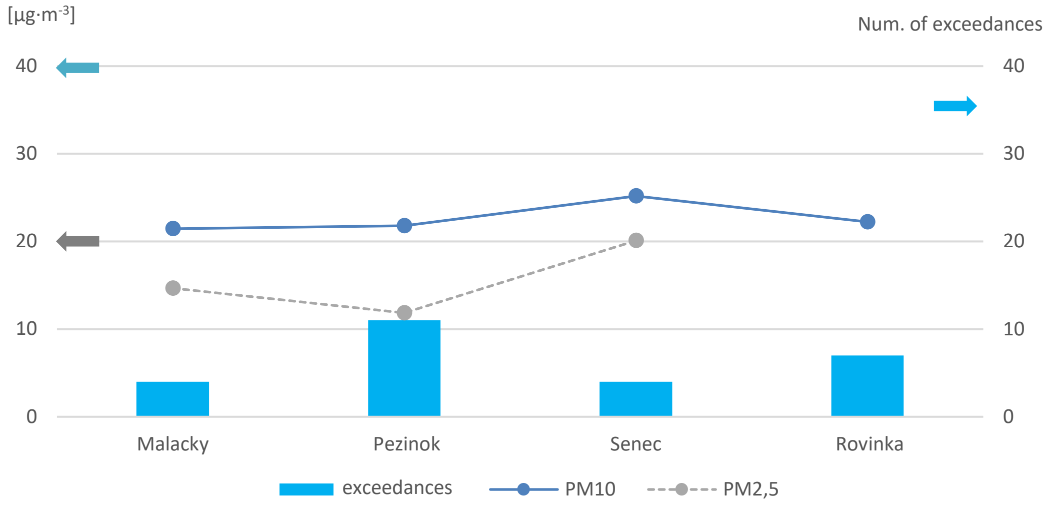
At the suburban background station Jeséniova, the quality of precipitation is monitored on a monthly basis. The qualitative composition of main ions, pH parameters and conductivity are monitored. The annual average pH value was 5.96, and even the monthly averages did not fall below pH 5. The measured concentrations of sulphate and nitrate were also low. It can be concluded that there is no excessive acidification of the environment in the Bratislava agglomeration. Detailed monitoring results are presented in Chapter 3.4 Regional monitoring of *Air pollution in the Slovak Republic 2021 Report*.

3.2 ZONE BRATISLAVA REGION

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

Fig. 3.10 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 2021.

Fig. 3.10 Average annual concentrations of PM_{10}, $PM_{2.5}$ and the number of exceedances of the daily limit value for PM_{10}.

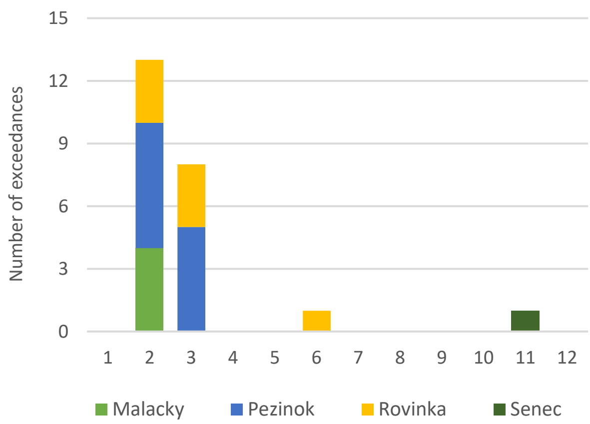


Number of exceedances - daily average concentrations higher than 50 µg·m^{-3}; the Senec, Boldocká station started measuring PM_{10} in september 2021, therefore the number of exceedances and the annual average value at this station does not reflect air pollution for the whole year.

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

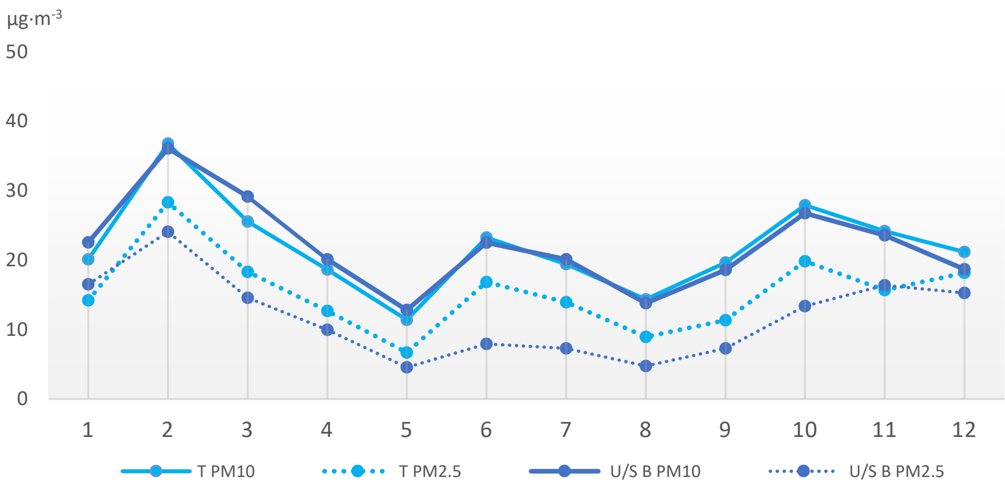
The limit value for the annual average concentration of PM_{10} (40 µg·m^{-3}) in the zone Bratislava region was not exceeded. The limit value for the number of exceedances (35) of the average daily limit concentration of PM_{10} (50 µg·m^{-3}) was not exceeded by any station (**Fig. 3.10**). The traffic station in Senec started measuring during September 2021. Average concentration of both PM_{10} and $PM_{2.5}$ (for the period 22. 9. – 31. 12. 2021) at this station reached the highest value measured in 2021 in the zone Bratislava region. This is only because the concentrations are highest at the end of the year (due to unfavourable dispersion conditions, residential heating, cold starts of car combustion engines, etc.). The traffic station in Malacky measured the average annual concentration 21 µg·m^{-3} and two remaining (urban and suburban) background stations in Pezinok and Rovinka 22 µg·m^{-3}. In the zone Bratislava region we recorded 4 exceedances of the daily limit value of 50 µg·m^{-3} PM_{10} in Malacky, in Pezinok 11, in Senec 4 and in Rovinka 7 (**Fig. 3.11**). These values are among the lowest in the NMSKO

Fig. 3.11 Number of PM_{10} daily limit value exceedances per month in 2021.



monitoring network across Slovakia. A special case is the exceedance measured in June in Rovinka: similarly to several other zones, the influence of long-range transport of dust from arid areas in the third decade of June was evident also here.

Fig. 3.12 Average monthly concentrations of PM_{10} a $PM_{2.5}$ in the zone by type of station.



***T PM10** and **T PM2.5** – average monthly concentration of PM_{10} and $PM_{2.5}$ at the urban trafic stations: Malacky and Senec (the station hasn't measured all year); **U/S B PM10** and **U/S B PM2.5** – average monthly concentration of PM_{10} and $PM_{2.5}$ at the urban/suburb background stations: Pezinok a Rovinka;*

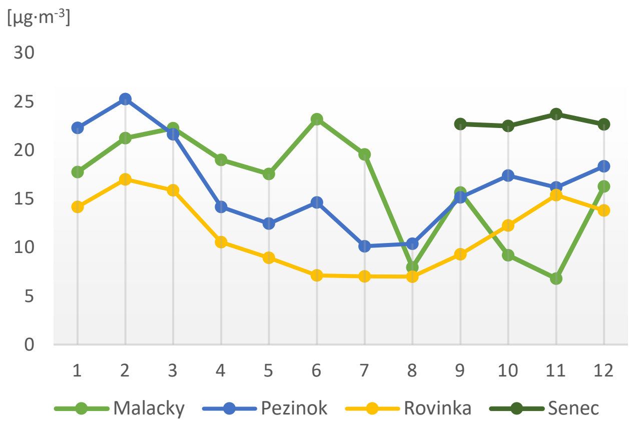
There is no significant seasonal trend in monthly average PM_{10} and $PM_{2.5}$ concentrations in 2021. The impact of domestic heating is lower than in more mountainous areas, as the greater part of the area is well ventilated. In some months (June, February), the effect of long-range transport of dust from arid areas combined with poor dispersion conditions is reflected in higher concentrations.

Increased concentrations of $PM_{2.5}$ fine particles in the air are a risk ones, mainly because of their unfavourable effects on human health. In the zone Bratislava region, PM_{10} and $PM_{2.5}$ do not show such a pronounced seasonal pattern as in other areas in Slovakia. Also in this zone, the mean annual concentration at all monitoring stations was higher than the WHO recommendation (up to 5 µg·m^{-3}). This recommendation was not met in any month of the year (**Fig. 3.11**), including summer, when $PM_{2.5}$ concentrations tend to be lowest.

3.2.2 Nitrogen dioxide

Nitrogen dioxide monitoring is carried out at four stations in the zone, the average monthly values for each station are shown in **Fig. 3.13**.

Fig. 3.13 Average monthly concentrations NO_2.



The main source of NO_2 emissions is road transport. The highest concentrations for this reason are recorded at the traffic stations – in this zone in Senec (23 µg·m^{-3}) (station, however measured only three months at the end of the year). It is interesting that the traffic station in Malacky measured in the year 2021 the same average NO_2 value as a background station in Pezinok (16 µg·m^{-3}), while th limit value is 40 µg·m^{-3}. Monthly concentrations do not have significant seasonal fluctuations. In the summer months there is an insignificant minimum, which illustrates **Fig. 3.13.** The local peaks registered in Malacky in June and

September may be a reflection of worsened dispersion conditions. Overall, NO_2 concentrations in the zoneare at a relatively low level, but no station met the WHO recommendation for an annual average level of this pollutant (10 µg·m^{-3}), which is significantly stricter than the EU limit.

3.2.3 Ozone

Ozone monitoring is carried out in this zone at the new monitoring station in Senec. Measurements started here in September 2021, measured concentrations did not reach high values (**Fig. 3.14**).

The highest concentrations of ground-level ozone generally occur in the warm months with high level of sunshine. **Fig. 3.15** and **Fig. 3.16** show the so-called daily course of O_3 concentration. It shows that concentrations increase with sunrise, peak around midday and gradually decrease in the evening to a minimum that occurs early in the morning. Large differences in ground-level ozone concentrations are also observed in the warm and cold seasons.

Fig. 3.14 *Monthly average O_3 concentrations.*

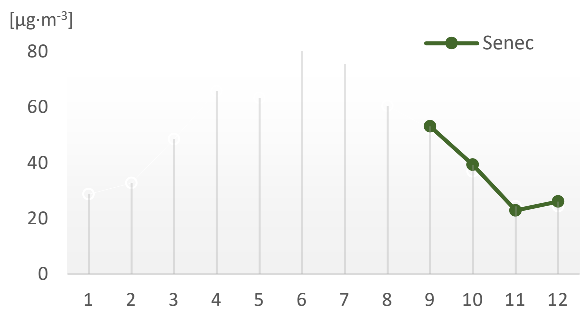


Fig. 3.15 *Daily O_3 concentration in January 2021.*

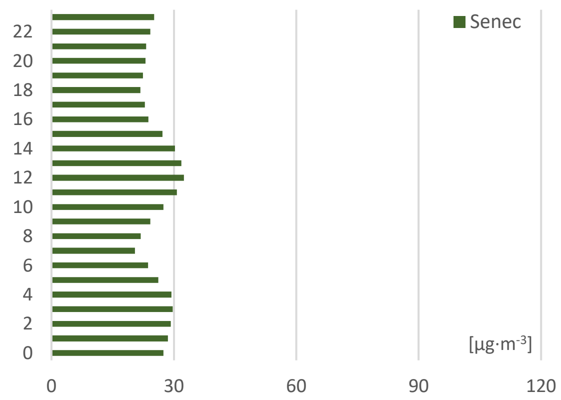
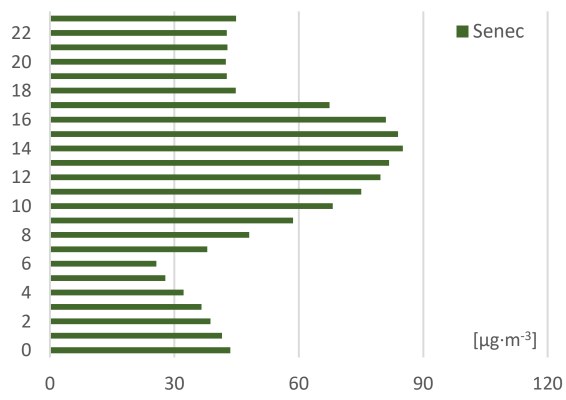


Fig. 3.16 *Daily O_3 concentration in September 2021.*

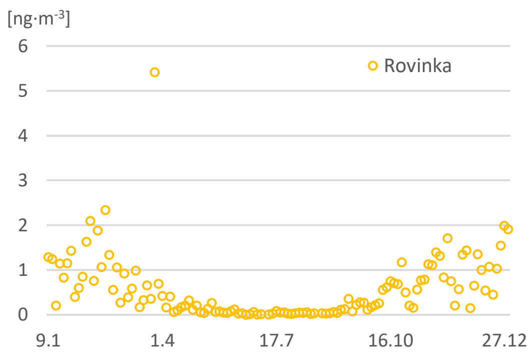


3.2.4 Benzo(a)pyrene

In the zone Bratislava region, benzo(a)pyrene is monitored at monitoring station Rovinka (**Fig. 3.17**). The annual average concentration in 2021 was 0.6 ng·m^{-3}, thus did not exceed the target value (1 ng·m^{-3}).

Higher levels of benzo(a)pyrene occur in winter, reflecting poor dispersion conditions in the area andlocally (to a lesser extent than in other areas) also the effect of domestic heating.

Fig. 3.17 *Results of benzo(a)pyrene measurements 2021.*



Tab. 3.4 *Assessment of air pollution by benzo(a)pyrene.*

	2017	2018	2019	2020	2021
Target value [ng·m⁻³]	1.0	1.0	1.0	1.0	1.0
Rovinka				0.4	0.6

4 AIR QUALITY MODELLING

Fig. 4.1 and **Fig. 4.2** show results of PM_{10} modeling 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 2021 Report*). For better clarity, only areas are shown for which the average annual concentration values were higher than the stricter annual limits recommended by the WHO. The results of modeling with a higher resolution are processed for 2019 in a separate study[5].

Fig. 4.1 *Average annual PM_{10} concentration in 2021 (RIO< IDW-R). Only values above 15 µg·m^{-3} are shown.*

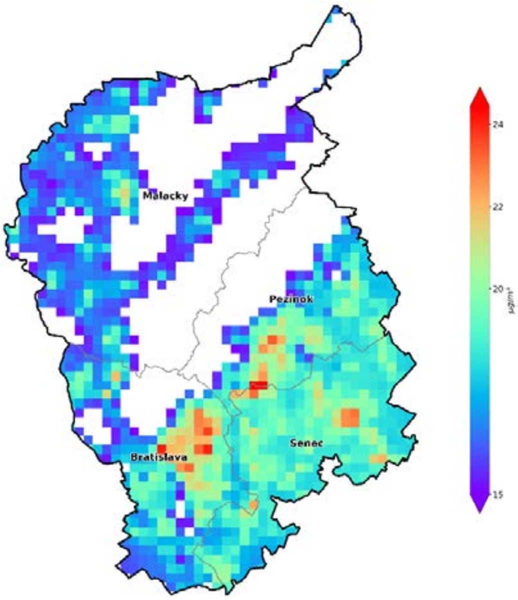


Fig. 4.2 *Number of exceedances of the PM_{10} daily limit value in 2021 (RIO, IDW-R). Only non-zero number of exceedances are shown*

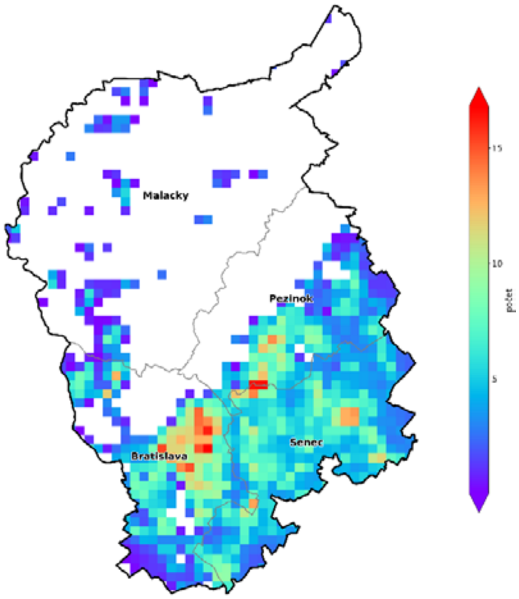


Fig. 4.3 shows the spatial distribution of average annual $PM_{2.5}$ concentrations according to the output of the RIO model in combination with the IDW-R model. According to the outputs of the model, the average annual concentration of $PM_{2.5}$ in the entire territory of the zone was higher than the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

[5] *Krajčovičová et al.: Štúdia kvality ovzdušia v aglomerácii Bratislava. SHMÚ.2020. available on https://www.shmu.sk/File/oko/studie_analyzy/Studia_BA_2020.pdf*

Fig. 4.3 *Annual average $PM_{2.5}$ in 2021 (RIO, IDW-R).*

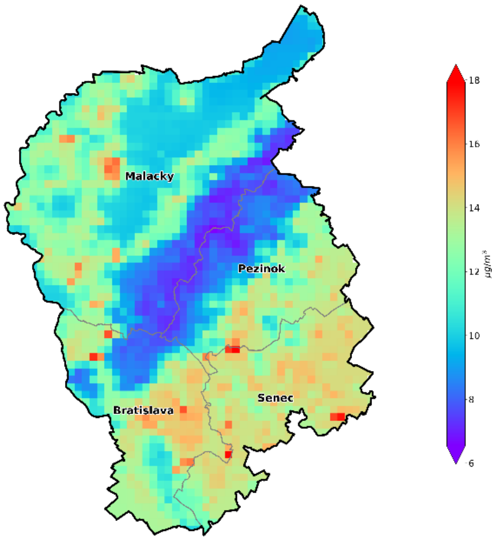
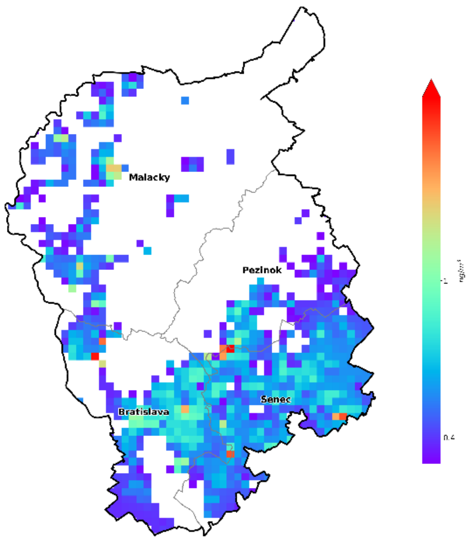


Fig. 4.4 *Annual average benzo(a)pyrene in 2021 (RIO, IDW-R).*



The map of the spatial distribution of average annual concentrations of benzo(a)pyrene according to the output of the RIO, IWD-R model (**Fig. 4.4**) shows the occurrence of higher concentrations in the area of Malacky, Gajary, Zohor, Hruba Borša and Slovenský Grob. However, for more accurate information, it would be necessary to carry out high-resolution modeling supplemented by monitoring for the mentioned areas.

4.1 Risk areas

Fig. 4.5 *Risk areas in Bratislava region.*

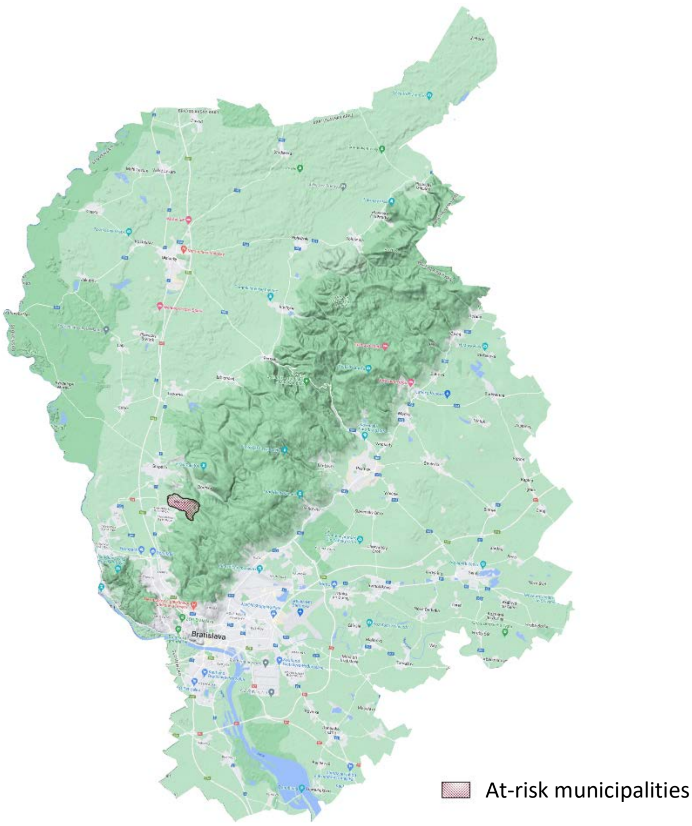


Fig. 4.5 shows the areas at risk of air quality deterioration due to pollutants (PM and benzo(a)pyrene) from domestic heating based on the modelling results. The modelling results were obtained by using the methodology of D. Štefánik: *Identification of at-risk municipalities with air quality threatened by local heating and adverse dispersion conditions (updated in 2022)*[6].

According to available data, the Bratislava region has the smallest number of at-risk municipalities of all regions (1 municipality). The reason is the terrain, which allows mostly good ventilation and a lower proportion of solid fuels for household heating.

It should be noted that the assessment is based on data from PHC 2021, which did not yet reflect the impact of the energy crisis. More detailed data on the type and consumption of fuels and the type of heating equipment at the level of municipalities and their parts are a necessary input for checking and refining the definition of risk areas. Also for high-resolution modeling, the outputs of which would help quantify the share of different types of sources and the contribution of regional background to air pollution.

5 SUMMARY

According to the monitoring results, the limit values for PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO and benzene were not exceeded in 2021 in the Bratislava agglomeration or in the zone Bratislava region.

Similarly, the target value for the annual mean concentration of benzo(a)pyrene was not exceeded at any NMSKO station. In the agglomeration Bratislava and the zone Bratislava region, no pollutant exceeded the limit value or the target value in the last three years. Therefore, no air quality management areas are defined in this agglomeration and zone on the basis of monitoring.

Based on the outputs of the study *Krajčovičová et al.: Štúdia kvality ovzdušia v aglomerácii Bratislava* (SHMÚ 2020)[7] we can conclude that in the Bratislava agglomeration, PM and NO_2 concentrations higher than the measured values at the traffic station Trnavské mýto may occur in the vicinity of busy canyon-type roads.

The impact of the petrochemical complex, located in Bratislava, Vlčie hrdlo, is only episodically manifested in the Bratislava agglomeration and in the neighbouring part of the zone Bratislava region, as shown by mathematical modelling with high spatial resolution. In general, on the basis of the available data, the zone Bratislava region can be classified as less problematic in terms of air quality.

[6] *https://www.shmu.sk/File/oko/mesacne_spravy/Popis_metody_na_urcenie_rizikovych_oblasti_aktualizacia.pdf*
[7] *https://www.shmu.sk/File/oko/studie_analyzy/Studia_BA_2020.pdf*