2022

AIR POLLUTION IN THE SLOVAK REPUBLIC

Air quality monitoring department
SLOVAK HYDROMETEOROLOGICAL INSTITUTE

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Analyses of air and atmospheric precipitation samples were carried out in the SHMÚ Testing laboratory.

CONTENT

FOREWORD

Every year the Slovak Hydrometeorological Institute (SHMÚ) publishes the Report on Air Quality in the Slovak Republic, which is one of the results of the systematic and professional work of the staff of the Air Quality Division.

The issue of air quality is not completely understandable for everyone, so we have tried to prepare the publication in such a way that not only experts, but also the general public can find important and necessary information in it.

The report includes results combining monitoring and modelling of air quality, which we, as an authorised organisation, carry out for the whole territory of the Slovak Republic. The resulting assessment is the result of the work of all the sections of the Air Quality Department, while the participation of other parts of the Institute, without whose help it would not have been possible to prepare this report, cannot be neglected.

We are the only organisation in Slovakia that carries out long-term monitoring of ambient air quality 24 hours a day, 365 days a year. The operation of the monitoring is directly dependent on funding from the state budget and the expansion and renewal of the monitoring network on funding from the European Union.

As part of the National Air Quality Monitoring Network Improvement Project, we have been able to prepare new stations for extended accreditation in 2022. Measurements are made using reference methods. The results of continuously monitored pollutants are published every hour on the SHMÚ website (*www.shmu.sk*) in the Air Quality section, where, besides the current ones, other important information can be found. The assessment of other pollutants, for which we carry out manual sampling and subsequent analysis in laboratories, is available later on in this Report.

In areas where we do not have monitoring stations, or to obtain spatial information about the air condition in the whole territory of Slovakia, we use air quality modelling. The main task of the Report is to identify areas with poor air quality based on the air quality assessment for the past year.

The year 2022 was exceptional as we obtained the first full year of air quality monitoring results at the new stations. For both PM_{10} and $PM_{2.5}$, we recorded exceedances of limit values at a total of 3 stations, 1 of which is newly established. This is AMS Plášťovce, where we can clearly attribute the exceedances of the limit values of PM particles to local heating stations (as there is no heavy traffic and industrial sources) – family houses that heat with solid fuel. Besides, another of the new stations, Žarnovica, only just missed the limit value for $PM_{2.5}$. As in previous years, the target value for the carcinogenic benzo(a)pyrene was exceeded at several stations, some of them new ones (Plášťovce, Žarnovica, Púchov and Oščadnica). This points to a potentially serious air quality problem also in unmonitored locations in Slovakia with worsened dispersion conditions and a higher share of solid fuels in heating. In order to improve air quality in Slovakia, it will therefore be necessary to focus in particular on local heating sites.

Ministry of the Environment of the Slovak Republic Act No. 137/2010 Coll. on air as amended, in order to ensure public information on air quality, authorized the Slovak Hydrometeorological Institute with the preparation and publication of:

- Report on air quality assessment in the Slovak Republic;
- Information on air quality.

With this report, the Slovak Hydrometeorological Institute, as an authorized organization, fulfils the obligations arising from §13 paragraph (1) letter c) and d) of the quoted Act and submits to the lay and professional public a report that contains all the details as required by Act No. 137/2010 Coll. on air, as amended[1].

[1] *The new Act No. 146 Call. on air protection comes into force on 1 July 2023.*

1 DESCRIPTION OF TERRITORY OF THE SLOVAK REPUBLIC IN TERMS OF AIR QUALITY

Pollutants of various physical and chemical properties are released into the atmosphere from natural sources or as a consequence of human activity. Air quality depends not only on the quantity of emissions and spatial distribution of air pollution sources, but also on meteorological conditions and the characteristics of the surrounding terrain.

Among the processes which influence air pollutants are included change of consistency (e.g. condensation of hot combustion products leaking from stacks at cooling), chemical reactions (e.g. oxidation of NO to NO_2 from road transport), transport in horizontal and vertical direction (advection, convection), dry, wet and hidden deposition. Dry deposition performs interception of pollutants on the earth surface, or on vegetation. Wet deposition means washing out by atmospheric precipitation, which by this way very effectively diminish air pollutant concentrations and enable their transport into the other components of environment – water, soil and sediments. Hidden deposition is the trapping of fog droplets (or clouds) on various surfaces, especially plant surfaces. This has a more important role in forest covers and in mountainous areas.

Orography affects the speed and direction of air flow and is one of the characteristics, determining the conditions for dispersion of pollutants, which are unfavourable at the territory of Slovakia, mainly in closed mountain basins. Frequent occurrence of inversions in these regions is the factor complicating pollutant dispersion and is one of the reasons of high pollutant concentration occurrence in winter seasons. Potential long-range transport of pollutants depends upon the weather conditions. Some of these pollutants can remain in air also several days. In the following text is introduced the short characteristics of the territory of SR from the aspects of orography and meteorological elements, which mostly influence the air quality.

Wind conditions

The direction of air flow in Central Europe is mostly influenced by the general air circulation and the relief of the landscape. In Slovakia, prevails west and northwest air circulation (being modified in some locations, mainly in passes, valleys and basins as a consequence of relief). In Záhorie, southeast wind prevails over the northwest, in Danube lowlands it is opposite case. Northern air convection dominates in middle Považie, Ponitrie and east Slovakia. In the lowlands of western Slovakia, the average annual wind speed at a height of 10 meters above the surface ranges from 3 to 4 $m \cdot s^{-1}$, in eastern Slovakia from 2 to 3 $m \cdot s^{-1}$.

In basins, the wind depends upon their location and openness towards the prevailing convection. Annual average wind velocity is in more open basins (e.g. Považie valley, Podtatranská basin, Košice basin) 2 – 3 $m \cdot s^{-1}$. In more closed basins, where is the major occurrence of inversions (e.g. Zvolen basin, Žiar basin, Žilina basin) it is 1 – 2 $m \cdot s^{-1}$ and in closed basins (e.g. Brezno basin, Rožňava basin, western part of Liptov basin in Ružomberok region) there is a more frequent occurrence of calm and average wind speeds are often even lower.

In mountains, the annual average wind velocity reaches 4 – 8 $m \cdot s^{-1}$. In lower areas there are also localities (Košice, Bratislava) with annual average wind velocity higher than 4 $m \cdot s^{-1}$, at the same time Bratislava belongs to the windiest cities in central Europe.

Well-ventilated regions can be characterized by lower pollutant concentrations, despite of nearby sources of air pollution.

- **Atmospheric precipitation**

  The amount of precipitation in Slovakia generally increases with altitude by approximately 50 – 60 mm per 100 m of height. Their annual sum varies from 500 mm (eastern part of Žitný ostrov, region Galanta and Senec) to 2 000 mm (the High Tatras).

  Relatively low precipitation totals are in the so-called rain shadow of mountains. It concerns e.g. Spiš basins, which are relatively dry and protected from southwest up to northwest by the Low Tatras and from south by Slovak Rudohorie.

  The major amount of precipitation occurs in June, July and August (40% – most rainy is June or July), in spring 25%, in autumn 20% and in winter 15% (the least amount of precipitation is in January, February and March).

  Large precipitation variability within the year causes mainly in lowlands often and sometimes long-lasting dry periods, creating conditions for increased erosion of soil not covered by vegetation. The Danube lowland, which is the warmest and relatively windiest area of Slovakia, belongs to the driest regions.

1.1 COUNTRY BREAKDOWN INTO AGGLOMERATIONS AND ZONES IN 2022

Pollution sources are not evenly distributed in the country. Due to the effective air quality assessment according to Directive 2008/50/EC of the European parliament and the Council on ambient air quality and cleaner air in Europe, as well as legislation of the Slovak Republic (e.g. Regulation of MoE SR No. 244/2016 Coll. of Acts on air quality, as amended), the territory of the Slovak Republic is divided into zones and agglomerations.

The list of agglomerations and zones is published in Appendix No. 11 to Regulation of MoE SR No. 244/2016 Coll. of Acts on air quality, as amended, and is published on the SHMÚ webpage (*https://www.shmu.sk/sk/?page=1&id=oko_info_az*).

1.1.1 Country breakdown into zones and agglomerations in 2022, for SO_2, NO_2, NO_X, PM_{10}, $PM_{2.5}$, benzene, polycyclic aromatic hydrocarbons and CO

Agglomerations: Bratislava (territory of the capital of the Slovak Republic, Bratislava), Košice (territory of the Košice city and municipalities Bočiar, Haniska, Sokoľany and Veľká Ida)
Zones: Banská Bystrica region, Bratislava region (without Bratislava agglomeration), Košice region (without Košice agglomeration), Nitra region, Prešov region, Trenčín region, Trnava region and Žilina region

More detailed information on zones and agglomerations are provided in the Annexes of this Report.

Tab. 1.1 contains information on the area and population of NUTS 3 regions according to the data available on the web pages of Statistical Office of the Slovak Republic.

Tab. 1.1 *Area and population in Slovak NUTS 3 regions.*

		Area [km^2]	Population*
Bratislava region	(Bratislavský kraj)	2 053	728 370
Trnava region	(Trnavský kraj)	4 146	565 573
Trenčín region	(Trenčiansky kraj)	4 502	570 675
Nitra region	(Nitriansky kraj)	6 344	670 696
Žilina region	(Žilinský kraj)	6 809	688 106
Banská Bystrica region	(Banskobystrický kraj)	9 454	617 777
Prešov region	(Prešovský kraj)	8 973	808 090
Košice region	(Košický kraj)	6 754	779 505

** Status to 31. 12. 2022*
Source: Statistical Office of the SR

1.1.2 Country breakdown into zones and agglomerations in 2022 for arsenic, cadmium, nickel, lead and ozone

Agglomeration: Bratislava (territory of the capital city of the Slovak Republic, Bratislava)

Zone: Slovakia (apart from Bratislava agglomeration)

The heavy metals As, Cd, Ni and Pb are currently not a problem in terms of exceeding limit or target values in the territory of the Slovak Republic. The share of solid fuels in domestic heating is still high in our territory. In contrast to neighbouring Poland, where there is a higher share of coal combustion, in our territory it is mainly wood combustion. Wood burning does not have a significant impact on arsenic concentrations in the air.

Tropospheric ozone is a regional issue, with a significant contribution from stratospheric transport and significant transboundary transport[2]. Road transport in major cities is a source of ozone precursors, but nitrogen oxides also cause ozone titration (the chemical reaction of ozone with oxides nitrogen, in which ozone decomposes) in the vicinity of the busiest roads. The ozone target value for the protection of human health is exceeded in several places in the territory of the Slovak Republic, particularly in the more photochemically active years, and there is limited scope for local actions to improve the situation.

[2] *EMEP Status Report 1/2021, Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components https://emep.int/publ/reports/2021/EMEP_Status_Report_1_2021.pdf*

2 AIR QUALITY MONITORING NETWORK

Despite of the fact, the first air pollutant measurements in Slovakia were carried out in the second half of the fifties in 20th century, systematic monitoring in our territory begun in 1967, when the first Act on air protection (Act No. 35/1967 Coll. of Acts about measures against air pollution) entered into force. Measurements, which included at the beginning only SO_2 and dust fallout in Bratislava, Košice and surrounding, were gradually supplemented for other air pollutants and locations. Legislation has changed over time – adding more pollutants to be monitored and tightening the limit values. An example of the latest modification is the reduction of the limit value for the $PM_{2.5}$ annual average concentration, which has been changed to 20 $\mu g \cdot m^{-3}$ from 2020 (the previous limit value was 25 $\mu g \cdot m^{-3}$). The current form of legislation in the Slovak Republic is an implementation of EU legislation. Tightening of legislative frameworks can be expected in the near future, especially in the wake of the new WHO recommendations on air quality presented in September 2021 and the proposal for a new Directive of the European Parliament and of the Council on Air Quality and Cleaner Air in Europe - 2022/0347 (COD).

As the aim of monitoring is to characterize air quality as best as possible, taking into account human health protection, the structure of monitoring network was proposed in such a way, as the individual stations characterize the extent of pollution in major pollution areas – in past those were mainly locations in vicinity of large industrial air pollution sources. These stations are also now a part of monitoring network, similarly as locations exposed to emissions from road transport. Air quality monitoring at regional background stations also has an important role to play in assessing long-term air quality trends, as for other stations these trends are mainly influenced by local sources of pollution. Locations, sufficiently distant from sources of anthropogenic air pollution, are also covered by monitoring. Monitoring stations located in these areas are called the regional background stations. Pollutants depending on their properties (e.g. sedimentation velocity, chemical reactivity) can persist in air even several days and according to air masses convection, can be transported on large distances. High concentrations of air pollutants can be therefore find also in relatively clean mountainous areas. Monitoring of air quality in regional background stations plays essential role also at the assessment of long-term air quality trends, because in case of other stations these trends are influenced predominantly by local sources.

Network of measurement stations under the name National monitoring air quality network (NMSKO) started to be build up already in ČSFR in 1991[3]. Currently, it comprises continual measurements using automatic instruments and manual measurements based on the sampling and chemical analyses in the SHMÚ Testing laboratory as well as other external laboratories. Manual monitoring covers the air measurements of heavy metal concentrations, volatile organic compounds VOC and polycyclic aromatic hydrocarbons PAH in air and also air quality monitoring and analyses of precipitation quality on regional background stations, with monitoring programme EMEP (Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe). Location of NMSKO network monitoring stations and their measurements programme in year 2022 is presented in **Fig. 2.1**.

Detailed list of monitoring instruments of individual stations and methods which instruments used is described in "Annex A – Measurement stations of monitoring air quality networks – 2022".

The UN ECE Convention on Long Range Transboundary Air Pollution (CLRTAP) was signed in Geneva in 1979. Up to now, in frame of the Convention were signed eight protocols. The first one among them was Protocol on Long-term Financing of the Co-operative Programme for Monitoring and Evaluation of the Long-range Transport of Air Pollutants in Europe (EMEP) (Geneva, 1984).

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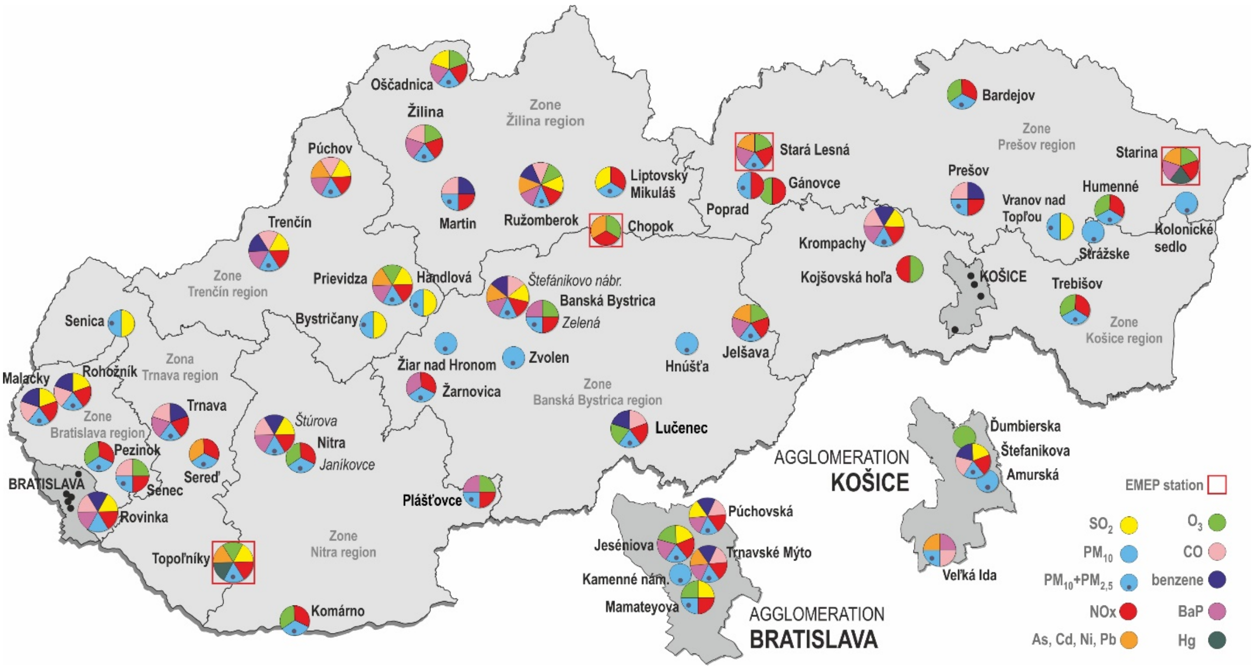
[3] *Dušan Závodský: História monitoringu a hodnotenia kvality ovzdušia na Slovensku. Meteorologický časopis 4/2010. Available: https://www.shmu.sk/File/ExtraFiles/MET_CASOPIS/2010-4_MC.pdf*

EMEP's goal is to monitor, model and evaluate the long-range transport of air pollutants in Europe and develop the basis for an international emission reduction strategy Today, the EMEP monitoring network comprises about 180 regional stations including four Slovak EMEP stations belonging to the national monitoring air quality network (NMSKO). The first EMEP station at the territory of the SR was established at Chopok meteorological observatory of SHMÚ, at an altitude of 2008 m. Measurements of air quality were put into operation already in 1977.

The monitoring programme of the EMEP network was gradually expanded at the stations. Measurements of sulphur compounds and precipitation analyses were complemented by nitrogen oxides, nitrates, ammonium ions in ambient air, particulate matter and ozone. In 1994, the measurements of volatile organic compounds (VOCs) began to be carried out in cooperation with the EMEP International Chemical Coordination Centre – NILU (the Norwegian Institute for Air Research in Kjeller). Later, measurements of heavy metals (HMs) and, from autumn 2020, organic and elemental carbon EC/OC in air were also included in the programme.

Fig. 2.1 National air quality monitoring network in year 2022.



Tab. 2.1 contains information about air quality monitoring stations belonging to NMSKO according to agglomerations and zones:

- characteristics of stations according to the dominant air pollution sources (traffic, background, industrial), the type of region, which individual station monitors (urban, suburban, rural/regional) and geographical coordinates;
- monitoring programme. Automatic continuous monitoring devices provide annual hourly concentrations of PM_{10}, $PM_{2.5}$, oxides of nitrogen, sulphur dioxide, ozone, carbon monoxide, benzene and mercury. The SHMÚ Testing laboratory in frame of manual monitoring analyses heavy metals and polycyclic aromatic hydrocarbons and the results are mean 24-hours values. Exceptions are EMEP stations, the monitoring programme of which is described in **Tab. 2.2** and **Tab. 2.3**.

__Tab. 2.1__ National air quality monitoring network (NMSKO).

AGGLOMERATION Zone	Station name	Type of area	Type of station	Continuously PM$_{10}$	PM$_{2.5}$	Oxides of nitrogen NO, NO_2, NO_X	Sulphur dioxide SO_2	Ozone O_3	Carbon monoxide CO	Benzene	Mercury Hg	Manually Heavy metals As, Cd, Ni, Pb	Polyaromatic hydrocarbons BaP
BRATISLAVA	Bratislava, Kamenné nám.	U	B	x	x								
	Bratislava, Trnavské mýto	U	T	x	x	x			x	x		x	x
	Bratislava, Jeséniova	S	B	x	x	x	x	x					x
	Bratislava, Mamateyova	U	B	x	x	x	x	x					
	Bratislava, Púchovská	U	T	x	x	x	x		x	x			x
	5 stations in total			5	5	4	3	2	2	2		1	3
KOŠICE	Košice, Amurská	U	B	x	x								
	Košice, Štefánikova	U	T	x	x	x	x		x	x			
	Košice, Ďumbierska	S	B					x					
	Veľká Ida, Letná	S	I	x	x				x			x	x
	4 stations in total			3	3	1	1	1	2	1		1	1
Banská Bystrica region	Banská Bystrica, Štefánikovo nábr.	U	T	x	x	x	x		x	x		x	x
	Banská Bystrica, Zelená	U	B	x	x	x		x					x
	Jelšava, Jesenského	U	B	x	x	x		x				x	x
	Hnúšťa, Hlavná	U	B	x	x								
	Lučenec, Gemerská cesta	U	T	x	x	x		x	x	x			
	Žiar nad Hronom, Jilemnického	U	B	x	x								
	Žarnovica, Dolná	S	B	x	x	x							x
	Zvolen, J. Alexyho	U	B	x	x								
	8 stations in total			8	8	5	1	3	2	2		2	4
Bratislava region	Malacky, Mierové nám.	U	T	x	x	x	x		x	x			
	Pezinok, Obrancov mieru	U	B	x	x	x		x					
	Rovinka	S	B	x		x	x		x	x			x
	Rohožník, Senická	U	T	x	x	x	x		x	x			
	Senec, Boldocká	U	T	x	x	x		x	x				
	4 stations in total[4]			4	3	4	2	2	3	2			1
Košice region	Kojšovská hoľa	R	B			x		x					
	Trebišov, T. G. Masaryka	S	B	x	x	x		x					
	Strážske, Mierová	U	B	x	x								
	Krompachy, SNP	U	T	x	x	x	x		x	x			x
	4 stations in total			3	3	3	1	2	1	1			1
Nitra region	Nitra, Štúrova	U	T	x	x	x	x		x	x			x
	Nitra, Janíkovce	U	B	x	x	x		x					
	Komárno, Vnútorná Okružná	U	B	x	x	x		x					
	Plášťovce	S	B	x	x	x		x					x
	4 stations in total			4	4	4	1	3	1	1			2
Prešov region	Humenné, Nám. Slobody	U	B	x	x	x		x					
	Stará Lesná, AÚ SAV, EMEP	R	B	x	x	x		x				x	x
	Gánovce, Meteo. st.	R	B			x		x					
	Poprad, Železničná	S	B	x	x	x							
	Prešov, Arm. gen. L. Svobodu	U	T	x	x	x			x	x			
	Starina, Vodná nádrž, EMEP	R	B			x		x			x	x	x
	Vranov nad Topľou, M. R. Štefánika	U	B	x	x		x						
	Kolonické sedlo	R	B	x	x								
	Bardejov, Pod Vinbargom	S	B	x	x	x		x					
	9 stations in total			7	7	7	1	5	1	1	1	2	2

[4] *AMS Malacky replaced AMS Rohožník*

AGGLOMERATION Zone	Station name	Type of		Continuously								Manually	
		area	station	PM_{10}	$PM_{2.5}$	Oxides of nitrogen NO, NO_2, NO_X	Sulphur dioxide SO_2	Ozone O_3	Carbon monoxide CO	Benzene	Mercury Hg	Heavy metals As, Cd, Ni, Pb	Polyaromatic hydrocarbons BaP
Trenčín region	Prievidza, Malonecpalská	U	B	x	x	x	x	x				x	x
	Bystričany, Rozvodňa SSE	S	B	x	x		x						
	Handlová, Morovnianska cesta	U	B	x	x		x						
	Trenčín, Hasičská	U	T	x	x	x	x		x	x			x
	Púchov, 1. mája	S	B	x	x	x	x		x			x	x
	5 stations in total			5	5	3	5	1	2	1		2	3
Trnava region	Topoľníky, Aszód, EMEP	R	B	x	x	x	x	x			x	x	
	Senica, Hviezdoslavova	U	T	x	x		x						
	Trnava, Kollárova	U	T	x	x	x			x	x			x
	Sereď, Vinárska	U	B	x	x	x						x	
	4 stations in total			4	4	3	2	1	1	1	1	2	1
Žilina region	Chopok, EMEP	R	B			x		x				x	
	Martin, Jesenského	U	T	x	x	x			x	x			
	Ružomberok, Riadok	U	B	x	x	x	x	x	x	x		x	x
	Žilina, Obežná	U	B	x	x	x		x	x				x
	Oščadnica	S	B	x	x								x
	Liptovský Mikuláš, Školská	U	B	x	x	x	x						
	6 stations in total			5	5	6	3	4	3	2		2	3
NMSKO altogether 53 monitoring stations [5]				48	47	40	20	24	18	14	2	12	21

Type of area: U – urban, S – suburban, R – rural/regional
Type of station: B – background, T – traffic, I – industrial

Air quality monitoring programme on EMEP stations in year 2022 is listed in **Tab. 2.2**. Ozone is measured continuously. The sampling interval for heavy metals is every third day in Topoľníky and Stará Lesná, and weekly in Starina and Chopok. VOCs are sampled at weekly intervals. Other pollutants are sampled at 24-hour intervals.

Tab. 2.2 *Measurement programme of EMEP stations – air.*

	Ozone (O_3)	Sulphur dioxide (SO_2)	Nitrogen dioxide (NO_2)	Sulphates (SO_4^{2-})	Nitrates (NO_3^-)	Nitric acid (HNO_3)	Chlorides (Cl)	Ammonia, Ammonium ions (NH_3, NH_4^+)	Alkali ions (K^+, Na^+, Ca^{2+}, Mg^{2+})	VOC	PM_{10} / TSP*	EC/OC	Lead (Pb)	Arsenic (As)	Cadmium (Cd)	Nickel (Ni)	Chromium (Cr)	Cooper (Cu)	Zinc (Zn)	Mercury (Hg)**
Chopok	x	x	x	x	x	x	x				x*		x	x	x	x	x	x	x	
Topoľníky	x										x		x	x	x	x	x	x	x	x
Starina	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
Stará Lesná	x										x	x	x	x	x	x	x	x	x	

** TSP – total suspended particles*
*** mercury is monitored out of EMEP monitoring programme*

[5] *52 stationary stations and one mobile station in Rovinka*

Precipitation quality (pH, conductivity, sulphates, nitrates, chlorides, ammonium and alkali ions) is analysed from samples, collected on EMEP stations, according to the monitoring programme, listed in **Tab. 2.3**, either on a daily basis (Chopok, Starina), or weekly basis (Topoľníky, Stará Lesná); precipitation quality at station Bratislava, Jeséniova is measured once a month. Results of analyses are weekly or monthly average values, depending on sampling interval.

Sampling precipitation intervals for heavy metal analyses are one month, apart from the EMEP station Starina with weekly sampling. Two types of precipitation collectors are used for precipitation sampling: "wet-only" and "bulk". "Wet-only" is precipitation collector measuring precipitation only – wet deposition is evaluated on the basis of the samples collected. Type "Bulk" (i.e. 'whole') samples collects both dry and wet deposition. This kind of sampling is carried out on the Chopok station, where the precipitation sampling is done into the open container due to unfavourable weather.

Tab. 2.3 *Measurement programme of precipitation on EMEP stations and on station Bratislava, Jeséniova.*

	pH	Conductivity	Sulphates (SO_4^{2-})	Nitrates (NO_3^-)	Chlorides (Cl^-)	Ammonium ions (NH_4^+)	Alkali ions (K^+, Na^+, Ca^{2+}, Mg^{2+})	Lead (Pb)	Arsenic (As)	Cadmium (Cd)	Nickel (Ni)	Chromium (Cr)	Copper (Cu)	Zinc (Zn)
Chopok	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Topoľníky	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Starina	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Stará Lesná	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Bratislava, Jeséniova	x	x	x	x	x	x	x	x	x	x	x	x	x	x

2.1 ASSESSMENT OF MONITORING EXTENT FOR PARTICULAR POLLUTANTS

Sulphur dioxide SO_2

This pollutant was monitored at 20 stations. Minimum required extent of monitoring[6] was fulfilled. Monitoring of sulphur dioxide was carried out continuously, using reference method, at all 20 stations. The required number of valid measured data (90%) was achieved at 18 monitoring stations. SO_2 measurements started at AMS Oščadnica at the beginning of 2022. The Malacky monitoring station ceased measurement on 29 April 2022 and was replaced by the Rohožník AMS on 5 August 2022.

Oxides of nitrogen NO_2 and NO_X

This pollutant was monitored at 40 stations. The minimum required monitoring coverage[6] was fulfilled. Nitrogen oxides were monitored continuously by the reference method at all 40 stations. The required number of valid measured data (90%) was achieved at 37 monitoring stations. Measurement of NO_2 at AMS Oščadnica started at the beginning of 2022. Monitoring station Malacky ceased measurement on 29 April 2022 and was replaced by AMS in Rohožník on 14 June 2022. The required number of valid measurements was not met at AMS Rovinka due to frequent power outages and faults on the electrical connection.

[6] *Number and location according to Annex No. 6 to Decree No. 244/2016 Coll. of the Ministry of Environment of the Slovak Republic. on air quality, as amended.*

- **Particulate matter PM_{10}**

This pollutant was monitored at 48 stations. The minimum required monitoring coverage[6] was met. PM_{10} monitoring was provided by the equivalent, continuous oscillation microbalance method (TEOM devices) and the beta radiation absorption method (BAM devices). The required number of valid measured data (90%) was reached at 47 monitoring stations AMS Malacky ceased measurement on 29 April 2022 and was replaced by AMS in Rohožník on 17 June 2022[7].

- **Particulate matter $PM_{2.5}$**

This pollutant was monitored at 47 stations. The minimum required monitoring coverage[6] was fulfilled. $PM_{2.5}$ monitoring was provided by the same method as PM_{10} measurements, by TEOM and BAM devices. The required number of valid measured data (90%) was reached at 46 monitoring stations. AMS Malacky ceased measurement on 29 April 2022 and was replaced by AMS Rohožník on 15 June 2022.

- **Carbon monoxide CO**

This pollutant was monitored at 18 monitoring stations. The minimum required monitoring coverage[6] was fulfilled. Carbon monoxide was monitored continuously, by reference method, at 18 stations. The required number of valid measured data (90%) was reached at 17 monitoring stations. AMS Malacky ceased measurement on 29 April 2022 and was replaced by AMS Rohožník on 15 June 2022. CO concentrations are below the lower limit assessment threshold (LAT), the number of monitoring sites is therefore sufficient.

- **Ozone O_3**

Ozone was monitored at 24 monitoring stations. The minimum required monitoring coverage[6] was fulfilled. Ozone was monitored continuously, using reference method, at all 24 stations. The required number of valid measured data (90%) was achieved at 21 monitoring stations. Data from 3 stations will be added to the database after processing.

- **Benzene**

Benzene was monitored at 14 monitoring stations. The minimum required monitoring coverage[6] was met. Monitoring of benzene was provided continuously, by the reference method, at all 14 stations, continuously by reference method. Required number of valid measured data (90%) was reached at 13 stations. AMS Malacky ceased measurement on 29 April 2022 and was replaced by AMS Rohožník on 7 July 2022.

- **Mercury**

Overall gas mercury was monitored at two EMEP stations (Topoľníky and Starina). Mercury monitoring was secured continuously, by differential Zeeman atomic absorption spectrometry. The proportion of valid measured data exceeded 90% at monitoring station Starina. The proportion of valid data at the EMEP station Topoľníky is 87% due to technical reasons. The measurement is in spite of the outage is representative for the year-long assessment as the concentrations fluctuate only slightly during the year.

- **Heavy metals (Pb, As, Cd, Ni)**

Heavy metals were monitored at 12 monitoring stations. Samples for heavy metal analysis are collected at the urban stations every other day during 24 hours on nitrocellulose filter, then analysed at the SHMÚ Testing laboratory by gas chromatography. In 2022, heavy metals (Pb, As, Cd, Ni) were sampled at one suburban, seven urban and four EMEP monitoring stations.

[7] *Therefore, the number of stations in the overall evaluation shows the AMS in Malacky and Rohožník as one AMS.*

- **Polyaromatic hydrocarbons – benzo(a)pyrene**

  In 2022, benzo(a)pyrene monitoring was provided at 21 monitoring stations. Sampling was realized every third day for 24 hours on a quartz filter. After extraction, the samples are analysed at the SHMÚ Testing laboratory by gas chromatography with mass detection (GC-MS). The minimum required number of monitoring stations[6] was fulfilled.

- **VOC**

  Volatile organic compounds $C_2 – C_8$, or so-called light hydrocarbons, started to be sampled at Starina station in the autumn of 1994. Starina is one of the few European stations included into the EMEP network with regular monitoring of VOCs. The analyses are carried out at the Central Laboratory of Air Quality (CLI) of the Czech Hydrometeorological Institute by inductively method coupled plasma gas chromatography.

- **EC/OC**

  In autumn 2021, in accordance with the EMEP monitoring strategy, monitoring of organic and elementary carbon in $PM_{2.5}$ started at Stará Lesná station. Chemical analyses are carried out at Central Laboratory of Air Quality (CLI) of the Czech Hydrometeorological Institute.

- **Air quality monitoring on EMEP stations**

  Air quality measurements were realized at all four EMEP monitoring stations (**Tab. 2.2**) in accordance with the EMEP monitoring strategy according to the approved monitoring programme.

- **Atmospheric precipitation monitoring on EMEP stations**

  Precipitation quality measurements were carried out at all four EMEP monitoring stations in accordance (**Tab. 2.3**) with the EMEP monitoring strategy according to the approved monitoring programme.

Apart from air quality monitoring stations in the NMSKO network, monitoring stations operated by operators of major air pollution sources (VZZO) are also established in the territory of the Slovak Republic for the purpose of monitoring air pollution level. The decision for establishing VZZO station is issued by the District Office, in region headquarters. The data from VZZO monitoring stations, that passed the functional tests (**Tab. 2.4**), serve as the supplementing data, to the NMSKO network measurements for the air quality assessment, provided that they were obtained by a reference or equivalent method. The concentrations of those pollutants, monitored in case of VZZO by different method (Annex A) are nevertheless important information for the air quality assessment.

Tab. 2.4 *Monitoring stations of other operators of large air pollution sources (VZZO).*

	District	Station name *	Type of		Geographical		Altitude [m]
			area	station	longitude	latitude	
BRATISLAVA	Bratislava II	Bratislava, Vlčie Hrdlo (Slovnaft, a.s.)	S	I	17°10'13"	48°07'41"	134
	Bratislava II	Bratislava, Pod. Biskupice (Slovnaft, a.s.)	U	B	17°13'01"	48°07'42"	132
KOŠICE	Košice II	Košice, Haniska (U.S. Steel, s.r.o.)	S	I	21°15'07"	48°36'54"	212
	Košice II	Košice, Poľov (U.S. Steel, s.r.o.)	R	B	21°11'54"	48°39'40"	271
Bratislava region	Senec	Rovinka (Slovnaft, a.s.)	S	B	17°13'34"	48°06'05"	133
Košice region	Košice okolie district	Veľká Ida (U.S. Steel, s.r.o.)	S	I	21°10´12"	48°33´35"	208
	Trebišov	Leles (Slovenské elektrárne, a.s.)	R	B	22°01´23"	48°27´46"	100
Nitra region	Šaľa	Trnovec nad Váhom (Duslo, a.s.)	S	B	17°55'43"	48°08'60"	117
Trenčín region	Prievidza	Oslany (Slovenské elektrárne, a.s.)	S	B	18°28´12"	48°37´60"	228
Žilina region	Ružomberok	Ružomberok (Mondi a.s. - Supra)	U	I	19°19'12"	49°04'43"	478

** Next of station name is quoted owner of station in bracket.*

Type of area: U – urban, S – suburban, R – rural/regional
Type of station: B – background, T – traffic, I – industrial

3 AIR QUALITY ASSESSMENT IN AGGLOMERATIONS AND ZONES OF SLOVAKIA

3.1 INTRODUCTION

Problems, concerning environment, accompanied technological progress of mankind since the ancient times. Environmental disasters connected with endangering of human life and health stimulated common procedure to search the solution of this issue. Due to the fact, the pollutants can be transported via air on long distances, the coordinated procedure of the major number of countries in air quality monitoring and assessment, proved to be an essential basis for taking action and has been reflected in international conventions as well as in European legislation, subsequently implemented in Slovak legislation.

Air quality assessment, according to the requirements of § 6 of Act No. 137/2010 Coll. on Air as amended is carried out by SHMÚ on the basis of air quality monitoring results with the use of mathematical modelling.

Chapter 3 introduces the processed air quality monitoring results. The air quality assessment using mathematical modelling is presented in Chapter **4**. Chapter **3.3** evaluates the results of air quality measurements in urban and rural areas according to limit and target values for the protection of human health. Chapter **3.4** processes the results of measurements of EMEP monitoring stations according to limit values for vegetation protection. The EMEP programme comprises also atmospheric precipitation quality analyses.

3.2 AIR QUALITY ASSESSMENT CRITERIA

Air quality (according to §5 section 4 of Act No. 137/2010 Coll. on Air, as amended) is considered good, if the air pollution level is lower than the limit value or target value.

Limit value is (in coincidence with §5 section 5 of Act No. 137/2010 Coll. on Air, as amended – hereinafter referred to as the Air Act) is the level of air pollution determined on the basis of scientific knowledge with the aim of preventing, avoiding or reducing harmful effects on human health or the environment as a whole, which is to be achieved at a given time and must not be exceeded from that time onwards; limit values and the conditions for their validity are laid down by implementing regulation pursuant to § 33 (b) for sulphur dioxide, nitrogen dioxide, carbon monoxide, lead, benzene, particulate matter PM_{10} and particulate matter $PM_{2.5}$.

The target value is, in accordance with §5 Section 11 of the Air Act, the level of air pollution determined with a view to preventing, avoiding or reducing harmful effects on human health or the environment as a whole to be achieved at a given time, where practicable; the target value is established by the implementing regulation under Section § 33 (b) for ozone, arsenic, cadmium, nickel and benzo(a)pyrene.

The alert threshold (according to §12 Section (6) of the Air Act) is the level of air pollution above which there is already a risk to human health from brief exposure of the population. If the alert threshold is exceeded, a severe smog warning must be issued. Alert thresholds are determined by implementing regulation under § 33(b) for sulphur dioxide, nitrogen dioxide, ozone and particulate matter PM_{10}.

The critical level for the purpose of air quality assessment is (according to §5 Section (10) of the Air Act) the level of air pollution, determined on the basis of scientific knowledge, above which, direct adverse effects on trees, plants or natural ecosystems, in addition to human, may occur; the critical level is determined by implementing regulation according to Section § 33 (b) for sulphur dioxide and nitrogen dioxide.

The method to be used to assess air quality in a particular location depends on the level of air pollution in that location. For this purpose, a lower and upper assessment threshold for each pollutant monitored has been established to assess the level of pollution.

The upper assessment threshold of air pollution is, according to Section §6 (8) of the Air Act, the determined level of air pollution below which a combination of fixed measurements and mathematical modelling techniques or even indicative measurements may be used to assess ambient air quality.

The lower assessment threshold of air pollution is, according to Section §6 (9) of the Air Act, the determined level of air pollution below which mathematical modelling or objective estimation techniques can be used to assess air quality.

Tab. 3.1 shows the limit values for the protection of human health and the critical levels for the protection of vegetation, upper and lower assessment thresholds of ambient air pollution levels for SO_2, NO_2, NO_X, PM_{10}, $PM_{2.5}$, Pb, CO and benzene. **Tab. 3.2** shows the target values for the protection of human health and for the protection of vegetation for As, Cd, Ni and benzo(a)pyrene (BaP).

Tab. 3.1 *Limit values for the protection of human health and critical levels for the protection of vegetation, upper and lower assessment thresholds of ambient air pollution level for pollutants.*

	Receptor	Interval of averaging	Limit value* [μg·m⁻³]		Assessment thresholds [μg·m⁻³]			
					Upper*		Lower*	
SO_2	Human health	1h	350	(24)				
SO_2	Human health	24h	125	(3)	75	(3)	50	(3)
SO_2	Vegetation	1y, winter season	20	(-)	12	(-)	8	(-)
NO_2	Human health	1h	200	(18)	140	(18)	100	(18)
NO_2	Human health	1y	40	(-)	32	(-)	26	(-)
NO_X	Vegetation	1y	30	(-)	24	(-)	19.5	(-)
PM_{10}	Human health	24h	50	(35)	35	(35)	25	(35)
PM_{10}	Human health	1y	40	(-)	28	(-)	20	(-)
Pb	Human health	1y	0.5	(-)	0.35	(-)	0.25	(-)
CO	Human health	8h (maximum)	10 000	(-)	7 000	(-)	5 000	(-)
Benzene	Human health	1y	5	(-)	3.5	(-)	2	(-)
$PM_{2.5}$	Human health	1y	20**		17		12	

* *permitted number of exceedances is listed in brackets*
** *limit value for $PM_{2.5}$ until 1.1.2020: 25 μg·m⁻³*
limit value for $PM_{2.5}$ since 1.1.2020: 20 μg·m⁻³

Tab. 3.2 *Target values for the protection of human health and vegetation for As, Cd, Ni and BaP.*

	Averaging period	Target value [ng·m⁻³]
As	1y	6
Cd	1y	5
Ni	1y	20
BaP	1y	1

3.3 AIR QUALITY MONITORING RESULTS - LOCAL AIR POLLUTION

Tab. 3.3 shows the proportion of valid data from air quality measurements in the NMSKO monitoring network for SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, benzene, O_3 and Hg.

***Tab. 3.3** Proportion of valid data* in % in year 2022.*

AGGLOMERATION Zone	Pollutant	SO_2	NO_2	PM_{10}	$PM_{2.5}$	CO	Benzene	O_3	Hg
BRATISLAVA	Bratislava, Kamenné nám.			99	98				
	Bratislava, Trnavské mýto		94	99	99	96	99		
	Bratislava, Jeséniova	96	92	99	99			97	
	Bratislava, Mamateyova	95	94	100	100			96	
	Bratislava, Púchovská	96	96	99	99	96	99		
KOŠICE	Košice, Štefánikova	95	96	100	100	95	98		
	Košice, Amurská			100	100				
	Košice, Ďumbierska							97	
	Veľká Ida, Letná			100	99	95			
Banská Bystrica region	Banská Bystrica, Štefánik. nábr.	94	95	99	99	95	98		
	Banská Bystrica, Zelená		96	99	99			*87	
	Jelšava, Jesenského		96	99	98			*64	
	Hnúšťa, Hlavná			99	99				
	Lučenec, Gemerská cesta		95	99	97	96	92	97	
	Zvolen, J. Alexyho			99	99				
	Žarnovica, Dolná		93	98	98				
	Žiar n/H, Jilemnického			99	99				
Bratislava region	Malacky, Mierové nám.[1)]	31	31	32	32	31	32		
	Pezinok, Obrancov mieru		95	99	99			97	
	Rohožník, Senická[1)]	33	53	54	54	50	49		
	Rovinka	95	88	95		93	91		
	Senec, Boldocká		96	98	98	96		97	
Košice region	Kojšovská hola		95					94	
	Trebišov, T. G. Masaryka		96	99	100			99	
	Strážske, Mierová			98	98				
	Krompachy, SNP	93	96	99	100	95	99		
Nitra region	Nitra, Janíkovce		96	99	99			95	
	Nitra, Štúrova	96	96	99	99	96	99		
	Komárno, Vnútorná Okružná		95	99	99			99	
	Plášťovce		94	99	99			99	
Prešov region	Gánovce, Meteo. st.		96					95	
	Humenné, Nám. Slobody		95	99	99			95	
	Prešov, Arm. gen. L. Svobodu		95	99	98	94	97		
	Vranov n/T, M. R. Štefánika	94		100	100				
	Stará Lesná, AÚ SAV, EMEP		96	99	99			96	
	Starina, Vodná nádrž, EMEP		96					95	100
	Kolonické sedlo, Hvezdáreň			99	99				
	Poprad, Železničná		94	99	99				
	Bardejov, Pod Vinbargom		96	99	99			99	
Trenčín region	Prievidza, Malonecpalská	95	96	99	99			*53	
	Bystričany, Rozvodňa SSE	96		99	99				
	Handlová, Morovnianska cesta	95		99	99				
	Púchov, 1. mája	93	93	99	99	93			
	Trenčín, Hasičská	96	96	99	99	96	99		
Trnava region	Senica, Hviezdoslavova	95		100	100				
	Trnava, Kollárova		92	99	99	95	99		
	Topoľníky, Aszód, EMEP	92	93	92	91			95	87
	Sereď, Vinárska		95	98	98				

AGGLOMERATION Zone	Pollutant	SO_2	NO_2	PM_{10}	$PM_{2.5}$	CO	Benzene	O_3	Hg
Žilina region	Chopok, EMEP		96					93	
	Liptovský Mikuláš, Školská	93	94	97	96				
	Martin, Jesenského		96	99	99	90	99		
	Oščadnica	*88	*89	98	99			92	
	Ružomberok, Riadok	96	96	99	99	95	99	90	
	Žilina, Obežná		96	100	99	93		96	

Legend: ≥ 90% of valid measurements ** will be added to the database*

1) AMS Malacky ceased measurement on 29 April 2022 and was replaced by AMS Rohožník on 5 August 2022

Air quality assessment according to limit values (LV) for the protection of human health for SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and benzene for individual monitoring stations and pollutants in 2022 is presented in **Tab. 3.4**.

Tab. 3.4 *Air quality assessment according to limit values for human health protection – 2022.*

AGGLOMERATION Zone		Health protection								
	Pollutant	SO_2		NO_2		PM_{10}		$PM_{2.5}$	CO	Benzene
	Averaging period	1 h	24 h	1 h	1 year	24 h	1 year	1 year	8 h 1)	1 year
	Parameter	number of exceedances	number of exceedances	number of exceedances	average	number of exceedances	average	average	average	average
	Limit value [μg·m⁻³]	350	125	200	40	50	40	20	10 000	5
	Maximum number of exceedances	24	3	18		35				
BRATISLAVA	Bratislava, Kamenné nám.					3	19	12		
	Bratislava, Trnavské mýto			0	31	9	24	15	780	0.54
	Bratislava, Jeséniova	0	0	0	9	0	15	11		
	Bratislava, Mamateyova	0	0	0	16	1	18	11		
	Bratislava, Púchovská	0	0	0	13	1	19	13	694	0.35
KOŠICE	Košice, Štefánikova	0	0	0	22	21	26	17	2 292	0.91
	Košice, Amurská					12	22	16		
	Veľká Ida, Letná					68	37	22	2 736	
Banská Bystrica region	Banská Bystrica, Štefánik. nábr.	0	0	0	24	20	26	16	1 644	0.94
	Banská Bystrica, Zelená			0	8	0	16	12		
	Jelšava, Jesenského			0	8	53	30	22		
	Hnúšťa, Hlavná					5	21	14		
	Lučenec, Gemerská cesta			0	15	19	24	17	1 494	0.74
	Zvolen, J. Alexyho					1	19	14		
	Žarnovica, Dolná			0	11	21	25	20		
	Žiar n/H, Jilemnického					0	16	12		
Bratislava region	Malacky, Mierové nám.2)	0	0	0	21	0	22	14	1 334	0.71
	Pezinok, Obrancov mieru			0	9	3	16	13		
	Rohožník, Senická2)	0	0	0	11	1	21	14	1 426	0.76
	Rovinka	1	0	0	12	0	19		667	0.86
	Senec, Boldocká			0	20	8	20	14	836	
Košice region	Kojšovská hola			0	3					
	Trebišov, T. G. Masaryka			0	11	10	22	16		
	Strážske, Mierová					5	20	16		
	Krompachy, SNP	0	0	0	13	13	23	17	1 607	0.94
Nitra region	Nitra, Janíkovce			0	9	1	17	11		
	Nitra, Štúrova	0	0	0	22	2	22	13	1 621	0.46
	Komárno, Vnútorná Okružná			0	13	12	24	14		
	Plášťovce			0	7	36	27	22		

AGGLOMERATION Zone		Health protection								
	Pollutant	SO_2		NO_2		PM_{10}		$PM_{2.5}$	CO	Benzene
	Averaging period	1 h	24 h	1 h	1 year	24 h	1 year	1 year	8 h [1)]	1 year
	Parameter	number of exceedances	number of exceedances	number of exceedances	average	number of exceedances	average	average	average	average
	Limit value [μg·m⁻³]	350	125	200	40	50	40	20	10 000	5
	Maximum number of exceedances	24	3	18		35				
Prešov region	Gánovce, Meteo. st.			0	8					
	Humenné, Nám. slobody			0	9	8	23	19		
	Prešov, Arm. gen. L. Svobodu			0	32	15	25	18	1 444	0.82
	Vranov n/T, M. R. Štefánika	0	0			7	20	16		
	Stará Lesná, AÚ SAV, EMEP			0	4	0	11	8		
	Starina, Vodná nádrž, EMEP			0	3					
	Kolonické sedlo, Hvezdáreň					1	15	11		
	Poprad, Železnicná			0	15	1	17	12		
	Bardejov, Pod Vinbargom			0	10	2	20	15		
Trenčín region	Prievidza, Malonecpalská	0	0	0	15	4	17	13		
	Bystričany, Rozvodňa SSE	0	0			3	19	14		
	Handlová, Morovnianska cesta	0	0			1	16	13		
	Púchov, 1. mája	0	0	0	10	10	22	16	1 647	
	Trenčín, Hasičská	0	0	0	26	8	23	14	1 417	0.78
Trnava region	Senica, Hviezdoslavova	0	0			2	19	14		
	Trnava, Kollárova			0	28	4	21	13	1 018	0.78
	Topoľníky, Aszód, EMEP	0	0	0	5	3	17	13		
	Sereď, Vinárska			0	13	6	19	12		
Žilina region	Chopok, EMEP			0	2					
	Liptovský Mikuláš, Školská	0	0	0	13	6	19	14		
	Martin, Jesenského			0	17	10	26	17	1 355	0.77
	Oščadnica	0	0	0	7	9	22	17		
	Ružomberok, Riadok	0	0	0	16	17	23	18	2 234	1.11
	Žilina, Obežná			0	20	18	24	17	2 160	

≥ 90% of valid measurements *Exceedances of limit value are marked in red.*

[1)] *maximum 8-hour concentration*

[2)] *AMS Malacky ceased measurement on 29 April 2022 and was replaced by AMS Rohožník on 5 August 2022*

The limit value for the average daily PM_{10} concentration (the average daily PM_{10} concentration must not exceed 50 μg·m⁻³ more than 35 times per calendar year) was exceeded in 2022 only at three monitoring stations – Veľká Ida, Letná; Jelšava, Jesenského and Plášťovce.

Tab. 3.5 *Air pollution assessment by heavy metals (As, Cd, Ni a Pb) – 2022.*

AGGLOMERATION Zone			As	Cd	Ni	Pb
	Pollutant	[ng·m⁻³]	As	Cd	Ni	Pb
	Target value	[ng·m⁻³]	6.0	5	20	-
	Limit value	[ng·m⁻³]	-	-	-	500
	Upper assessment threshold	[ng·m⁻³]	3.6	3	14	350
	Lower assessment threshold	[ng·m⁻³]	2.4	2	10	250
BRATISLAVA	Bratislava, Trnavské mýto		0.3	0.1	0.6	4.0
Slovakia	Banská Bystrica, Štefánikovo náb.		0.4	0.3	0.8	8.0
	Jelšava, Jesenského		0.5	0.2	0.1	5.4
	Ružomberok, Riadok		0.3	0.2	0.6	4.4
	Veľká Ida, Letná		0.5	0.5	0.4	21.5
	Prievidza, Malonecpalská		0.4	0.1	0.3	2.2
	Sereď, Vinárska		0.4	0.1	0.3	13.2
	Púchov, 1. mája		0.3	0.1	0.4	3.6

In **Tab. 3.6** are presented annual mean concentrations of benzo(a)pyrene (BaP) in air according to measurements in years 2017 – 2022.

Tab. 3.6 *Assessment of benzo(a)pyrene air pollution.*

AGGLOMERATION Zone		2017	2018	2019	2020	2021	2022
	Target value [ng·m^{-3}]	1.0	1.0	1.0	1.0	1.0	1.0
	Upper assessment threshold [ng·m^{-3}]	0.6	0.6	0.6	0.6	0.6	0.6
	Lower assessment threshold [ng·m^{-3}]	0.4	0.4	0.4	0.4	0.4	0.4
BRATISLAVA	Bratislava, Jeséniova			0.2	0.2	0.3	0.3
	Bratislava, Trnavské Mýto	0.4	0.9	0.4	0.5	0.5	0.5
	Bratislava, Púchovská					0.9	0.4
KOŠICE	Veľká Ida, Letná	4.3	5.8	4.5	4.6	6.1	5.4
Banská Bystrica region	Banská Bystrica, Štefánikovo nábrežie	2.9	2.1	1.7	1.6	1.7	1.4
	Banská Bystrica, Zelená			1.1	1.2	1.3	0.9
	Jelšava, Jesenského		3.9	4.0	3.0	2.8	2.7
	Žarnovica, Dolná					2.2	2.7
Bratislava region	Rovinka				0.4	0.6	0.5
Košice region	Krompachy, SNP			2.7	2.1	2.2	2.2
Nitra region	Nitra, Štúrova	1.3	0.9	0.8	0.6	0.8	0.6
	Plášťovce					2.2	*2.4
Prešov region	Starina, Vodná nádrž, EMEP		1.2	0.4	0.3	0.4	0.2
	Stará Lesná, EMEP			0.4	0.3	0.4	0.3
Trenčín region	Prievidza, Malonecpalská			1.4	1.2	1.1	**0.9
	Trenčín, Hasičská				0.8	1.1	
	Púchov, 1. mája					4.7	2.0
Trnava region	Trnava, Kollárova		0.9	0.7	0.5	0.6	***0.5
Žilina region	Žilina, Obežná		6.0	2.0	1.9	1.9	1.9
	Ružomberok, Riadok				4.5	2.3	2.2
	Oščadnica					12	****2.5

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

* *Plášťovce – failure from 11.3. to the end of March and from 6.6. to 5.7.2022*

** *Prievidza – failure from 24.1. to 21.4.2022*

*** *Trnava – failure from 19.9.2022 to 4.11.2022*

**** *Oščadnica – failure throughout December 2022*

The target value for BaP was exceeded at 10 stations. Although the measurements in Plášťovce and Oščadnica do not reach the required proportion of valid data due to the disturbance, their distribution during the year allows us to assume with high probability that the target value was exceeded also at these locations. The proportion of valid data at both AMSs was 88%, the distribution over the seasons was approximately even, in the case of Plášťovce slightly to the detriment of spring and summer and in the case of Oščadnica to the detriment of winter.

Air quality assessment shall be carried out by continuous measurement in agglomerations and zones where the level of air pollution by an air pollutant is higher than the upper assessment threshold. Where sufficient data are available, exceedances of the upper and lower assessment threshold shall be determined on the basis of concentrations measured over the last five years. The air pollution assessment threshold shall be considered to be exceeded if an exceedance occurs in at least three individual years out of the last five years.

If less than five years of data are available, exceedances of the upper and lower assessment threshold of air pollution levels can be detected by combining results from measurement campaigns of shorter duration carried out over a one-year period – and at locations likely to have the highest levels of air pollution – with results obtained from emission inventories and modelling (Decree of the Ministry of the Environment of the Slovak Republic 244/2016 Coll. on air quality, as amended). Classification of monitoring stations according to the upper and lower assessment threshold are presented in **Tab. 3.7** and **Tab. 3.8**.

Tab. 3.7 Classification of AMS according to upper resp. lower assessment thresholds (UAT resp. LAT) for the air quality assessment to determine the assessment method for the years 2018 – 2022.

AGGLOMERATION Zone	Station	UAT and LAT with regard to the protection of human health																							
		SO_2			NO_2						PM_{10}						$PM_{2.5}$			CO			Benzene		
		24h average			1h average			annual average			24h average			annual average			annual average			8h maximum			annual average		
		> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT
BRATISLAVA	Bratislava, Kamenné nám.											x				x		x							
	Bratislava, Trnavské mýto					x		x			x				x			x				x			x
	Bratislava, Jeséniova			x			x			x		x				x			x						
	Bratislava, Mamateyova			x			x			x		x				x		x							
	Bratislava, Púchovská			x			x			x			x			x			x			x			x
KOŠICE	Košice, Štefánikova			x			x			x	x				x		x					x			x
	Košice, Amurská										x				x			x							
	Veľká Ida, Letná										x			x			x					x			
Banská Bystrica region	Banská Bystrica, Štefánikovo nábr.			x			x			x	x				x		x					x			x
	Banská Bystrica, Zelená						x			x		x				x		x							
	Zvolen, J. Alexyho											x				x		x							
	Jelšava, Jesenského						x			x	x			x			x								
	Hnúšťa, Hlavná										x				x			x							
	Žarnovica, Dolná						x			x	x				x		x								
	Lučenec, Gemerská cesta						x			x		x			x			x				x			x
	Žiar nad Hronom, Jilemnického											x				x		x							
Bratislava region	Malacky, Mierové nám.			x			x			x	x				x			x				x			x
	Pezinok			x			x			x		x				x		x				x			
	Rovinka			x			x			x	x				x							x			x
	Rohožník, Senická**			x			x			x		x			x			x				x			x
	Senec, Boldocká						x			x		x				x		x				x			
Košice region	Kojšovská hoľa*						x			x															
	Strážske, Mierová										x				x		x								
	Krompachy, SNP			x			x			x	x				x		x					x			x
	Trebišov, T. G. Masaryka						x			x	x				x			x							
Nitra region	Nitra, Janíkovce						x			x		x				x		x							
	Nitra, J. Štúrova			x			x		x		x				x			x				x			x
	Komárno, Vnútorná Okružná						x			x	x				x			x							
	Plášťovce						x			x	x				x		x								
Prešov region	Humenné, Nám. slobody						x			x	x				x		x								
	Prešov, Arm. gen. L. Svobodu						x	x			x				x		x					x			x
	Gánovce, MS SHMÚ*						x			x															
	Starina, Vodná nádrž, EMEP*						x			x															
	Vranov n/Topľou, M. R. Štefánika			x							x				x			x							
	Stará Lesná, AÚ SAV, EMEP*						x			x			x			x			x						
	Kolonické sedlo, Hvezdáreň											x				x			x						
	Poprad, Železničná						x			x			x		x				x						
	Bardejov, Pod Vinbargom						x			x		x				x		x							
Trenčín region	Prievidza, Malonecpalská			x			x			x		x				x		x							
	Bystričany, Rozvodňa SSE			x								x				x		x							
	Handlová, Morovnianska cesta			x								x				x		x							
	Púchov, 1. mája			x			x			x		x			x			x				x			
	Trenčín, Hasičská			x			x			x	x				x			x				x			x

AGGLOMERATION Zone	Station	SO2 24h average			NO2 1h average			NO2 annual average			PM10 24h average			PM10 annual average			PM2.5 annual average			CO 8h maximum			Benzene annual average		
		> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT
Trnava region	Senica, Hviezdoslavova,			x							x				x			x							
	Trnava, Kollárova					x			x		x				x			x				x			x
	Topoľníky, Aszód, EMEP*			x			x			x		x				x		x							
	Sereď, Vinárska						x			x		x				x		x							
Žilina region	Martin, Jesenského						x			x	x				x			x				x			x
	Liptovský Mikuláš, Školská			x			x			x			x			x		x							
	Oščadnica			x			x			x		x			x			x							
	Chopok, EMEP*						x			x															
	Ružomberok, Riadok			x			x			x	x				x		x					x			x
	Žilina, Obežná						x			x	x				x		x					x			

Column group heading: UAT and LAT with regard to the protection of human health

* *stations indicate the regional background level*

** *AMS Rohožník started measuring PM_{10}, $PM_{2.5}$, NO_2 and CO during June 2022, benzene in July and SO_2 in August. (AMS Rohožník replaced AMS Malacky, which ceased measurement in the first half of 2022).*

Tab. 3.8 *AMS stations monitoring heavy metals and benzo(a)pyrene according to upper (UAT) and lower assessment threshold (LAT) for the air quality assessment in 2018–2022.*

Station	As			Cd			Ni			Pb			BaP		
	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT
Bratislava, Jeséniova															x
Bratislava, Trnavské mýto			x			x			x			x		x	
Bratislava, Púchovská															x
Veľká Ida, Letná			x			x			x			x	x		
Banská Bystrica, Štefánikovo nábr.			x			x			x			x	x		
Banská Bystrica, Zelená													x		
Jelšava, Jesenského			x			x			x			x	x		
Žarnovica, Dolná													x		
Rovinka														x	
Krompachy, SNP													x		
Nitra, Štúrova													x		
Plášťovce													x		
Starina, Vodná nádrž, EMEP															x
Stará Lesná, EMEP															x
Prievidza, Malonecpalská						x			x			x	x		
Trenčín, Hasičská*															
Púchov, 1. mája						x			x			x	x		
Trnava, Kollárova														x	
Žilina, Obežná													x		
Ružomberok, Riadok			x			x			x			x	x		
Oščadnica													x		
Sereď, Vinárska			x			x			x			x			

* *outage due to technical failure*

Tab. 3.9 shows the annual average concentrations of tropospheric ozone in 2010 – 2022 compared to the photochemical extremely active year 2003.

Tab. 3.9 *Annual average concentrations of ground-level ozone [μg·m^{-3}] in years 2003, 2009 – 2022.*

Station	2003	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Bratislava, Jeséniova	71	61	63	65	62	60	71	56	64	68	66	61	62	65
Bratislava, Mamateyova	53	46	51	53	48	46	54	36	51	54	54	49	50	50
Košice, Ďumbierska	68	63	73	62	61	55	57	55	55	63	56	46	49	53
Banská Bystrica, Zelená		56	60	66	66	58	48	45	57	56	47	48	54	57
Jelšava, Jesenského	55	44	-	-	41	36	45	48	49	49	45	39	41	38
Kojšovská hoľa	91	90	87	83	78	75	61	81	80	82	78	72	74	79
Nitra, Janíkovce		53	-	62	58	52	63	43	60	60	54	56	58	59
Humenné, Nám. slobody	66	53	53	55	60	40	41	50	52	51	54	49	49	51
Stará Lesná, AÚ SAV, EMEP	67	67	65	63	71	56	66	58	63	67	59	57	47	49
Gánovce, Meteo. st.	68	63	64	66	67	58	66	38	53	56	57	51	53	54
Starina, Vodná nádrž, EMEP	73	51	59	60	64	55	64	58	60	64	62	54	57	55
Prievidza, Malonecpalská		49	51	52	50	53	54	39	51	52	49	46	47	41
Topoľníky, Aszód, EMEP	67	55	-	59	64	51	51	49	47	54	55	24	49	54
Chopok, EMEP	109	87	96	93	96	52	88	91	98	95	90	91	89	91
Žilina, Obežná	48	47	48	49	53	42	36	43	38	44	44	36	38	36
Ružomberok, Riadok								37	37	36	36	35	40	37
Bardejov, Pod Vinbargom													44	45
Trebišov, T. G. Masaryka													49	49
Plášťovce													49	47
Komárno, Vnútorná Okružná													47	46
Senec, Boldocká													35	49
Pezinok, Obrancov mieru														58
Lučenec, Gemerská cesta														42
Oščadnica														48
Average	65	59	61	63	63	53	58	52	57	59	57	51	50	52

≥ 90% requested valid data

Regulation of MoE SR No. 244/2016 Coll. of Acts on air quality, as amended, determines a ozone target value for the protection of human health as follows: *The highest daily 8-hour mean concentration shall not exceed 120 μg·m^{-3} for more than 25 days per calendar year in an average of three year**. The number of days with exceedances of the ground-level ozone target value is shown in **Tab. 3.10**.

**Methodical note: The average period is the largest daily 8-hour mean (chosen by examining 8-hour moving averages calculated from hourly data and updated hourly. Each 8-hour average thus calculated shall be assigned to the day on which it ends, i.e., the first calculation period for any one day is the period from 5 p.m. on the previous day to 1.00 a.m. on that day; the last calculation period for any one day is the period from 4 p.m. to 12 p.m. of that day).*

Tab. 3.10 *Number of days with exceedances of the ground-level ozone target value for the protection of human health.*

Station	2020	2021	2022	Average 2020 – 2022
Bratislava, Jeséniova	17	23	37	26
Bratislava, Mamateyova	12	15	25	17
Košice, Ďumbierska	0	0	7	2
Banská Bystrica, Zelená	0	3	9	4
Jelšava, Jesenského	2	2	*7	2
Kojšovská hoľa	2	4	16	7
Nitra, Janíkovce	9	15	31	18
Humenné, Nám. Slobody	3	1	5	3
Stará Lesná, AÚ SAV, EMEP	5	0	0	2
Gánovce, Meteo. st.	0	0	2	1

Station	2020	2021	2022	Average 2020 – 2022
Starina, Vodná nádrž, EMEP	4	0	1	2
Prievidza, Malonecpalská	2	3	3*	3
Topoľníky, Aszód, EMEP	0	3	9	4
Chopok, EMEP	33	22	34	30
Žilina, Obežná	0	0	3	1
Ružomberok, Riadok	0	0	0	0
Bardejov, Pod Vinbargom		0	3	2
Trebišov, T. G. Masaryka		2	5	4
Plášťovce		19	21	20
Komárno, Vnútorná Okružná		7	11	9
Senec, Boldocká		*2	11	11
Pezinok, Obrancov mieru			21	21
Lučenec, Gemerská cesta			6	6
Oščadnica			8	8

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

** a given year is not included in the average, due to lack of data in the summer period*

The ground-level ozone AOT40 values for vegetation protection are presented in **Tab. 3.11**. AOT40 is the sum of exceedances of level 80 μg·m^{-3} calculated from 1-hour concentrations during the day (from 8:00 to 20:00 CET) from 1st May to 31st July. The target value is 18 000 μg·m^{-3} (refers to the average over 5 consecutive calendar years). This value was exceeded at six stations (i.e. at these stations the average of the AOT40 values for years 2018 – 2022 exceeded value 18 000 μg·m^{-3}).

Tab. 3.11 *Ground-level ozone AOT40 values for vegetation protection (May – July). The AOT40 target value is 18 000 μg·m^{-3}.*

Station	2018	2019	2020	2021	2022	Average 2018 – 2022
Bratislava, Jeséniova	25 103	20 609	12 501	19 274	23 763	20 250
Bratislava, Mamateyova	22 658	19 340	10 655	17 655	20 072	18 076
Košice, Ďumbierska	14 384	11 752	3 269	7 368	12 662	9 887
Banská Bystrica, Zelená	16 982	8 298	7 723	15 869	*19 716	12 218
Jelšava, Jesenského	6 660	12 361	5 191	10 186	*17 622	8 600
Kojšovská hoľa	18 706	12 202	4 995	13 260	19 435	13 720
Nitra, Janíkovce	25 036	13 313	12 741	18 931	24 322	18 869
Humenné, Nám. slobody	10 833	13 326	5 981	12 578	16 047	11 753
Stará Lesná, AÚ SAV, EMEP	22 437	8 666	7 890	2 491	6 210	9 539
Gánovce, Meteo. st.	6 646*	8 954	3 251	6 707	11 317	7 557
Starina, Vodná nádrž, EMEP	13 116	11 601	5 072	11 737	9 560	10 217
Prievidza, Malonecpalská	15 889	8 301	6 198	11 799	*15 529	10 547
Topoľníky, Aszód, EMEP	15 886	17 690	-	13 176	16 686	15 860
Chopok, EMEP	32 667	23 711	15 957	23 654	26 536	24 505
Žilina, Obežná	13 364	11 800	559	4 794	5 338	7 171
Ružomberok, Riadok	3 789*	5 307	1 999	*8 041	2 935	3 414
Bardejov, Pod Vinbargom				10 607	12 711	11 659
Trebišov, T. G. Masaryka				12 369	15 806	14 088
Plášťovce				*24 211	19 720	19 720
Komárno, Vnútorná Okružná				*17 818	12 824	12 824
Senec, Boldocká*				-	14 893	14 893
Pezinok, Obrancov mieru					19 368	19 368
Lučenec, Gemerská cesta					14 834	14 834
Ošcadnica					14 893	14 893

** A given year was not calculated in the average, due to lack of data in the summer season.*
Exceedance of the target value is marked in red.

According to the assessment of monitoring stations' measurements of the other operators (industrial stations outside NMSKO), the limit value for PM_{10} was not exceeded at any site (**Tab. 3.12**).

Tab. 3.12 *Air pollution assessment according to limit values for the protection of human health in 2022 from industrial stations of other operators – VZZO.*

AGGLOMERATION Zone	Pollutant Averaging period Limit value [µg·m⁻³] (number of exceedances)	Health protection						
		SO_2		NO_2		PM_{10}		CO
		1 h 350 (24)	24 h 125 (3)	1 h 200 (18)	1 year 40	24 h 50 (35)	1 year 40	8 h [1)] 10 000
BRATISLAVA	Bratislava, Pod. Biskupice (Slovnaft, a.s.)	0	0	0	16	9	20	912
	Bratislava, Vlčie Hrdlo (Slovnaft, a.s.)	0	0	0	16	3	8	686
KOŠICE	Košice, Poľov (U.S. Steel, s.r.o.)					2	14	
	Košice, Haniska (U.S. Steel, s.r.o.)					6	18	
Bratislava region	Rovinka (Slovnaft, a.s.)	1	0	0	13	2	19	587
Košice region	Veľká Ida (U.S. Steel, s.r.o.)					15	28	
	Leles (Slovenské elektrárne, a.s.)	1	0	0	7	12	14	
Nitra region	Trnovec nad Váhom (Duslo, a.s.)	0	0	0	5	4	20	
Trenčín region	Oslany (Slovenské elektrárne, a.s.)	0	0	0	8	7	16	
Žilina region	Ružomberok (Mondi a.s. - Supra)					9	19	

1) maximum 8-hour concentration

3.3.1 Air quality assessment according to limit and target values for human health protection concerning SO_2, NO_2, PM_{10}, $PM_{2.5}$, benzene, CO and benzo(a)pyrene by agglomeration and zone in 2022

In the Annexes (*Air quality evaluation of NUTS-3 regions*), divided by region, the results of measurements are assessed, concerning limit and target values of individual pollutants for human health protection in individual zones and agglomerations. Air quality assessment is complex problem, for which the mathematical modelling methods are used, in addition to monitoring. Those data are used to supplement information on the spatial distribution of air pollutant concentrations as well as on the relationship to pollutant emission sources (where input information is available). Air quality assessment using mathematical modelling is presented in Chapter **4**.

3.3.2 Air quality assessment according to limit and target values for human health protection concerning Pb, As, Cd, Ni and O_3, by agglomeration Bratislava and zone Slovakia in 2022

- **Agglomeration Bratislava**

Neither the limit value for Pb nor the target values for As, Cd, Ni were exceeded in the Bratislava agglomeration.

The target value for ozone (the highest daily 8-hour mean concentration does not exceed 120 $\mu g \cdot m^{-3}$ for more than 25 days per calendar year on a three-year average) was exceeded at the monitoring station Bratislava, Jeséniova. This could be due to several factors – good availability of ozone precursors, higher NO_2/NO ratio in favour of NO_2 at these sites, so that ozone is not degraded by nitric oxide from road traffic as much as at busy roads. Episodes of long-range transport may also have occurred here. In 2022, there was one exceedance of the information threshold at AMS Bratislava, Jeséniova.

- **Zone Slovakia**

  For Pb, As, Cd, Ni and O_3 the zone defines the territory of the Slovak Republic apart from the territory of the Slovak capital Bratislava.

  Neither the limit value for Pb nor the target values for As, Cd and Ni have been exceeded in the Slovakia zone.

  The target value for ozone was exceeded at the EMEP monitoring station Chopok. The station is located at an altitude of 2008 m above sea level, where, in addition to horizontal long-range transport, transport from the lower stratosphere contributes to increased concentrations of tropospheric ozone.

3.3.3 Smog warning system

The smog warning system is one of the mechanisms aimed at protecting the health of the population in the event of a short-term deterioration in air quality, whereby the information threshold for SO_2, NO_2, O_3 and PM_{10} or the alert threshold for O_3 and PM_{10} are assessed. A smog announcement shall be issued when the information threshold is exceeded and a severe smog alert shall be issued when the alert threshold is exceeded, if at the same time, according to the development of air pollution and the meteorological forecast, it is not reasonable to expect a reduction in the concentration of the pollutant concerned below the alert threshold within the next 24 hours.

Individual pollutants have different settings in the smog warning system - the information (or warning) threshold for ground-level ozone is exceeded if the hourly average concentration exceeds 180 $\mu g \cdot m^{-3}$ (or 240 $\mu g \cdot m^{-3}$). For NO_2 and SO_2, only the alert threshold is set, which is exceeded if three consecutive hourly average concentrations exceed the set threshold (500 $\mu g \cdot m^{-3}$ for SO_2 and 400 $\mu g \cdot m^{-3}$ for NO_2). For PM_{10}, the parameter is the 12-hour moving average, with an information threshold of 100 $\mu g \cdot m^{-3}$ and an alert threshold of 150 $\mu g \cdot m^{-3}$.

The conditions for issuing a announcement of termination of a smog situation or a announcement of lifting of a severe smog alert shall be met if the concentration does not exceed the relevant threshold and this condition persists:

- continuously for 24 hours and, according to the development of air pollution and the meteorological forecast, it is not reasonable to expect that the relevant threshold value will be exceeded again within the next 24 hours; or
- for at least 3 hours and, according to an assessment of the development of air pollution on the basis of the meteorological forecast, it is almost impossible that the relevant threshold value will be exceeded again within the next 24 hours.

The conditions for the operation of the smog warning system are set out in Decree of the Ministry of the Environment of the Slovak Republic No. 244/2016 Coll. on air quality, as amended.

The duration of exceeding the information and warning thresholds for PM_{10} and O_3 in 2022 compared to 2021 is presented in **Tab. 3.13**.

The alert threshold for NO_2 and SO_2 has not been exceeded since 2013. The concentration of ground-level ozone exceeded the information threshold at AMS Bratislava, Jeséniova in 2022 for only one hour.

The number of smog alerts for PM_{10} was slightly lower in 2022 compared to 2021. No severe smog alerts were issued (the exceedance of the alert threshold was related to New Year's Eve celebrations) and several smog alerts were issued in connection with the exceedance of the information threshold (four for Jelšava, two for Veľká Ida and one each for Martin, Žilina and Oščadnica). In the case where an improvement in the dispersion situation could be expected on the basis of the meteorological forecast, no announcement or warning was issued.

***Tab. 3.13** Duration of exceedances (in hours) of the information threshold (IT) and the alert threshold (AT) for individual pollutants.*

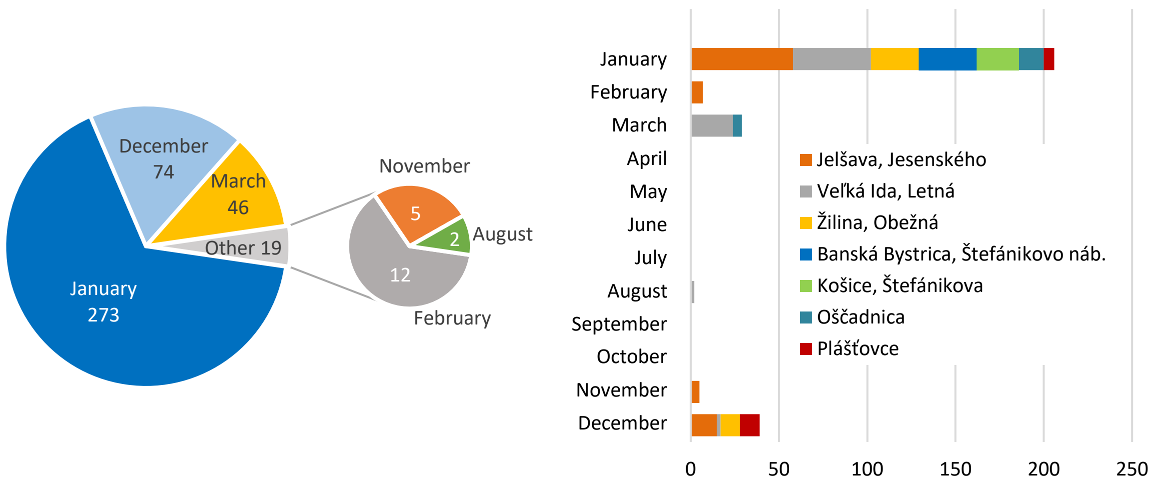
AGGLOMERATION Zone	Pollutant	SO_2		NO_2		O_3				PM_{10}			
	Year	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
	Alert / Information threshold	AT	AT	AT	AT	IT	IT	AT	AT	IT	IT	AT	AT
	Averaging period	3 h consec.	3 h consec	3 h consec	3 h consec	1 h	1 h	1 h	1 h	12 h	12 h	12 h	12 h
	Limit value [µg·m⁻³]	500	500	400	400	180	180	240	240	100	100	150	150
BRATISLAVA	Bratislava, Kamenné nám.									0	0	0	0
	Bratislava, Trnavské mýto			0	0					13	0	0	0
	Bratislava, Jeséniova	0	0	0	0	0	1	0	0	0	0	0	0
	Bratislava, Mamateyova	0	0	0	0	0	0	0	0	1	8	0	0
	Bratislava, Púchovská	0	0	0	0					0	0	0	0
KOŠICE	Košice, Štefánikova	0	0	0	0					55	24	0	0
	Košice, Amurská									6	0	0	0
	Košice, Ďumbierska					0	0	0	0				
	Veľká Ida, Letná									91	72	0	0
Banská Bystrica region	Banská Bystrica, Štefánik.nábr.	0	0	0	0					42	33	0	0
	Banská Bystrica, Zelená			0	0	0	0	0	0	0	0	0	0
	Jelšava, Jesenského			0	0	0	0	0	0	138	85	0	0
	Hnúšťa, Hlavná									8	0	0	0
	Lučenec, Gemerská cesta			0	0		0		0	0	0	0	0
	Zvolen, J. Alexyho									0	0	0	0
	Žarnovica, Dolná			0	0					11	14	0	0
	Žiar n/H, Jilemnického									0	0	0	0
Bratislava region	Malacky, Mierové nám.**	0	0	0	0					0	0	0	0
	Pezinok, Obrancov mieru			0	0		0		0	0	0	0	0
	Rohožník, Senická*		0		0					0	0	0	0
	Rovinka	0	0	0	0					0	0	0	0
	Senec, Boldocká			0	0	0	0	0	0	9	9	0	
Košice region	Kojšovská hoľa			0	0	0	0	0	0				
	Trebišov, T. G. Masaryka			0	0	0	0	0	0	0	6	0	0
	Strážske, Mierová									0	0	0	0
	Krompachy, SNP	0	0	0	0					9	15	0	0
Nitra region	Nitra, Janíkovce			0	0	0	0	0	0	0	0	0	0
	Nitra, Štúrova	0	0	0	0					5	0	0	0
	Komárno, Vnútorná Okružná			0	0	0	0	0	0	0	9	0	0
	Plášťovce			0	0	0	0	0	0	8	17	0	0
Prešov region	Gánovce, Meteo. st.			0	0	0	0	0	0				
	Humenné, Nám. slobody			0	0	0	0	0	0	14	0	0	0
	Prešov, Arm. gen. L. Svobodu			0	0					22	6	0	0
	Vranov n/T, M. R. Štefánika	0	0							0	0	0	0
	Stará Lesná, AÚ SAV, EMEP			0	0	0	0	0	0	0	0	0	0
	Starina, Vodná nádrž, EMEP			0	0	0	0	0	0	0	0	0	0
	Kolonické sedlo, Hvezdáreň									0	0	0	0
	Poprad, Železničná			0	0					0	0	0	0
	Bardejov, Pod Vinbargom			0	0	0	0	0	0	0	0	0	0
Trenčín region	Prievidza, Malonecpalská	0	0	0	0	0	0	0	0	0	0	0	0
	Bystričany, Rozvodňa SSE	0	0							0	0	0	0
	Handlová, Morovianska cesta	0	0							1	6	0	0
	Púchov, 1.mája	0	0	0	0					0	13	0	0
	Trenčín, Hasičská	0	0	0	0					0	0	0	0

AGGLOMERATION Zone	Pollutant	SO_2		NO_2		O_3				PM_{10}			
	Year	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
	Alert / Information threshold	AT	AT	AT	AT	IT	IT	AT	AT	IT	IT	AT	AT
	Averaging period	3 h consec.	3 h consec	3 h consec	3 h consec	1 h	1 h	1 h	1 h	12 h	12 h	12 h	12 h
	Limit value [μg·m⁻³]	500	500	400	400	180	180	240	240	100	100	150	150
Trnava region	Senica, Hviezdoslavova	0	0							0	0	0	0
	Trnava, Kollárova			0	0					6	0	0	0
	Topoľníky, Aszód, EMEP	0	0	0	0	0	0	0	0	0	13	0	4
	Sereď, Vinárska			0	0					0	0	0	0
Žilina region	Chopok, EMEP			0	0	0	0	0	0				
	Liptovský Mikuláš, Školská	0	0	0	0					8	4	0	0
	Martin, Jesenského			0	0					9	6	0	0
	Oščadnica		0		0		0		0	11	19	0	0
	Ružomberok, Riadok	0	0	0	0	0	0	0	0	10	15	0	1
	Žilina, Obežná			0	0	0	0	0	0	1	38	0	12

* *AMS Malacky ceased measurement on 29 April 2022 and was replaced by AMS Rohožník on 5 August 2022*

The highest number of hours with exceedances of the information threshold was recorded in 2022 at the monitoring station Jelšava, Jesenského (85), with exceedances at this station measured during January, February, November and December. The highest number of exceedances at Jelšava was recorded in January (58).

Fig. 3.1 *Number of hours with an information threshold (IP) exceedance for PM_{10} for all AMS split by months of the year (left) and by stations with the highest number of IP exceedances (right).*



3.4 REGIONAL MONITORING

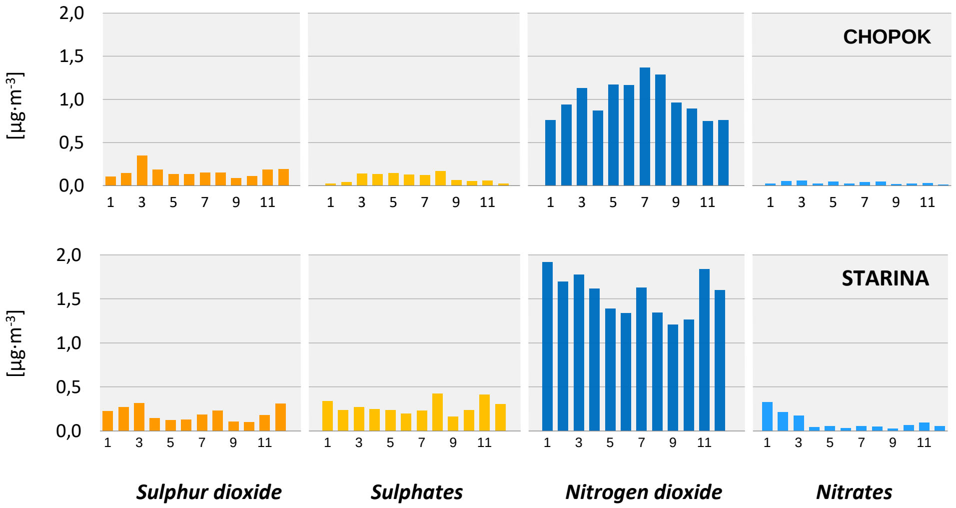
Regional air pollution is the pollution of the boundary layer of the atmosphere of a natural landscape type, at a sufficient distance from local industrial and urban sources. The boundary layer of the atmosphere is the layer in which pollution is mixed from the earth's surface up to the height of about 1 000 m. In remote regions, unlike the cities, industrial emissions are more or less evenly vertically dispersed throughout this layer and therefore ground level concentrations are lower than in cities. In the following text are presented results from the EMEP regional monitoring stations, Chapter 3.4.1 presents the results of air quality monitoring and Chapter 3.4.2 deals with the quality of atmospheric precipitation.

3.4.1 Air

- **Sulphur dioxide, sulphates**

Sulphur dioxide and sulphates are among the substances with acidifying potential. Concentrations of these substances have been kept at a low levels over the long term and meet the legislative limits of the critical level of air pollution for protection of vegetation (20 µg $SO_2 \cdot m^{-3}$) for both calendar year and winter period by a large margin. In 2022, the average annual concentrations at Chopok and Starina were 0.32 µg $SO_2 \cdot m^{-3}$ and 0.39 µg $SO_2 \cdot m^{-3}$, respectively. Also, for the winter period, the concentrations at both Chopok 0.42 µg $SO_2 \cdot m^{-3}$ and Starina 0.45 µg $SO_2 \cdot m^{-3}$ were at a low level and met the legislative limits. The limit values are set by Decree of the Ministry of the Environment of the Slovak Republic No. 244/2016 Coll., as amended, in Annex 2. Annual average concentrations of sulphur dioxide and sulphates are given in **Tab. 3.14**. The values are converted to mass sulphur. **Fig. 3.2** illustrates the monthly course of sulphur and nitrogen compounds.

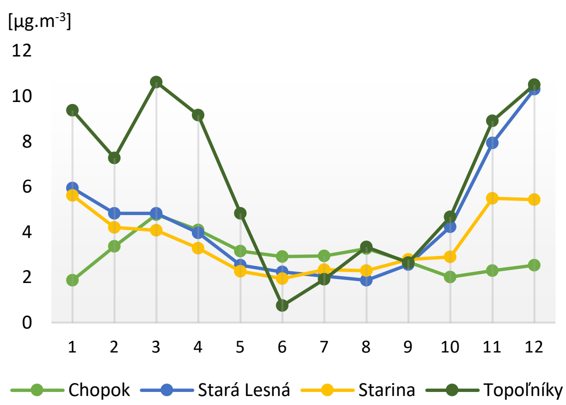
Fig. 3.2 *Average monthly concentrations of air pollutants – 2022 (converted to sulphur and nitrogen, respectively).*



- **Nitrogen dioxide, nitrates**

Nitrogen compounds can also contribute to environmental acidification. Therefore, the critical level of air pollution for the protection of vegetation has been set by legislation at 30 µg $NO_X \cdot m^{-3}$ per calendar year, which is listed in Decree No. 244/2016 Coll. of the Ministry of the Environment of the SR on air quality, in Annex 2, as amended. At regional stations the Chopok (2.98 µg $NO_X \cdot m^{-3}$), Stará Lesná (4.44 µg $NO_X \cdot m^{-3}$), Starina (3.55 µg $NO_X \cdot m^{-3}$) and Topoľníky (6.08 µg $NO_X \cdot m^{-3}$) the limit value was not exceeded. **Fig. 3.3** shows the monthly average concentrations of nitrogen oxides, which did not exceed 11 µg $NO_X \cdot m^{-3}$ at any regional station. The annual mean concentrations of nitrogen dioxide and nitrate are shown in **Tab. 3.14**. The values are converted to mass of nitrogen.

Fig. 3.3 *Average monthly NO_X concentrations in air – 2022.*



***Tab. 3.14** Annual average concentrations of pollutants [μg·m^{-3}] in air on EMEP stations – 2022.*

	SO_2	SO_4^{2-}	NO_2	NO_3^-	HNO_3	Cl^-	NH_3	NH_4^+	Na^+	K^+	Mg^{2+}	Ca^{2+}
Chopok	0.16	0.09	1.00	0.03	0.10	0.06	-	-	-	-	-	-
Starina	0.19	0.27	1.56	0.10	0.11	0.07	0.77	0.27	0.10	0.10	0.02	0.13

SO_2, SO_4^{2-} – converted to mass of sulphur, NO_x, NO_3^-, HNO_3, NH_3, NH_4^+ – converted to nitrogen

Ammonia, ammonium ions and ions of alkali metals

Detailed air quality composition in accordance with the EMEP monitoring strategy has been carried out since 2007 at the Starina regional monitoring station Concentrations of ammonia, ammonium, sodium, potassium, calcium and magnesium cations are monitored in the air on a daily basis. The annual average concentrations of the above components (NH_3 a NH_4^+ converted to nitrogen) are presented in **Tab. 3.14**. For ammonium ions the annual concentration was 0.27 μg N·m^{-3} and for ammonia 0.77 μg N·m^{-3}.

Atmospheric aerosol, heavy metals

PM_{10} and TSP concentrations (measured at Chopok) as well as more detailed characteristics of the composition of particulate matter at EMEP stations, which include the proportions of lead, copper, cadmium, nickel, chromium, zinc, arsenic and elemental and organic carbon in PM_{10}/TSP for 2022 are presented in **Tab. 3.15**.

***Tab. 3.15** Annual average concentrations of PM_{10}, TSP, EC/OC, O_3 [μg·m^{-3}] and heavy metals [ng·m^{-3}] in air at EMEP stations – 2022.*

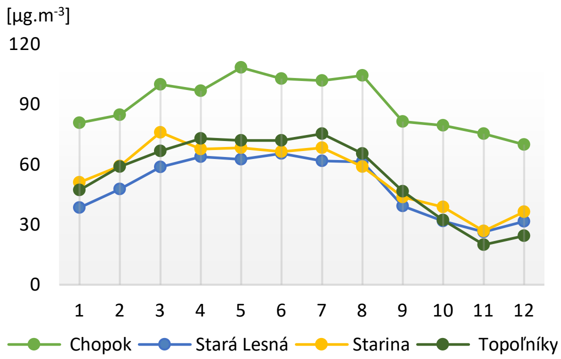
	PM_{10}/TSP[1]	Pb	Cu	Cd	Ni	Cr	Zn	As	Hg[2]	EC/OC	O_3
Chopok[1]	7.1	1.04	0.23	0.03	0.28	0.40	3.15	0.11	-	-	91
Topoľníky	13.9	3.39	1.11	0.08	0.21	0.42	11.66	0.28	1.3	-	54
Starina	11.1	2.03	0.56	0.09	0.13	0.27	7.73	0.13	1.3	-	55
Stará Lesná	9.7	2.87	0.89	0.07	0.26	0.33	9.61	0.17	-	3.6/0.4	49

[1] TSP – total suspended particles, is measured on Chopok; PM_{10} values were determined by gravimetry;
[2] Hg is measured out of EMEP monitoring program.

Ozone

Stará Lesná station has the longest time series of ozone measurements, since 1992. Ozone measurements in Topoľníky, Starina and Chopok started during 1994. In 2022, the annual average ozone concentration was 91 μg·m^{-3} at Chopok, 54 μg·m^{-3} at Topoľníky, 49 μg·m^{-3} at Stará Lesná and 55 μg·m^{-3} at Starina (**Tab. 3.15**). **Fig. 3.4** illustrates the monthly O_3 concentrations at EMEP stations. The highest concentrations generally occur at Chopok due to the location of the monitoring station at high altitudes (2008 m a.s.l.).

***Fig. 3.4** Average monthly O_3 concentrations in air – 2022.*



Volatile Organic Compounds

VOCs (Volatile Organic Compounds) C2 – C8, (so-called light hydrocarbons) started to be sampled at the Starina station in autumn 1994.

The concentration values of individual compounds vary throughout the year. The lower hydrocarbons (ethane, ethene, propane and propene) have a seasonal pattern, with high concentrations occurring in winter. In contrast, the highest concentrations of isoprene occur in the summer months. This is due to the fact that it is a chemical substance whose emissions are biogenic in nature, produced by plants.

The emission production of isoprene increases with increasing temperature. Benzene and its derivatives are not seasonal, and their concentrations are constant throughout the year. Laboratory analyses of VOCs were carried out in 2022 at the Central Laboratory of Air Quality (CLI) of the Czech Hydro-meteorological Institute (ČHMÚ) in Prague.

Tab. 3.16 *Annual average concentrations of volatile organic compounds [μg·m^{-3}] at EMEP station Starina – 2022.*

ethane	ethene	propane	propene	i-butane	butene	2-metylbutane	pentane	hexane	isoprene
2.55	1.24	1.43	0.40	0.52	0.73	0.45	0.96	0.60	0.55
Σ butenes	**Σ pentenes**	benzene	i-octane	heptene	toluene	ethylbenzene	octane	m+p-xylene	o-xylene
0.21		0.75	0.15	0.11	0.88	0.11	0.38	1.20	0.61

3.4.2 Atmospheric precipitation

The chemical composition of atmospheric precipitation is regularly monitored at all EMEP stations and at the urban background station Bratislava, Jeséniova.

Tab. 3.17 *Annual weighted averages of pollutants concentrations in atmospheric precipitation – 2022.*

	Precip. [mm]	pH	Cond. [μS·cm^{-1}]	SO_4^{2-} [mg·l^{-1}]	NO_3^- [mg·l^{-1}]	NH_4^+ [mg·l^{-1}]	Cl^- [mg·l^{-1}]	Na^+ [mg·l^{-1}]	K^+ [mg·l^{-1}]	Mg^{2+} [mg·l^{-1}]	Ca^{2+} [mg·l^{-1}]
Chopok	1006	5.49	8.31	0.20	0.19	0.31	0.26	0.21	0.07	0.03	0.17
Topoľníky	350	6.09	12.26	0.27	0.29	0.68	0.26	0.27	0.19	0.07	0.40
Starina	627	5.33	11.00	0.31	0.32	0.44	0.26	0.29	0.33	0.06	0.32
Stará Lesná	606	5.66	9.82	0.35	0.35	0.51	0.34	0.30	0.18	0.07	0.36
Bratislava, Jeséniova	475	6.09	12.28	0.28	0.28	0.53	0.27	0.32	0.17	0.10	0.74

SO_4^{2-} – converted to sulphur, NO_3^-, NH_4^+ – converted to nitrogen

Major ions, pH, conductivity

In 2022, precipitation totals at regional stations ranged from 350 to 1 006 mm, with the lowest amount of precipitation at Topoľníky and the upper limit of the range at Chopok. Annual average PH values ranged from 5.33 at Starina to 6.09 at Topoľníky (**Tab. 3.17**, **Fig. 3.6**). The conductivity of atmospheric precipitation is a reflection of the dissociated ions in the precipitation. Sulphate concentrations in precipitation (**Tab. 3.17**, **Fig. 3.6**), converted to sulphur were in the range 0.20 to 0.35 mg·l^{-1} at the EMEP stations. The lowest values occurred at Chopok and at all stations the values were slightly higher compared to previous years. Due to the significant decrease of sulphate concentrations in the air over the last decades, nitrates, which in the past contributed to the acidity of precipitation to a lesser extent than sulphates, have started to play a greater role nowadays, also due to less significant decreases in their concentrations. Nitrates converted to nitrogen showed a concentration range 0.19 to 0.35 mg·l^{-1} at the EMEP stations. (**Tab. 3.17**, **Fig. 3.6**). The lower end of the range is represented by Chopok and the upper by Stará Lesná. Ammonium ions are also among the main ions and their concentration range at the EMEP stations was 0.31 – 0.68 mg·l^{-1} (**Tab. 3.17**). The evolution of the annual average pH values of atmospheric precipitation at the EMEP stations over the last eleven years is presented in **Fig. 3.5**.

Fig. 3.5 *pH in atmospheric precipitation.*

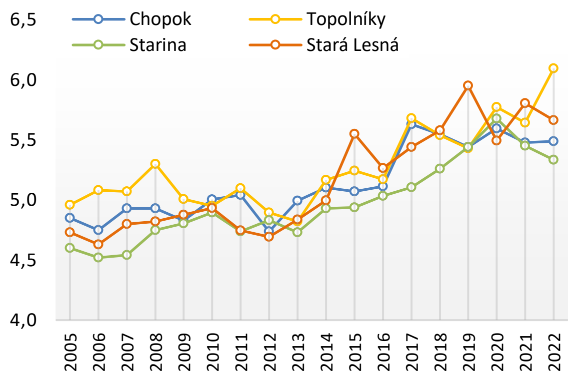
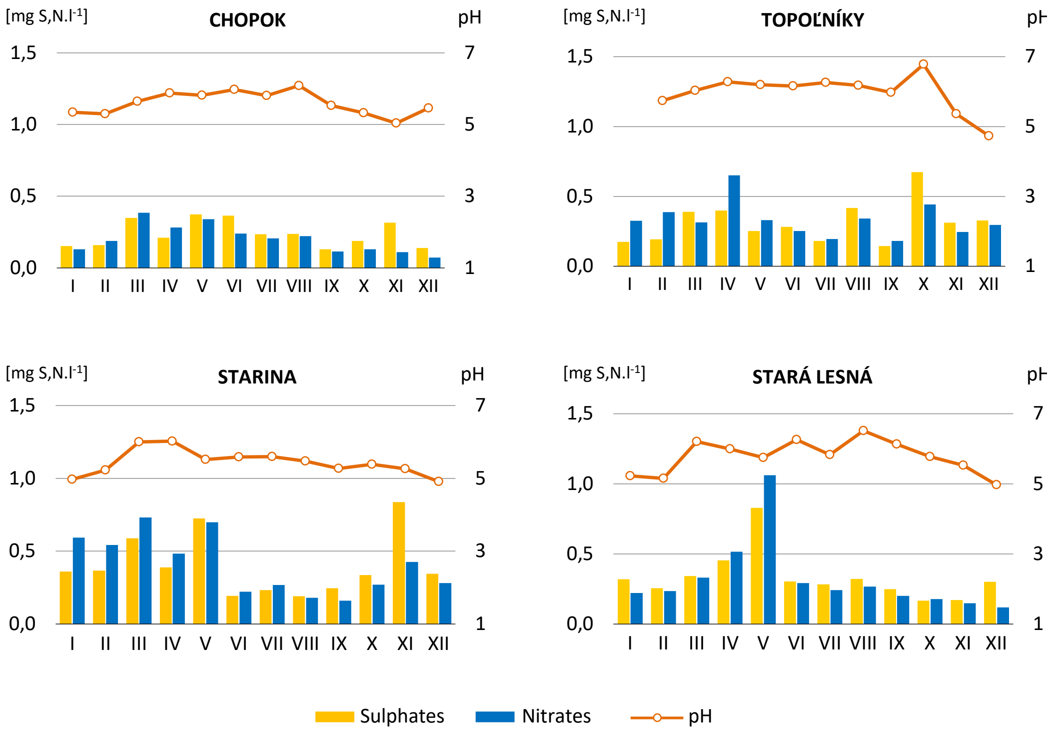


Fig. 3.6 *Atmospheric precipitation – 2022.*



Heavy metals in atmospheric precipitation

Monitoring of heavy metals in precipitation is carried out on the basis of the monitoring strategy of the CCC EMEP (Chemical Coordinating Centre of EMEP). Heavy metals – lead, copper, cadmium, nickel, chromium, chromium, zinc and arsenic ions – are monitored at stations Level 1. At the monitoring station Bratislava, Jeséniova the same range of heavy metals has been measured. However, this is for comparison purposes only and is not evaluated as a regional station. The results of the annual weighted averages of heavy metal concentrations in atmospheric precipitation for the year 2022 are presented in **Tab. 3.18**. Zinc, lead and copper have a higher abundance than other metals among the metals monitored, similar to the metals in air (**Tab. 3.15**). The long-term trend of heavy metals in precipitation is decreasing, but the concentrations in particular of lead and cadmium in air and in precipitation are high in Slovakia compared to most of the countries participating in the EMEP monitoring.

Tab. 3.18 *Annual weighted averages of heavy metal concentrations in atmospheric precipitation at EMEP stations – 2022.*

	Precipitation [mm]	Pb $[\mu g \cdot l^{-1}]$	Cd $[\mu g \cdot l^{-1}]$	Cr $[\mu g \cdot l^{-1}]$	As $[\mu g \cdot l^{-1}]$	Cu $[\mu g \cdot l^{-1}]$	Zn $[\mu g \cdot l^{-1}]$	Ni $[\mu g \cdot l^{-1}]$
Chopok	1043	2.00	0.15	0.28	0.34	1.08	22.99	0.54
Topoľníky	375	1.42	0.31	0.23	0.76	1.22	24.08	0.28
Starina	627	1.35	0.12	0.23	0.65	1.19	16.79	0.49
Stará Lesná	607	0.78	0.13	0.22	0.44	1.04	14.08	0.39
Bratislava, Jeséniova	676	0.78	0.17	0.25	0.29	2.49	4.35	0.48

3.5 SUMMARY

In 2020 and 2021, new AMS were established in the following locations within the framework of the NMSKO Improvement Project: in **Lučenec**, **Žarnovica**, **Pezinok**, **Senec**, **Trebišov**, **Komárno**, **Plášťovce**, **Poprad**, **Bardejov**, **Púchov**, **Sereď**, **Oščadnica**, **Liptovský Mikuláš** and **Bratislava** (**Púchovská Street**). Another change, which is not related to the project, is the relocation of the monitoring station from Malacky to Rohožník during 2022. As most of the new stations were only gradually starting their measurements during 2021, 2022 is the first comprehensive period that allows us to assess the new sites on a year-round basis. At the new sites, high concentrations were measured in 2022, in particular in Plášťovce (exceedance of the limit value for average daily concentrations of PM_{10}) and Oščadnica (exceedance of the information threshold for PM_{10} in January and March). At the new AMS in Žarnovica, Oščadnica and Plášťovce, the target value for benzo(a)pyrene was exceeded.

■ PM_{10}

In 2022, no monitoring stations exceeded the limit value of 40 $\mu g \cdot m^{-3}$ for annual average concentration of PM_{10}. The highest values of this indicator were recorded at Veľká Ida, Letná (37 $\mu g \cdot m^{-3}$) and Jelšava, Jesenského (30 $\mu g \cdot m^{-3}$). Exceedances of the limit value for the protection of human health for 24-hour concentrations occurred at three AMS (Jelšava, Jesenského, Veľká Ida, Letná and Plášťovce), with the highest number of exceedances recorded in January, March and December (**Fig. 3.7**). The Košice agglomeration (including the nearby industrial station in Veľká Ida) had the highest proportion of exceedances and the zone Banská Bystrica region (**Fig. 3.8**). In August, there were 12 exceedances in Veľká Ida, of which two (24^{th} and 25^{th} August 2023) were probably caused by long-distance transport of dust from dry areas. In these days, exceedances were recorded at another 8 AMS in eastern Slovakia.

Fig. 3.7 *Number of days with average daily PM_{10} concentrations > 50 $\mu g \cdot m^{-3}$ at AMS where the limit value was exceeded in 2022, broken down by month of the year.*

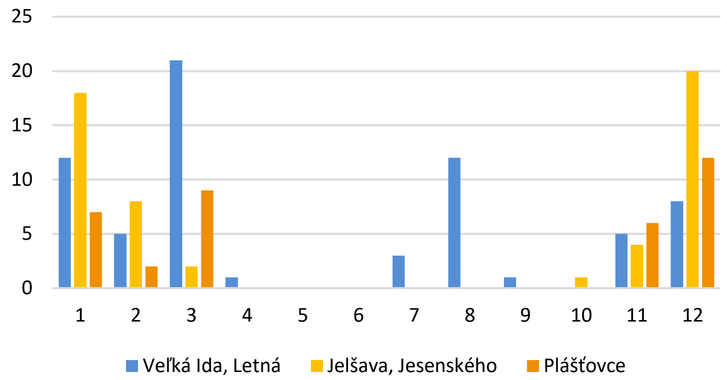
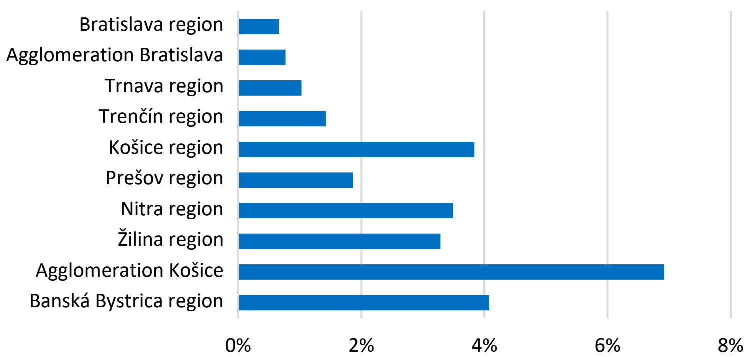


Fig. 3.8 *Relative number of exceedances of the daily limit value for PM_{10} with respect to relative to all measurements in the zone/agglomeration.*



The distribution of values of the average daily concentration of $PM_{10} > 50\ \mu g \cdot m^{-3}$ measured at the original and new stations is illustrated in **Fig. 3.9**. In the zone Nitra region, all exceedances were measured at the new AMS in Plášťovce, and the new AMS in Žarnovice in the Banská Bystrica region also had a high number of exceedances (**Fig. 3.10**).

Fig. 3.9 *Number of days with average daily concentration of $PM_{10} > 50\ \mu g \cdot m^{-3}$ at new and legacy stations by zone and agglomeration.*

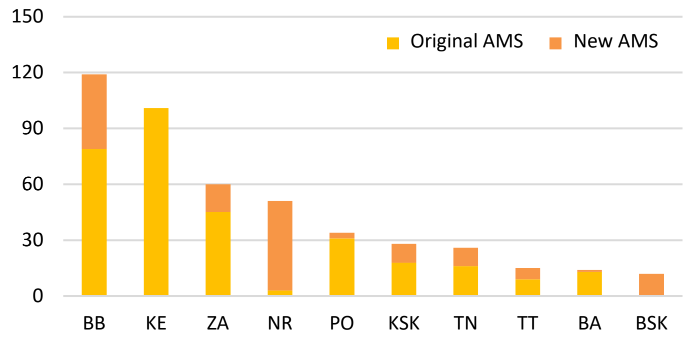
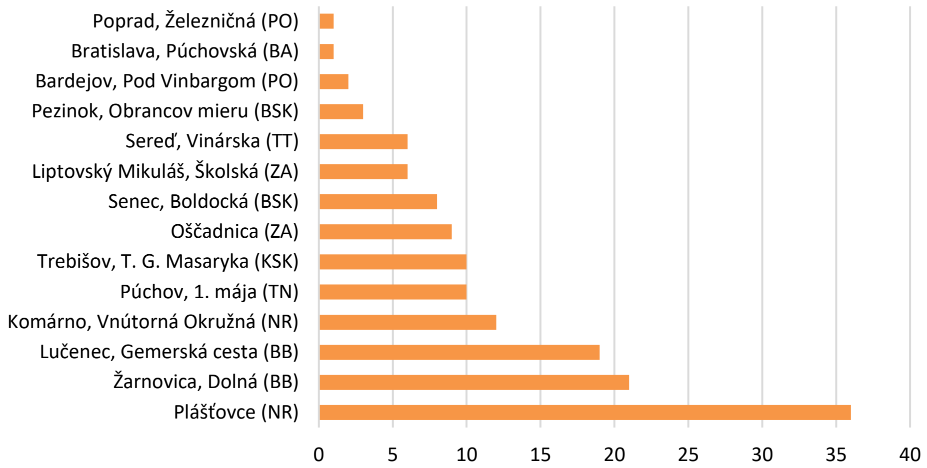


Fig. 3.10 *Number of days with average daily concentration of $PM_{10} > 50\ \mu g \cdot m^{-3}$ at new stations (zone/agglomeration abbreviation is given in brackets).*



A comparison of average daily concentrations at stations with exceedances of the limit value for PM_{10} in 2021 and 2022 is illustrated in **Fig. 3.11**.

Fig. 3.11 *Comparison of PM_{10} concentrations measured at stations exceeding the limit value in 2021 (Veľká Ida; Jelšava; Banská Bystrica, Štefánikovo nábr.) and 2022 (Veľká Ida; Jelšava; Plášťovce) with the regional background station (Stará Lesná).*

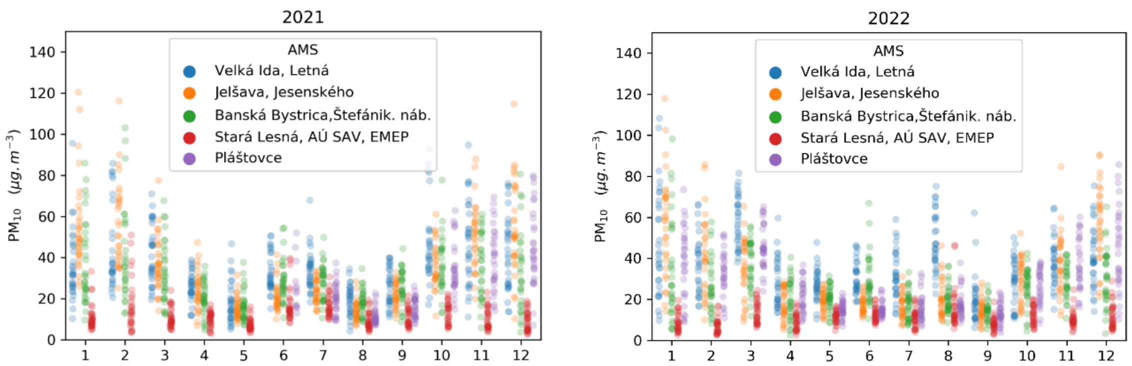
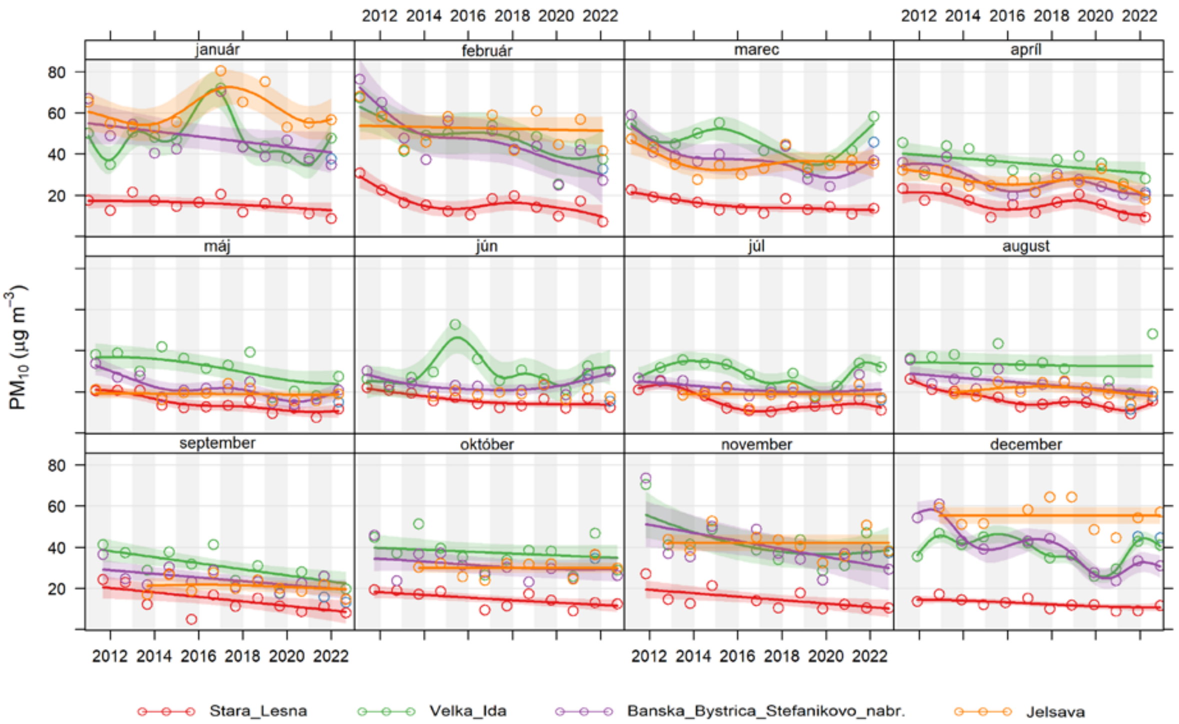


Fig. 3.12 shows the long-term trend of PM_{10} in Jelšava compared to Veľká Ida and the traffic station in Banská Bystrica, Štefánikovo nábr., which experienced an exceedance of the limit value for PM_{10} in 2021. In the summer months, due to better dispersion conditions, the values measured in Veľká Ida are also lower. The long-term slightly decreasing trend may reflect a decrease in regional background pollution combined with a decrease in industrial source emissions.

Fig. 3.12 *Monthly average PM_{10} concentrations at AMS Jelšava, Jesenského and Veľká Ida, Letná compared to the regional background station Stará Lesná and the traffic station in Banská Bystrica, Štefánikovo nábr.*



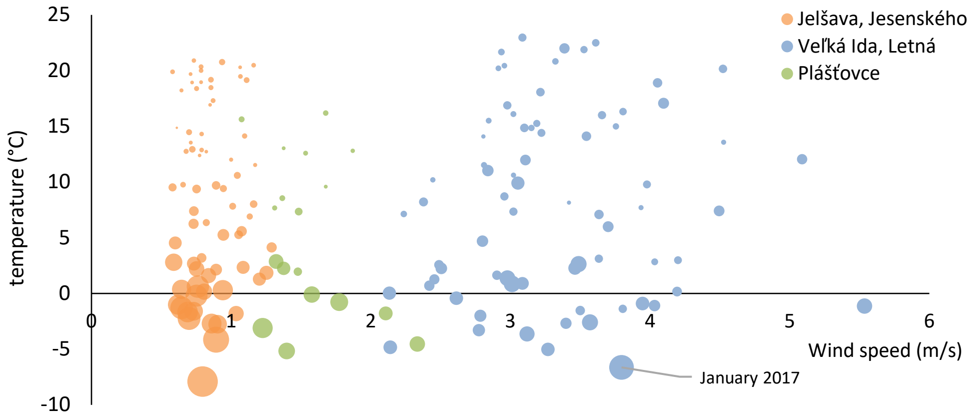
The cold January 2017 had an impact on all AMS. The minimum in the summer months is much more pronounced in Jelšava compared to Velika Ida, reflecting the different seasonality of the dominant sources at the two sites. Concentrations measured at the site mainly influenced by domestic heating (Jelšava) are comparably high as at the industrial station Veľká Ida, Letná, sometimes even higher. Both stations show the highest concentrations of PM in the long term (Veľká Ida, as mentioned above, is also affected to a lesser extent by domestic heating, in its case also by the influence of the metallurgical complex and to a lesser extent by transport (there is a non-electrified railway line nearby)). The year-to-year variation of concentrations measured at the traffic AMS Banská Bystrica, Štefánikovo nábr. is also influenced by construction works in the vicinity of the station in previous years.

- **$PM_{2.5}$**

For $PM_{2.5}$, a limit value of 20 µg·m^{-3} (for the annual average concentration) is set, which entered into force on 1 January 2020 (Commission Implementing Decision 2011/850/EU, Annex 1, point 5). In 2022, the limit value was exceeded at 3 automatic air quality monitoring stations: Veľká Ida, Letná; Jelšava, Jesenského and Plášťovce.

When comparing the dependence of $PM_{2.5}$ concentrations on monthly mean minimum temperature and wind speed (**Fig. 3.13**), we see that while the higher PM2.5 values in Jelšava and Plášťovce are measured in cool period, in Veľká Ida they can occur at any time of the year, which is characteristic of the year-round influence of the metallurgical complex located in its vicinity. The highest concentrations were in Jelšava and in Veľká Ida were recorded in the extremely cold January 2017. It is likely that in Veľká Ida in addition to the impact of the industrial source of air pollution, there is also an impact of domestic heating from nearby settlements of marginalised population groups. At the same time, the low wind speeds are clearly discernible in Jelšava, which are related to worse dispersion conditions.

Fig. 3.13 Comparison of the dependence of monthly average $PM_{2.5}$ concentrations on average wind speed and average minimum temperature in Jelšava, Veľká Ida (2017 – 2022) and Plášťovce (2022).



In Jelšava, the dominant source of PM is solid fuel heating of households, while this location is also influenced by a local industrial source (magnesite production). Combustion processes contribute mainly to the fine size fraction of PM, mechanical processes in magnesite production contribute to the coarser dust particle fraction. Very unfavourable dispersion conditions in winter are usually also a problem in Jelšava. The new AMS in Plášťovce, like Jelšava, shows high values at low temperatures, indicating sources of air pollution related to heating.

The health consequences of PM air pollution depend on both the size and composition of the particulate matter (PM). The smaller the particles are, the more the serious health consequences appear. European and Slovak legislation therefore shifts the focus of attention to $PM_{2.5}$. An indicator that reflects the trend of the population burden of $PM_{2.5}$ concentrations is the $PM_{2.5}$ Average Exposure Indicator (AEI). It is defined as a three-year moving average of annual averages of $PM_{2.5}$ from selected urban and suburban background stations. For example, the AEI 2022 is calculated as the average of the three average annual concentrations from these stations in 2020, 2021 and 2022. Table 3.19 shows the values of this indicator since 2010, which is the reference year for the AEI. According to Annex 4 to Decree No. 244/2016 Coll. on air quality, the national exposure reduction target for $PM_{2.5}$ is set at 18 $\mu g \cdot m^{-3}$, which was to be achieved by 2020. This has been achieved. The national exposure reduction target for $PM_{2.5}$ in 2022 has also been met by the Slovak Republic.

National exposure reduction target for $PM_{2.5}$

Exposure reduction target relative to the Average Exposure Indicator in 2010		Year by which the exposure reduction target should be met
Initial concentration in $\mu g \cdot m^{-3}$	Reduction target	
≤ 8.5	0%	2020
> 8.5 – < 13	10%	
= 13 – < 18	15%	
= 18 – < 22	20%	
≥ 22	All appropriate measures to achieve 18 $\mu g \cdot m^{-3}$	

Exposure concentration reduction obligation for $PM_{2.5}$

Exposure concentration reduction obligation applicable from 2015	20 $\mu g \cdot m^{-3}$

Tab. 3.19 shows the evolution of the $PM_{2.5}$ Average Exposure Indicator over the last twelve years. Its decline in 2021 can probably be explained by the decrease in emissions in Slovakia and in neighbouring countries.

Tab. 3.19 *$PM_{2.5}$ Average Exposure Indicator (AEI) in 2010 – 2022.*

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
AEI [$\mu g \cdot m^{-3}$]	24.4	24.4	23.1	22.6	20.4	19.9	18.7	19.0	18.4	18.1	16.5	15.7	15.9

SO_2

In contrast to PM, NO_2, CO and benzo(a)pyrene, SO_2 is mainly emitted by large industrial sources and power engineering industry (heat power plants). In the winter months, the impact can be domestic heating with high sulphur coal, but high SO_2 concentrations were not have been recorded, this is probably a minority heating method in the territory of the Slovak Republic.

In Rovinka, the average hourly SO_2 concentration exceeded the value of 350 $\mu g \cdot m^{-3}$ once (the limit value is 24 exceedances at most). In 2022, there were no monitoring stations in Slovakia exceeded the alert threshold. Measured concentrations are below the limit value for long periods.

The critical value for the protection of vegetation is 20 $\mu g \cdot m^{-3}$ per calendar year and winter period. This limit value has not been exceeded during 2022 at any of the EMEP stations, neither for the calendar year nor for the winter period. All values were below the lower threshold for assessing the level of ambient air with regard to the protection of vegetation.

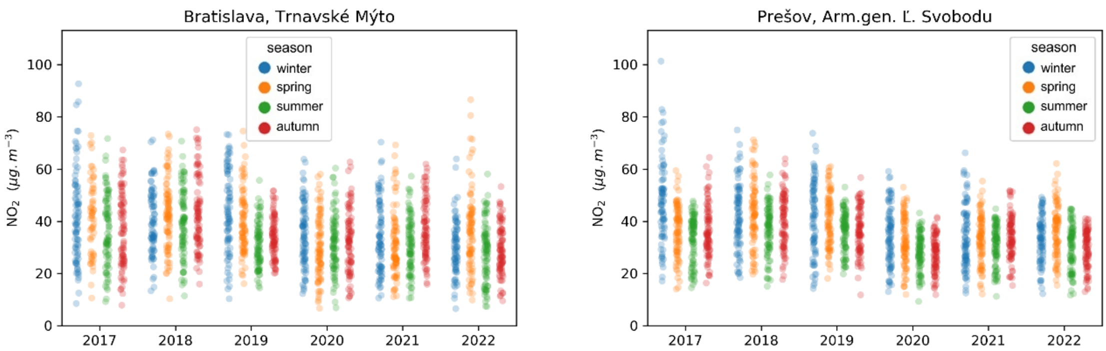
NO_2

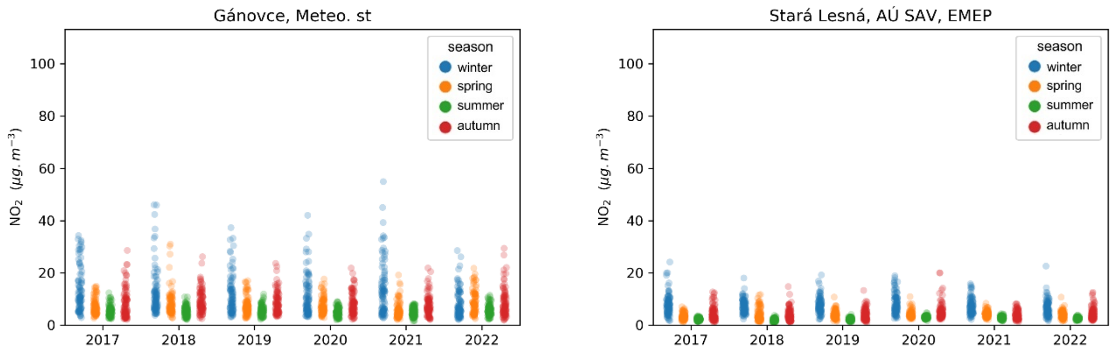
NO_2 is formed in atmosphere by oxidation of NO, emitted from road traffic and various industrial sources. The share of NO/NO_2 therefore changes significantly with distance from the source – e.g. from the road – in favour of NO_2.

In 2022, the annual limit value for NO_2 (40 $\mu g \cdot m^{-3}$) was not exceeded at any monitoring station. The limit value for the protection of human health for hourly concentrations of this pollutant was also not exceeded. In 2022, there was also no exceedance of the alert threshold for NO_2.

The highest annual average was recorded at two traffic stations - Bratislava, Trnavské Mýto (31 $\mu g \cdot m^{-3}$) and Prešov, Arm. gen. L. Svobodu (32 $\mu g \cdot m^{-3}$). **Fig. 3.14** illustrates a comparison of the values measured at both AMS.

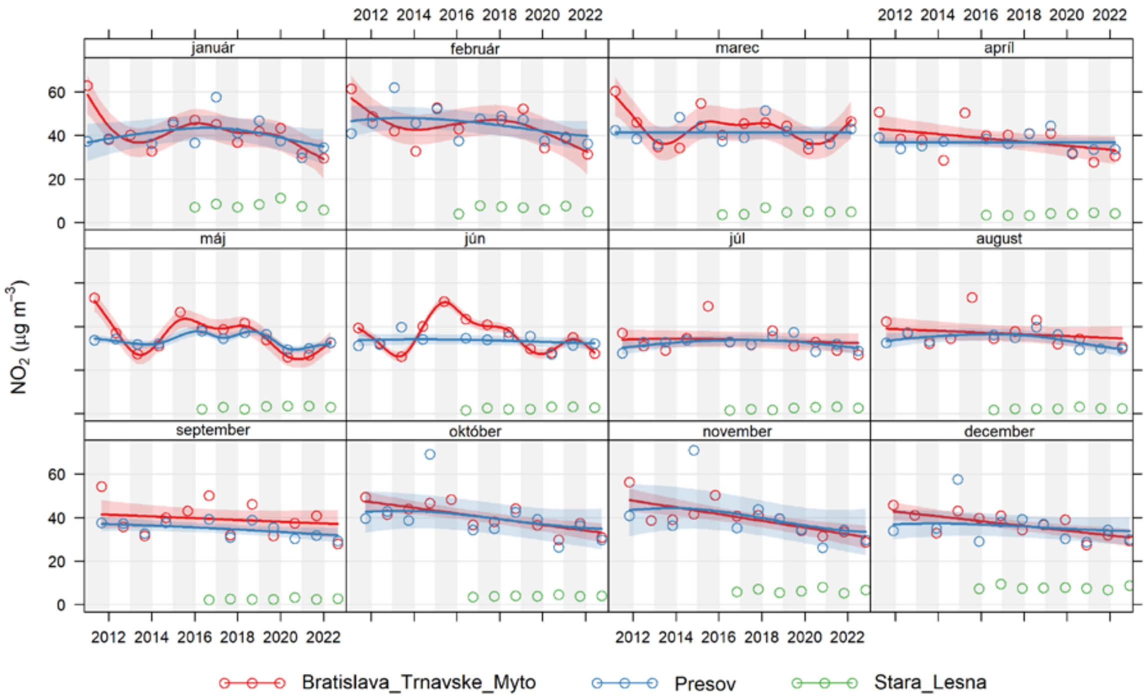
Fig. 3.14 *Average daily NO_2 concentrations at AMS Bratislava, Trnavské Mýto and Prešov, Arm. gen. L. Svobodu compared to regional background sites (Gánovce and Stará Lesná).*





The last exceedance of the limit value for the annual average NO_2 concentration was measured in 2018 at AMS Bratislava, Trnavské Mýto and Prešov, Arm. gen. L. Svobodu. In the long-term trend, NO_2 concentrations at both AMS have a slightly decreasing trend (**Fig. 3.15**). Local maxima are probably influenced by meteorological conditions.

Fig. 3.15 *NO_2 at AMS Bratislava, Trnavské Mýto, Prešov and Stará Lesná in the years 2011 – 2022.*

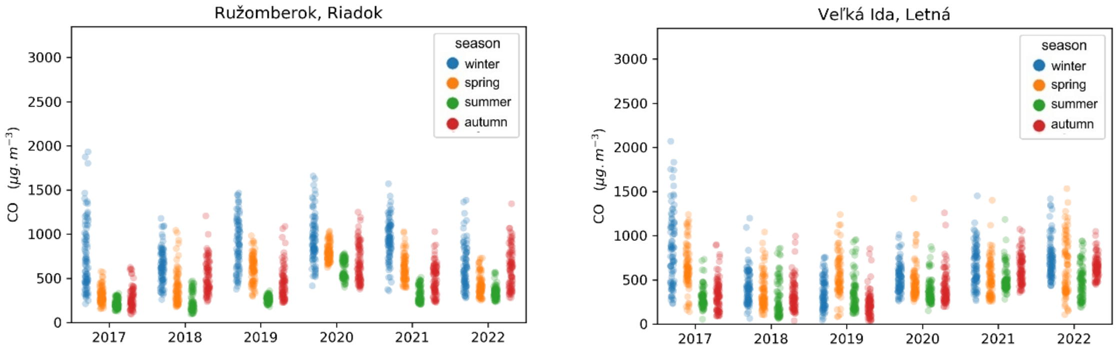


The critical air pollution level for vegetation protection (30 μg·m^{-3} per calendar year expressed as NO_X) was not exceeded at any of the EMEP stations in 2022. The values were well below the lower threshold for assessing air pollution level that is designed to protect vegetation and natural ecosystems.

CO

Source of CO emission are combustion processes in industry, power engineering, household heating and road transport. None of the monitoring stations in Slovakia exceeded the limit value for CO in 2022. The level of air pollution for the previous period 2012 – 2022 is below the lower threshold for assessing the level of ambient air pollution. In **Fig. 3.16** we can compare the course of average daily concentrations at two different locations – at AMS Veľká Ida, Letná the concentrations are distributed approximately evenly throughout the year, at AMS Žilina, Obežná the maximum occurs in the winter months.

Fig. 3.16   Average daily CO concentrations at AMS Ružomberok, Riadok, and Veľká Ida, Letná.

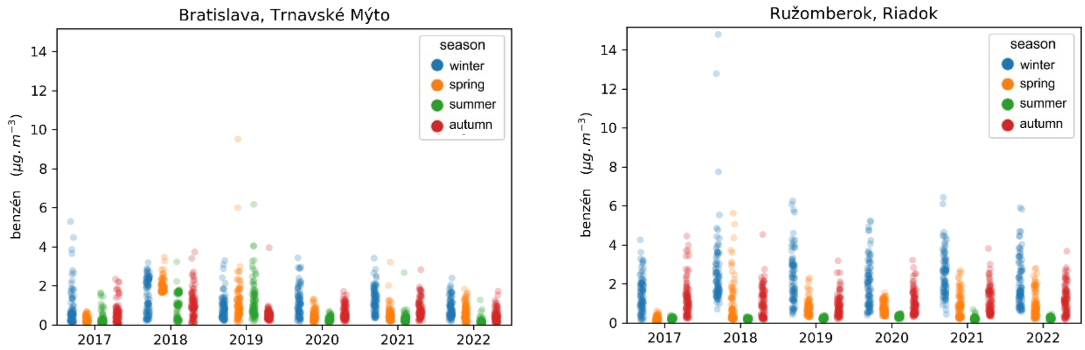


Benzene

Benzene emissions come from road transport, and to a lesser extent from industrial sources.

The highest level of benzene in yearly monitoring was measured at the station Ružomberok, Riadok in 2022 (1.1 $\mu g \cdot m^{-3}$). However, the values of annual average concentrations were significantly well below the limit value of 5 $\mu g \cdot m^{-3}$. **Fig. 3.17** illustrates the course of benzene concentrations in 2017 – 2022 at the Bratislava, Trnavské Mýto traffic station (where, in addition to road traffic, the impact of the refinery may also be episodic) and at the urban background station in Ružomberok.

Fig. 3.17   Average daily benzene concentrations at AMS Bratislava, Trnavské Mýto and Ružomberok, Riadok.



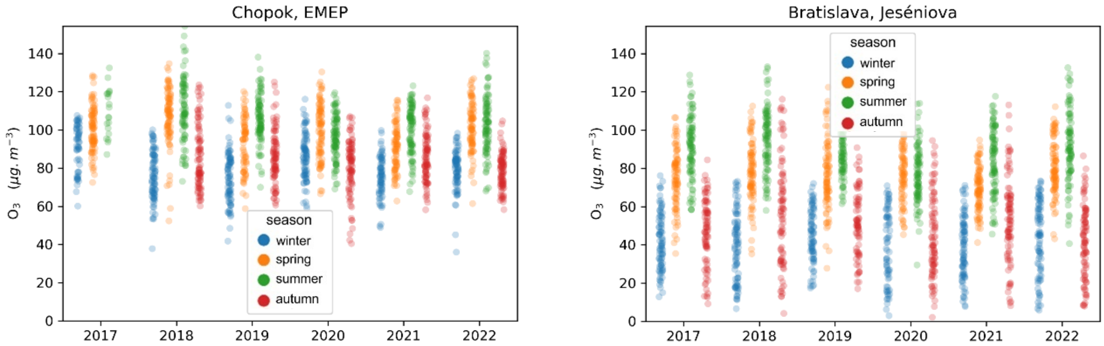
Ozone

The tropospheric ozone issue is regional in nature, as both ozone and its precursors are subject to long-range transport in both horizontal and vertical directions. The situation is complicated also by chemism and its formation and chemical degradation in the atmosphere – ozone is formed in the presence of solar radiation, e.g. from nitrogen monoxide (from road traffic) and volatile organic hydrocarbons (from various combustion processes, paints and dissolvents, but also from biogenic sources) or CO (from road transport or industrial sources). The amount of ozone formed depends on the concentration ratio of its precursors. In the presence of nitrogen monoxide, however, ozone decomposes, which is why there is usually low ozone concentrations in the vicinity of busy roads.

Fig. 3.18 shows the seasonality of tropospheric ozone concentrations, which, unlike other pollutants (see Annex B of this Report), has a pronounced peak in summer. Ground-level ozone is formed from photochemical reactions of, for example, from nitrogen monoxide or carbon monoxide and volatile organic substances. The reaction depends on the intensity of solar radiation. At high mountain altitudes (e.g. on Chopok), ozone concentrations are highest (**Fig. 3.18**).

The target value of ground-level ozone was exceeded by measurements at two stations: Bratislava, Jeséniova and Chopok, EMEP. In 2022, the information threshold was exceeded at AMD Bratislava, Jeséniova.

Fig. 3.18 *Daily average concentrations of ground-level ozone at monitoring stations in Bratislava, Jeséniova and Chopok, EMEP.*



Pb, As, Ni, Cd

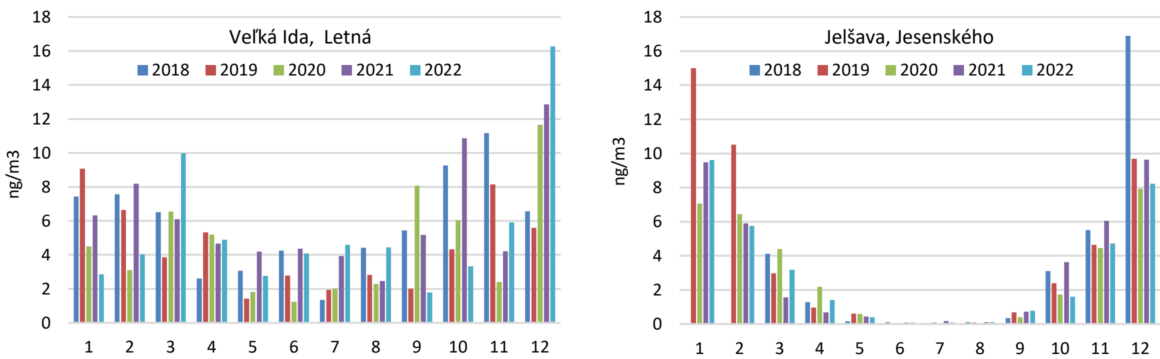
Neither the limit value nor the target value was exceeded in 2022. The annual average concentrations of heavy metals measured at NMSKO stations are mostly only fraction of their target or limit value.

BaP

Benzo(a)pyrene and other polycyclic aromatic hydrocarbons were monitored at 20 stations in 2022 (the sampler at AMS Trenčín Hasičská had a malfunction), of which the target value for the annual average BaP concentration was exceeded at these 10 stations: AMS Veľká Ida, Letná; Jelšava, Jesenského; Žarnovica, Dolná; Oščadnica; Plášťovce; Krompachy, SNP; Ružomberok, Riadok; Púchov, 1. May; Žilina, Obežná and Banská Bystrica, Štefánikovo nábrežie. The first seven stations exceeded the target more than twice. The highest annual average concentration, and the highest measured values, was achieved by Veľká Ida (5.4 ng·m^{-3}). The AMS in Prievidza, Malonecpalská had a malfunction on 24 January – 21 April and it is very likely that with sufficient measurements the target value would have been exceeded at this station as well. At most sites local heating is the decisive source, at Veľká Ida it is largely the contribution of the industrial complex, especially from coke production.

Fig. 3.19 compares the average monthly concentrations over the last 5 years at the site where BaP concentrations are mainly influenced by industry (Veľká Ida) with the station where BaP emissions originate mainly from domestic heating (Jelšava). In the latter case, very low values outside the heating season are characteristic. This pattern is typical for all monitoring stations except Veľká Ida.

Fig. 3.19 *Comparison of average monthly BaP concentrations at the monitoring station Veľká Ida, Letná (left) and Jelšava, Jesenského (right).*



4 RESULTS OF AIR QUALITY MATHEMATICAL MODELLING

The Air Act No 137/2010 Coll., as amended, defines the procedure for air quality assessment and criteria in full compliance with EU directives and enables to use mathematical modelling for air quality assessment in addition to measurements at monitoring stations. The basic method for the assessment of air quality in Slovakia is the monitoring, carried out by the SHMÚ at NMSKO stations. Mathematical modelling methods are used as supplementary method to measurements.

Calculations for air quality assessment using mathematical modelling were performed by modified RIO and CMAQ models. These models differ in their methodology from the models used for air quality assessment before the year 2020. This should be taken into account when comparing current results with results from Air Quality Reports in 2020 and earlier.

4.1 BRIEF CHARACTERISTICS OF MODELS USED

- **Chemical-transport model CMAQ v5.3**

The *Community Multiscale Air Quality Modelling System* - CMAQ[8], is being developed and supported at EPA's National Exposure Research Laboratory Development Center in Research Triangle Park, NC. CMAQ is a third-generation air quality model, which means it can model multiple pollutants simultaneously at large scales that can span continents. It is a three-dimensional Eulerian chemical-transport model that is used to simulate ozone, atmospheric aerosols (PM), sulphur oxides, nitrogen oxides, and other pollutants in the troposphere. Expressed mathematically, CMAQ calculates the change in pollutant concentrations over time for each grid cell using the continuity equation. These changes in concentration are caused by processes such as emissions, advection, diffusion, chemical transformations of the pollutant and processes of removal from the atmosphere, such as dry and wet deposition. For the air quality assessment, a simulation was run with a horizonal resolution of 2 x 2 km with meteorological data from the ALADIN model. The computational domain of the model covers the Central European region.

- **Regression-interpolation model RIO**

The RIO[9] model is an advanced interpolation-regression model. The inputs are measured concentrations and various auxiliary spatial proxy fields that are related to the spatial distribution of a given pollutant - such as maps of altitude, traffic intensity, ventilation index, gridded emissions from local heating plants - while the set of these so-called drivers is specific to a particular pollutant. Model results, e.g. also CMAQ model results, satellite observations, etc., can also serve as spatial drivers, and by using the RIO model we can obtain a higher spatial resolution of concentrations. In the first step of the calculation, the model detects spatial correlations of a given pollutant with each possible spatial driver at the locations of monitoring stations. Next, it optimizes the so-called β parameter, which is obtained by combining the selected spatial drivers that best correlate with the spatial distribution of the pollutant. The model calculates the β parameter that achieves the best correlation with the measured data. The differences between the values at the monitoring station locations calculated using the β parameter and the actual measurements are then interpolated using the ordinary kriging method and then added to the data calculated using the β parameter for each grid point. For the air quality assessment by the RIO model, a resolution of 1 x 1 km was used.

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[8] *United States Environmental Protection Agency. (2020). CMAQ (Version 5.3.2) [Software]. Available from https://doi.org/10.5281/zenodo.4081737*

[9] *Janssen, S., Dumont, G., Fierens, F., Mensink, C., 2008: Spatial interpolation of air pollution measurements using CORINE land cover data. Atmos. Environ. 42, 4884–4903. doi: 10.1016/ j.atmosenv.2008.02.043*

■ **IDW-R**

Interpolation model RIO belongs to the so-called approximate interpolation methods, which means, that field of concentrations smoothest and in places of monitoring stations do not calculate necessarily the same concentration as it had been measured. Therefore, the outputs of model RIO or CMAQ for the time being have to be adapted by the technique of IDW-R (inverse distance weighting - regression). In the first step of IDW-R is calculated linear regression curve among the measured data and outputs of model. In the second step is carried out standard IDW interpolation of differences between the measured data and data, calculated by linear regression and by this is gained the 2D map with interpolation differences. This is multiplied by the rescaled input data with values from 0 to 1 and consequently added to the values calculated by regression. Technique is possible to repeat several times consequently under the improving statistical parameters. To the final comparison of model with measurements was used root mean square error (RMSE) and systematic error (BIAS).

4.2 RESULTS AND OUTPUTS

■ **PM_{10}**

The dominant source of PM_{10} emissions is household heating, mainly with solid fuel, which accounts for more than 60% of total PM_{10} emissions. The share of PM_{10} emissions from road transport is less than 10%, yet their impact on air quality near busy roads is not negligible. Large and medium industrial sources and system energy production make up approximately 10% of PM_{10} emissions, waste management and agriculture contribute to a lesser extent[10]. The problem of modelling PM with a chemical-transport or dispersion model is also complicated by the relatively significant, although time-limited, impact of activities whose emissions are difficult to quantify and at least approximately localize in space and time - e.g. construction and demolition work, agricultural work such as ploughing or harvesting, and the illegal burning of agricultural residues and waste.

The spatial distribution of PM_{10} concentrations in Slovakia was calculated by the RIO model, while the outputs from the AtmoStreet Gaussian model for the year 2022[11] (6.9%), the ventilation index[12] (13%), altitude (45.8%), land use[13] (34.2%)[14] (%) were used as proxy spatial fields. After subsequent adjustment of the results using the IDW-R method and comparison with measurements, we get RMSE = 0.4 $\mu g{\cdot}m^{-3}$ and BIAS = –0.03 $\mu g{\cdot}m^{-3}$.

The annual mean concentrations of PM_{10} are shown in **Fig. 4.1**. As can be seen, the limit value for the annual mean concentration (40 $\mu g{\cdot}m^{-3}$) was not exceeded anywhere in this spatial resolution of the model. The highest concentrations of PM_{10} occur in the valleys of central Slovakia, Gemer, Šariš, Spiš, the vicinity of Košice and in the north-west of Slovakia.

In **Fig. 4.2** shows the number of days with daily mean concentration of $PM_{10} > 50\ \mu g{\cdot}m^{-3}$. The number of such days per year must not exceed 35. We can see from the picture that this condition is not met for Gemer valleys close to Jelšava, the vicinity of Veľká Ida, southern Slovakia around Plášťovce and areas in north-western Slovakia, especially in Orava and lower Liptov. In general, the poorly ventilated basin areas of Slovakia with a high share of solid fuels used for local heating have a higher number of exceedances.

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[10] https://www.ceip.at/status-of-reporting-and-review-results - IIR by individual years and countries.
[11] This model included emissions from local heating plants without considering background concentrations.
[12] The height of mixing multiplied by average wind velocity in layers under this height.
[13] CORINE Land Cover 2018 https://www.eea.europa.eu/data-and-maps/data/external/corine-land-cover-2018
[14] Percents in brackets express the contribution of individual spatial fields.

Fig. 4.1 *Annual mean concentrations of PM_{10} [$\mu g \cdot m^{-3}$] in year 2022.*

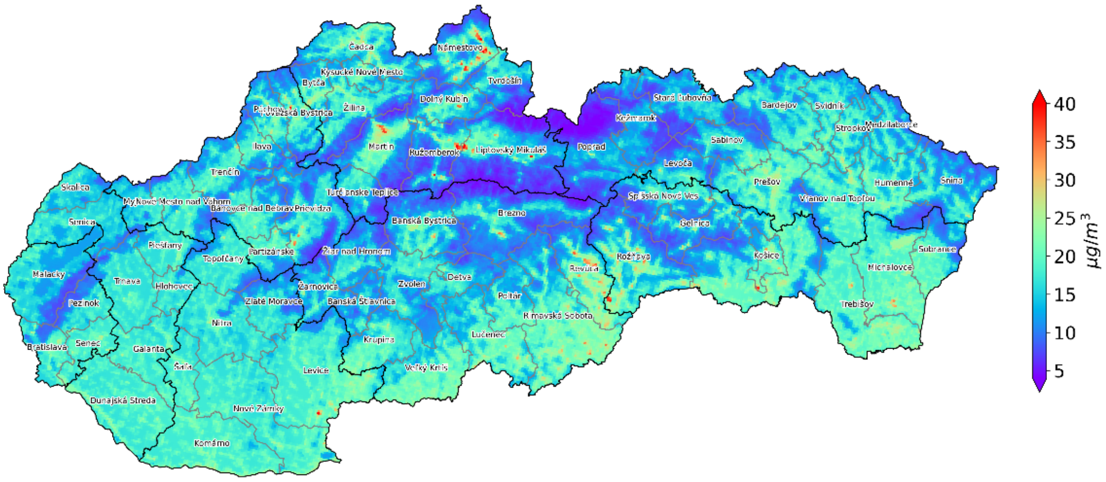
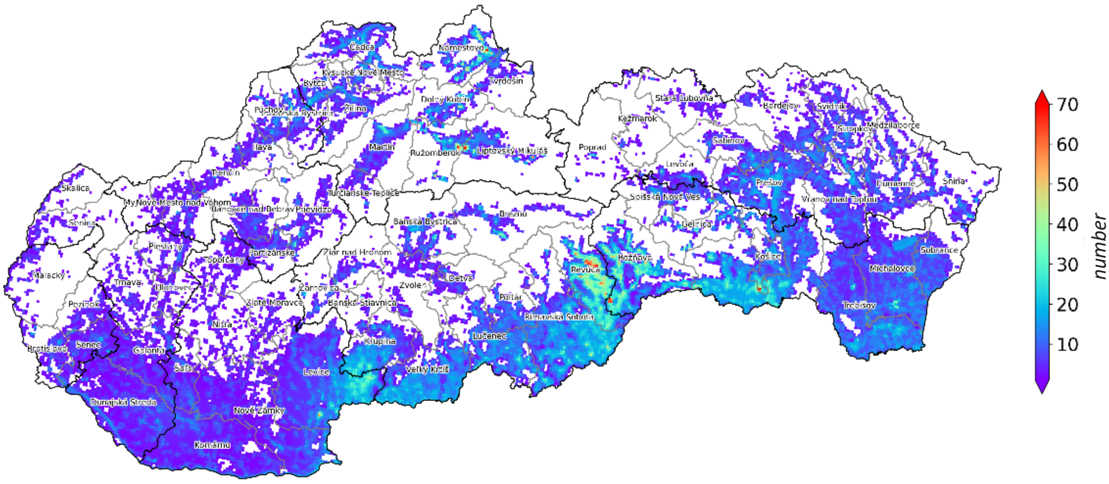


Fig. 4.2 *Number of days exceeding the limit value for the 24-hour PM_{10} concentration (50 $\mu g \cdot m^{-3}$) in 2022. Only areas with a non-zero number of exceedances are shown.*



■ $PM_{2.5}$

The dominant source of $PM_{2.5}$ emissions is household heating, mainly with solid fuels, which accounts for up to 80% of total emissions of $PM_{2.5}$ every year[15].

The spatial distribution of $PM_{2.5}$ concentrations in Slovakia was calculated by the RIO model, while the outputs from the AtmoStreet model for 2022, which used only the emissions from local heating (12.9%), ventilation index (18%), altitude (53.3%) and land use[16] (14.9%) were used as additional spatial data.

After subsequent adjustment of the output of the RIO model using the IDW-R method, we get RMSE = 0.2 $\mu g \cdot m^{-3}$ and BIAS = –0.05 $\mu g \cdot m^{-3}$ when compared with the measurements. The resulting annual mean concentrations of $PM_{2.5}$ are shown in **Fig. 4.3**.

In 2022, the limit value of the average annual concentration of $PM_{2.5}$ (20 $\mu g \cdot m^{-3}$) was exceeded only in a few places, namely in Orava, Dolný Liptov, Gemer in the vicinity of Jelšava, in the vicinity of Košice, in the vicinity of Martin and Čierny Balog, based on modelling with this spatial resolution. The highest concentrations are similarly to PM_{10} concentrations, in locations with a high share of solid fuels used for local heating, in closed mountain valleys.

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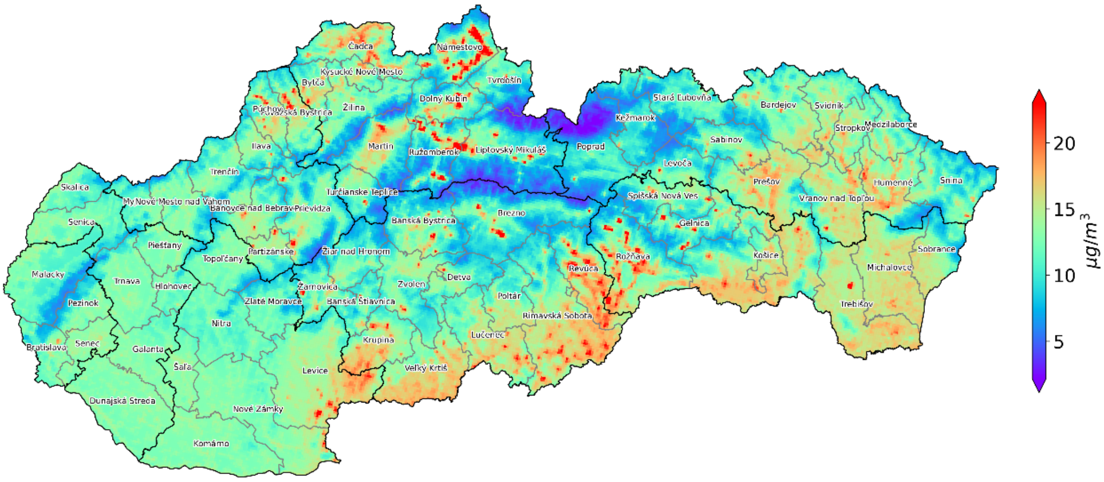
[15] *https://www.ceip.at/status-of-reporting-and-review-results* - - IIR by individual years and countries

[16] *CORINE Land Cover 2018 https://www.eea.europa.eu/data-and-maps/data/external/corine-land-cover-2018*

Fig. 4.3 *Annual mean concentration $PM_{2.5}$ [$\mu g \cdot m^{-3}$] in the year 2022.*

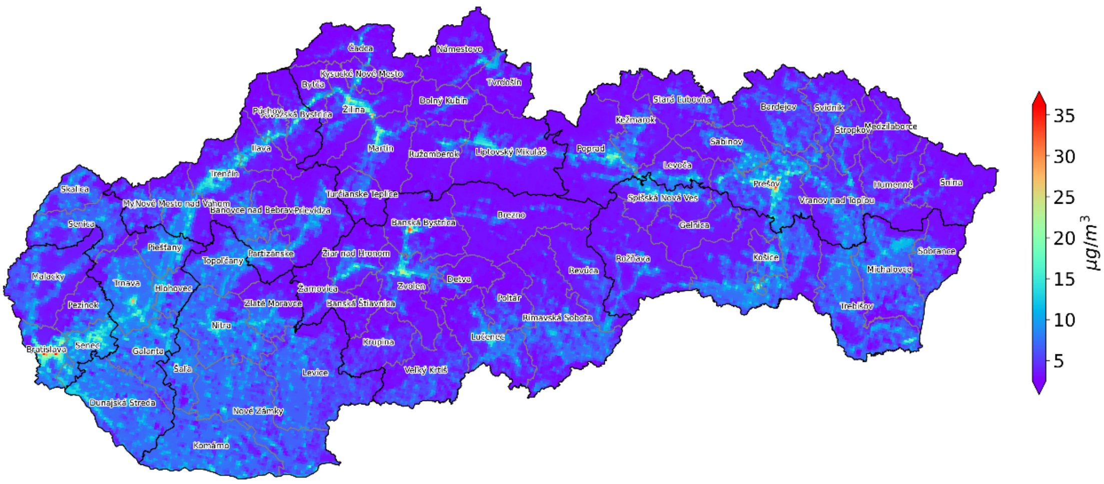


■ NO₂

Although the contribution to emissions from road transport represents around 35% of total NO_X emissions, the impact of road transport in the vicinity of busy roads is considerably more significant than the impact of other types of sources, whose flue gases released from higher chimneys are effectively dispersed under normal meteorological conditions.

The spatial distribution of NO_2 concentrations in Slovakia was calculated by the RIO model, while the following spatial proxy data were used: model AtmoStreet output, which used emissions from road transport, industry and local heating for 2022 (34.7%), altitude (8%) and land use[17] (57.3%). After subsequent modification of the model by the IDW-R method and comparison with measurements, we get RMSE = 0.9 $\mu g \cdot m^{-3}$ and BIAS = –0.08 $\mu g \cdot m^{-3}$. The resulting average annual concentrations of NO_2 are shown in **Fig. 4.4**. The highest concentrations occur in the vicinity of large cities, i.e. in places with increased intensity of road traffic. It can be seen from the figure that in the given resolution the limit value for the average annual concentration (40 $\mu g \cdot m^{-3}$) was not exceeded in 2022. Also, the limit value of the average hourly concentration (200 $\mu g \cdot m^{-3}$ - this value must not be exceeded more than 18 times per calendar year) was not exceeded either for measured or for modelled concentration values.

Fig. 4.4 *Annual mean concentration of NO_2 [$\mu g \cdot m^{-3}$] in the year 2022.*



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[17] *https://land.copernicus.eu/pan-european/corine-land-cover*

Ozone

The spatial distribution of ozone concentrations in Slovakia was calculated by the RIO model, with AtmoStreet model output (2022), which used only the emissions from road transport (18.3%), altitude (53.8%), ventilation index (28%) used as auxiliary spatial fields. After subsequent adjustment of the calculated concentrations by the IDW-R method and comparison with the measurements, we get RMSE = 0.8 $\mu g \cdot m^{-3}$ and BIAS = 0 $\mu g \cdot m^{-3}$. Data from monitoring stations in 2022 were included in the analysis. The resulting annual mean ozone concentrations are shown in **Fig. 4.5**. **Fig. 4.6** illustrates the number of days in which the eight-hour average ground-level ozone concentration exceeded 120 $\mu g \cdot m^{-3}$ (i.e., the target value for the protection of human health), showing the average number of days for the period 2020 – 2022. (This average number of days must not exceed 25). From the picture we can see that more than 25 exceedances on average for the period of 2020 – 2022 are in high mountain areas and areas in western Slovakia. **Fig. 4.7** shows the average AOT40 values for the protection of vegetation for the period 2018 – 2022 (according to Decree of the Ministry of the Interior of the Slovak Republic No. 244/2016 Coll. on air quality, as amended). The target value of 18 000 is also exceeded in high mountain locations and in western Slovakia.

Fig. 4.5 *Annual mean concentration of ozone [$\mu g \cdot m^{-3}$] in the year 2022.*

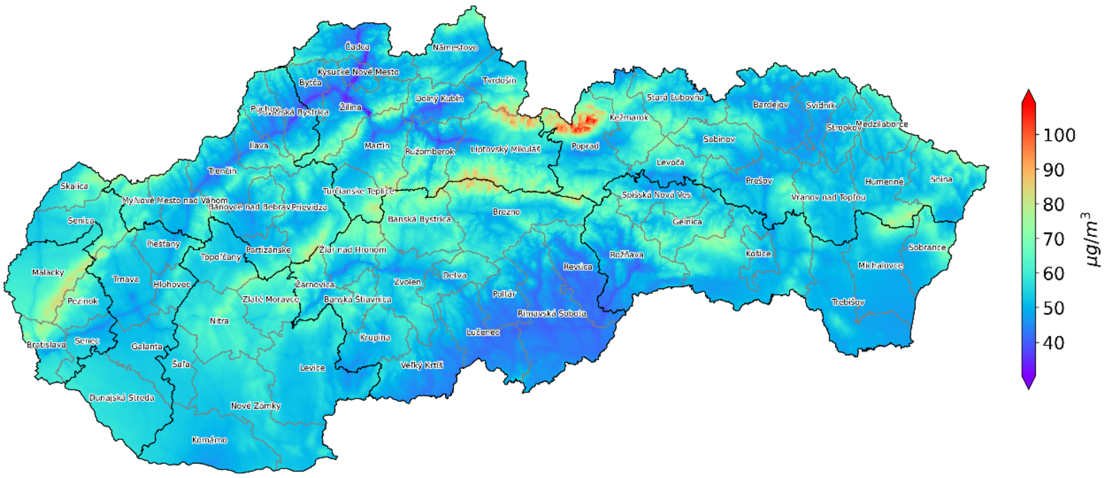


Fig. 4.6 *Number of days, in which eight-hour mean concentration of surface ozone exceeded value 120 $\mu g \cdot m^{-3}$ (mean during years 2020 – 2022).*

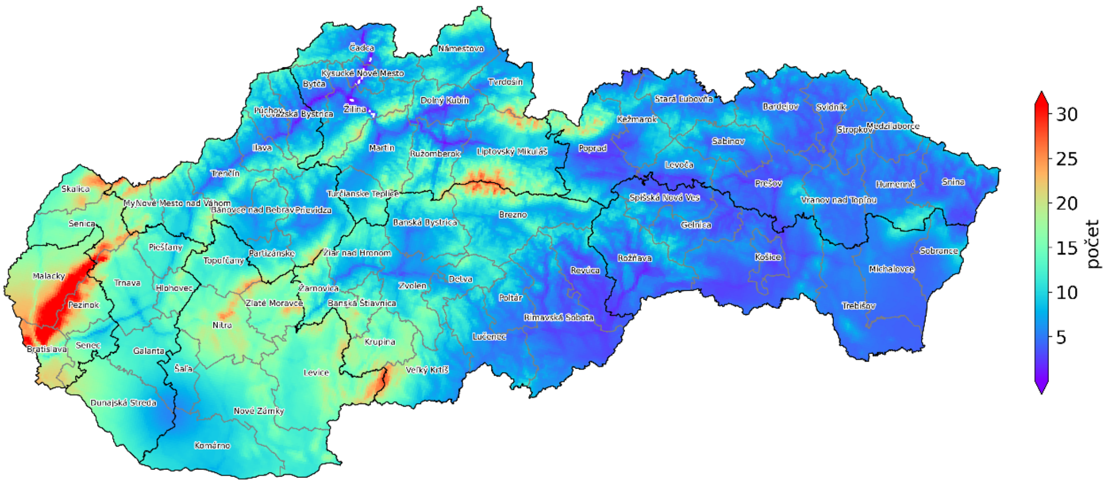
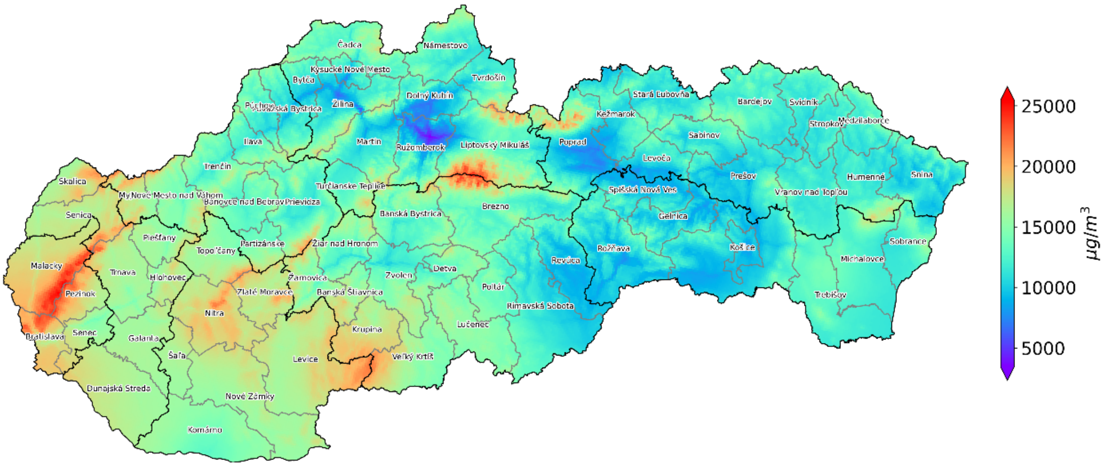


Fig. 4.7 *Mean values of AOT40 during period of five years (2018 – 2022).*



Average annual concentrations of ground-level ozone generally increase with altitude, which is caused by the penetration of stratospheric ozone into the upper troposphere. In 2022, as in the previous years, the maximum values were measured at the places with highest altitudes and the minimum values at stations in city centres, where ozone is destroyed by high concentrations of NO. Increased ozone values are also found in peripheral areas of larger urban agglomerations, or in industrial zones, where ozone is created mainly by photochemical reactions of nitrogen oxides with VOCs and CO. For a more detailed investigation of the spatial distribution of tropospheric ozone, it would be necessary to use a chemical-transport model with high resolution and high-quality emission inputs of ozone precursors. In order to better calibrate the model, it would be necessary to cover the territory with a denser network of stations, or to carry out a series of indicative measurements that would characterize several types of environments (locations directly affected by road transport, locations at different distances from the centre of the agglomeration, or from sources of ozone precursors). Maps on **Fig. 4.5** to **Fig. 4.7** therefore do not capture the reality accurately enough.

■ SO_2

On SO_2 emissions participate mainly large industrial sources and energetics, as opposed to PM and benzo(a)pyrene. The share of household heating in total emissions is less than 10%. Locally, the impact of small sources can be more pronounced in areas where coal is used to a greater extent for heating of households.

The spatial distribution of SO_2 concentrations in Slovakia was calculated by the CMAQ model, while meteorological data from the ALADIN model were used.

The most important SO_2 emissions are height sources (chimneys of industrial or energy plants). These sources were obtained from the NEIS (National Emissions Information System) database for the territory of the Slovak Republic. The most important sources of SO_2 were U.S. Steel Košice, s.r.o., SLOVNAFT, a.s. (Bratislava), Slovalco, a.s. (Žiar nad Hronom) and Slovenské elektrárne, a.s. (Nováky power plant). According to preliminary data, SO_2 emissions registered in the NEIS database decreased in 2022 compared to 2021, mainly due to the energy crisis and the subsequent reduction in production. For example, annual SO_2 emissions from aluminium production (Slovalco, a.s.) decreased more than twice.

Furthermore, SO_2 emissions from local heating and emissions from road transport (which in the case of SO_2 represent less than 1% of total emissions) were also included in the simulation. Outside the Slovak Republic, emissions from the TNO-MAC III[18] database were used. Another necessary characteristic is changes in emissions during the year, which were determined based on the nature and type of source

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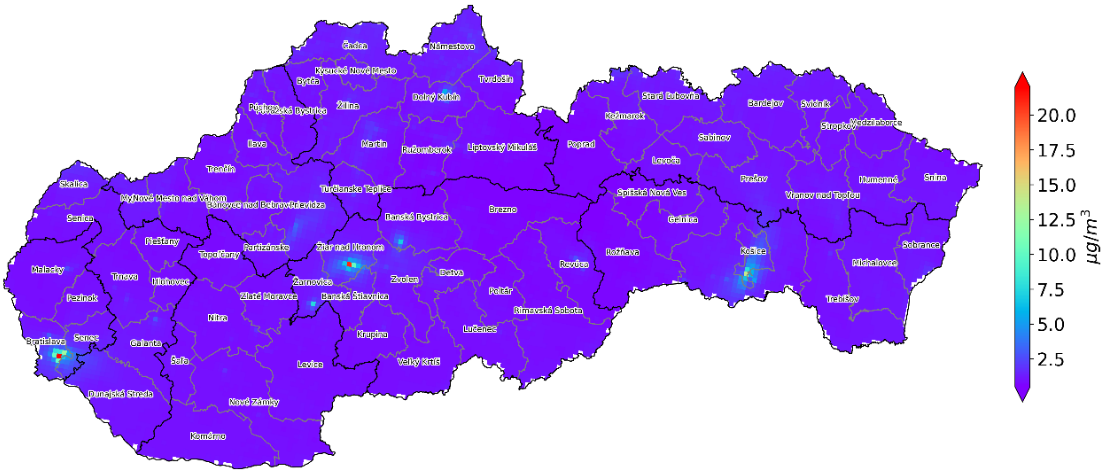
[18] *Kuenen, J.J.P., Visschedijk, A.J.H., Jozwicka, M., Denier van der Gon, H.A.C., 2014. TNOMACC_ II emission inventory; a multi-year (2003-2009) consistent high-resolution European emission inventory for air quality modelling. Atmos. Chem. Phys. 14, 10963–10976. https://doi.org/10.5194/acp-14-10963-2014*

(year-round operation, seasonal operation, energy, local heating, etc.). However, in the case of large sources, these changes are often sudden and large and cannot be retrospectively reconstructed with the necessary accuracy. It contributes to the uncertainty of model output.

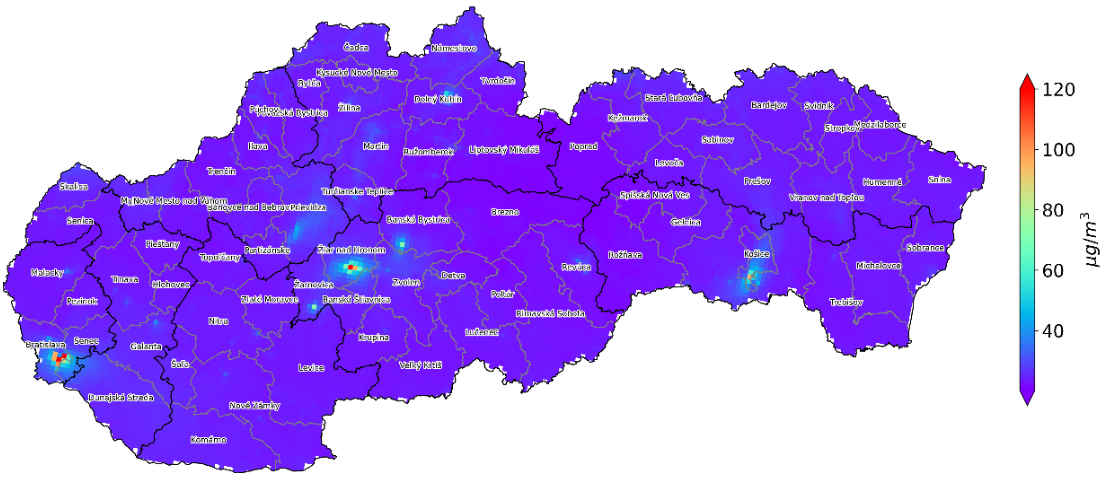
Measured annual mean concentrations of SO_2 have been low in recent years It seems, that at such low values the level of sensitivity of measured instruments (analysers) SO_2 was reached, therefore in case of annual mean concentrations of SO_2 the model is not calibrated with values of measured concentrations. On resulting map of annual mean concentrations of SO_2 from modelling (**Fig. 4.8**) is possible to see that the highest concentrations are in locations with direct reach of significant point sources.

Fig. 4.8 *Annual mean concentrations of SO_2 [$\mu g \cdot m^{-3}$] in the year 2022.*



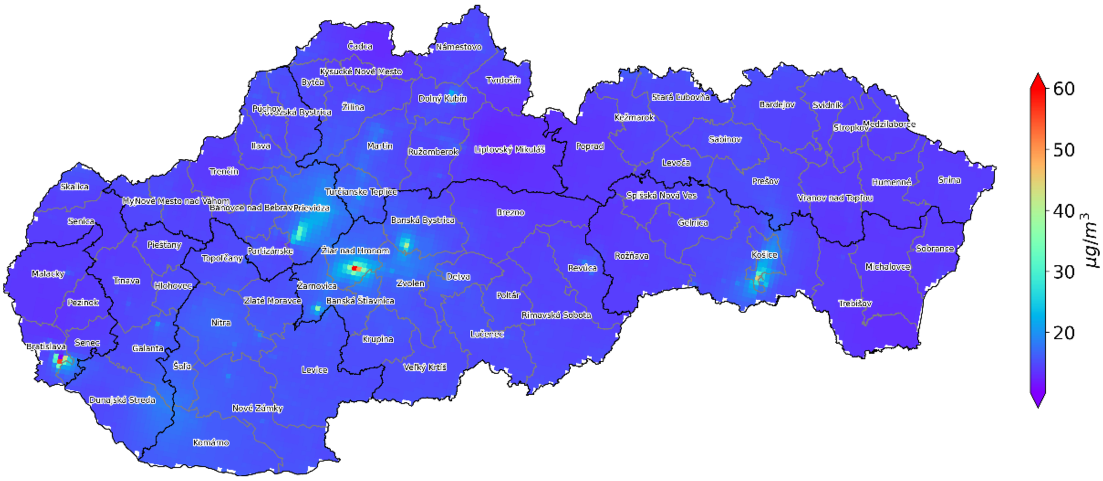
Hourly mean SO_2 concentrations should not exceed 350 $\mu g \cdot m^{-3}$ more than 24 times in a calendar year. Therefore, the 99.7 percentile of the hourly values is calculated (this percentile corresponds roughly to the 25th highest hourly concentration). Interestingly, in the case of the 99.7 hourly percentile, our measurement results correlate reasonably well with the CMAQ model ($r = 0.75$). It can be assumed that the measurements capture the peak concentrations reasonably well. The concentrations calculated by the CMAQ model were then processed by the IDW-R method to obtain the best agreement with the measurements (RMSE = 5.1 $\mu g \cdot m^{-3}$ and BIAS = –0.01 $\mu g \cdot m^{-3}$). The resulting 99.7 hourly percentile of SO_2 concentrations is at **Fig. 4.9**, from which it can be seen that the 25th highest hourly concentration was well below the limit value of 350 $\mu g \cdot m^{-3}$.

Fig. 4.9 *99.7 percentile [$\mu g \cdot m^{-3}$] from hourly mean values of SO_2 concentrations in year 2022.*



The daily mean SO2 concentration should not exceed 125 µg·m^{-3} more than 3 times in a calendar year. This is represented by the 99.2 percentile of the average daily values, which corresponds to roughly the 4th highest daily concentration. As in the previous case, the CMAQ model results were further processed by the IDW-R method (RMSE = 5.3 µg·m^{-3} and BIAS = 0.04 µg·m^{-3}). The resulting 99.2 percentile of the average daily SO_2 concentrations is shown in **Fig. 4.10**, from which it can be seen that the 4th highest average daily concentration was well below the limit value of 125 µg·m^{-3}.

Fig. 4.10 *99.2 percentile [µg·m^{-3}] from daily mean values of SO_2 concentrations in year 2022.*



CO

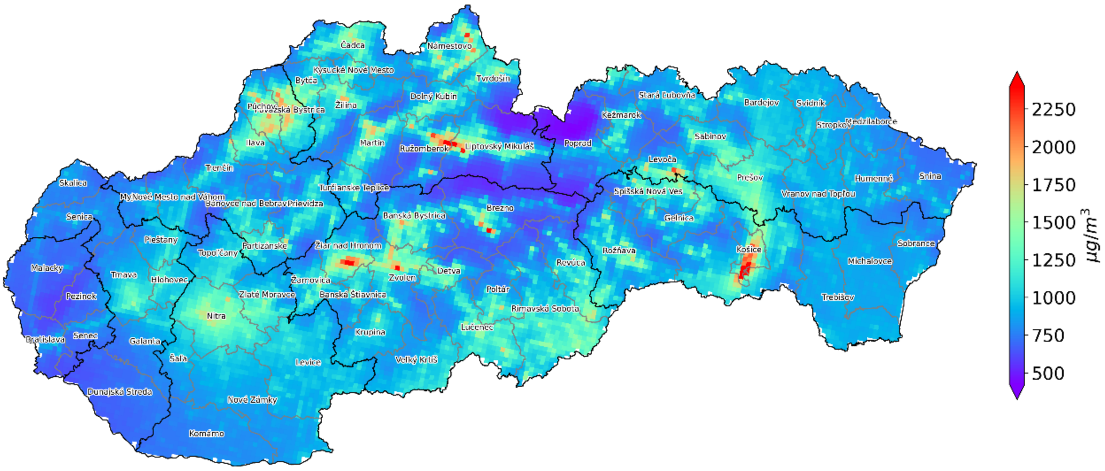
The spatial distribution of CO concentrations in Slovakia was calculated by the CMAQ model, using meteorological data from the ALADIN model.

The most important sources of CO emissions are local heating (almost 55% of total emissions), followed by industrial point sources. All significant chimneys (vents) registered in NEIS database were included in the calculation. Also, emissions from road transport (approximately 20% from total emission inputs) and agriculture (approximately 5% from total emission inputs) were included in the simulation.

Outside the territory of SR emissions from TNO-MAC III database were used. Maximum daily 8-hour moving average CO concentrations in year 2022 on **Fig. 4.11** were gained from CMAQ model and consequently processed by the use of IDW-R method. Limit value of 10 000 µg·m^{-3} was not exceeded. When comparing model with measurements, RMSE is 23.3 µg·m^{-3} and BIAS is –1.4 µg·m^{-3}. From the figure we can see that the highest concentrations of CO are close to important point sources, in areas of important roads and near local heating plants. Since CO is measured mainly at traffic and industrial monitoring stations, it is difficult to determine the actual background concentration, also because CO is chemically stable and remains in the atmosphere for a relatively long time. The lowest measured maximum 8-hour moving CO concentration reached the value of approximately 1000 µg·m^{-3}, therefore the lower interval depicted is from 0 to 1000 µg·m^{-3}.

This pollutant does not introduce the problem from point of exceedance the limit value for human health protection.

Fig. 4.11 Maximum daily 8-hour moving concentrations of CO [μg·m^{-3}] in year 2022.

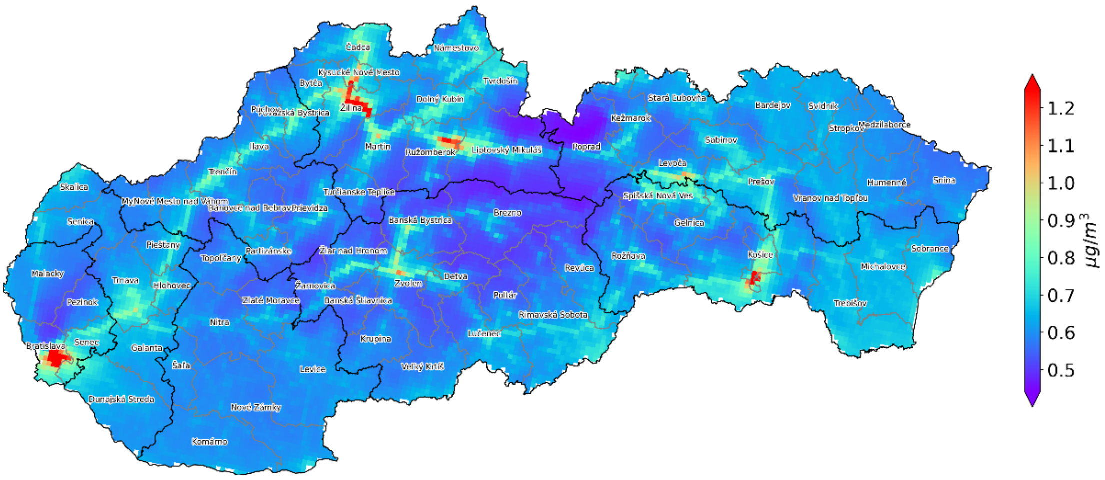


Benzene

Spatial distribution of benzene concentrations in Slovakia was calculated by CMAQ model, whereby the meteorological data from ALADIN model were used.

The highest share on emission inputs for benzene modelling comes from road transport (approximately 66%), local heating (more than 19%) and industrial sources (more than 16%) while the most significant sources are SLOVNAFT, a.s. Bratislava a U. S. Steel Košice, s.r.o. Outside the territory of SR the emissions from TNO-MAC III[19] database were used. Annual mean concentrations of benzene in year 2022 on **Fig. 4.12** were obtained from CMAQ model and then processed by IDW-R method. Comparison of model results with measurements gives RMSE = 0.1 μg·m^{-3} and BIAS = – 0.05 μg·m^{-3}. It can be seen from **Fig. 4.12**, that the highest concentrations of benzene are in vicinity of significant roads, mainly in areas with adverse dispersion conditions and in domains affected by two industrial sources mentioned above. However, in total the benzene concentrations are below the limit value 5 μg·m^{-3} also in vicinity of the most significant sources.

Fig. 4.12 Annual mean concentrations of benzene [μg·m^{-3}] in year 2022.



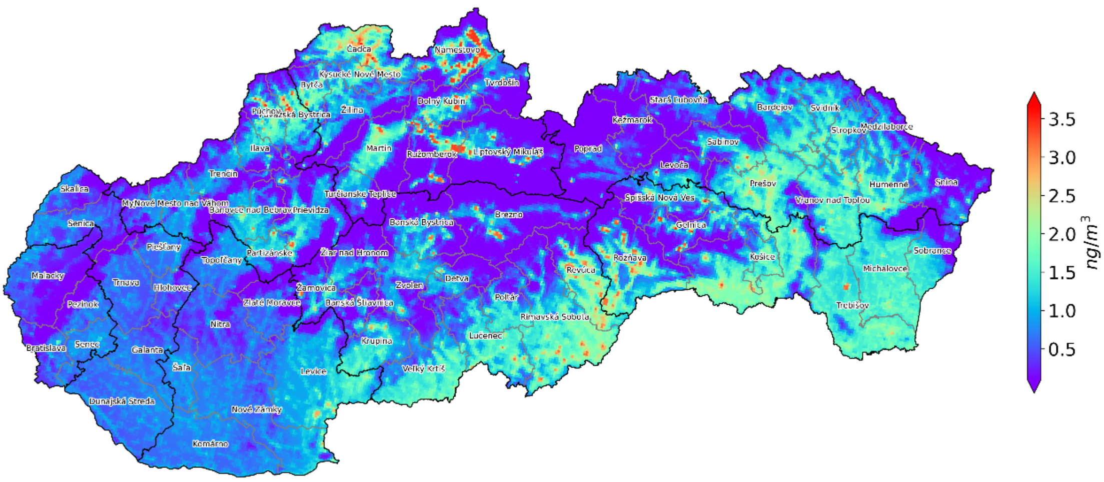
[19] *Kuenen, J.J.P., Visschedijk, A.J.H., Jozwicka, M., Denier van der Gon, H.A.C., 2014. TNOMACC_ II emission inventory; a multi-year (2003-2009) consistent high-resolution European emission inventory for air quality modelling. Atmos. Chem. Phys. 14, 10963–10976. https://doi.org/10.5194/acp-14-10963-2014*

Benzo(a)pyrene

The most significant source of benzo(a)pyrene emissions is, similarly to the case of $PM_{2.5}$, heating of households with solid fuels. The share of domestic heating in total benzo(a)pyrene emissions is close to 70%, while in 2017 (when there was a January with subnormal temperature[20]), for example, the share was more than 80%[21]. Of the industrial sources, the most pronounced is coke production, the effect of which can be seen in the high concentrations from measurements at the industrial monitoring station Veľká Ida, Letná. In 2022, the highest annual mean concentration of benzo(a)pyrene among monitoring stations in Slovakia was recorded here again, namely 5.4 ng·m^{-3}. Note that this station is in a village, where local heating and marginalised Roma community neighbourhood also plays a role. Household heating is almost exclusively manifested in higher concentrations of benzo(a)pyrene in mountain valleys with good availability of firewood and frequent occurrence of adverse dispersion conditions and temperature inversions, especially during the winter months. An example of a monitoring station located in such an area is Jelšava, Jesenského. The annual mean concentration of benzo(a)pyrene in 2022 at this station was 2.7 ng·m^{-3}, with a target value of 1 ng·m^{-3}. The same high value was also achieved at the station Žarnovica, Dolná.

The RIO and IDW-R interpolation models were used to assess the benzo(a)pyrene spatial distribution, as the use of a chemical-transport model for benzo(a)pyrene is associated with large uncertainties in the spatial and temporal distribution of emissions, and the situation is complicated by complex chemical reactions that are still under investigation[22]. However, due to the relatively small number of stations at which monitoring programme includes this pollutant, it is also quite difficult to perform a good regression and interpolation with the RIO model. Since the correlation between measured concentrations of benzo(a)pyrene and the annual mean $PM_{2.5}$ concentrations calculated at the monitoring station sites by the combination of RIO and IDW-R is quite high (correlation coefficient $r = 0.9$), we used the calculated values of annual mean $PM_{2.5}$ concentrations as input to the IDW-R model. The spatial distribution of annual mean benzo(a)pyrene values in Slovakia calculated in this way is shown in **Fig. 4.13**. Comparing with the measurements we get RMSE = 0.2 ng·m^{-3} and BIAS = 0.01 ng·m^{-3}. The target value for the annual mean concentration of benzo(a)pyrene of 1 ng·m^{-3} was exceeded at many measurement sites. This is also reflected in the modelling results, with the highest concentrations in the east of the country. The model may overestimate benzo(a)pyrene concentrations particularly around Košice and the East Slovakian Lowland, as it is strongly influenced by the high annual average concentration measured at Veľká Ida, which together with Krompachy is one of only two stations in the Košice Region where benzo(a)pyrene is monitored.

Fig. 4.13 *Annual mean concentrations of benzo(a)pyrene [ng·m^{-3}] in year 2022.*



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[20] http://www.shmu.sk/sk/?page=1613&id=

[21] https://www.ceip.at/status-of-reporting-and-review-results/2019-submissions, - the data submitted in year 2019 are related to the year 2017 http://www.shmu.sk/File/oko/rocenky/SHMU_Sprava_o_kvalite_ovzdusia_SR_2018_v3.pdf

[22] Fernández, Israel. (2020). Understanding the reactivity of polycyclic aromatic hydrocarbons and related compounds. Chemical Science. 11. 10.1039/D0SC00222D.

4.3 CONCLUSION

Mathematical models, no matter how sophisticated, are only approximation of reality, and their results are associated with a relatively high degree of uncertainty that is highly dependent on the quality of the input data. The most important input data are meteorological fields and the spatial distribution of emissions. At present, meteorological data can be considered much more reliable than emission data in terms of annual assessment, so it can be said that emission data are the primary source of uncertainty in the outputs of mathematic air quality models. Another factor to consider when assessing the spatial distribution of concentrations using regional-scale models is their spatial resolution. The models used in our analysis have a horizontal spatial resolution of 1 or 2 km. Therefore, the calculated concentration represents the average concentration over a 1 x 1 km area (or 2 x 2 km). However, the spatial variability of concentrations over such an area, especially in urban or human-influenced areas, is usually quite large. Thus, a model with a resolution of 1 x 1 km necessarily smoothest local maxima (and of course overestimates local minima). This is particularly relevant to areas where there is a high concentration of local heating plants or busy roads inside built-up areas, as these sources are located at a low height above the ground and usually cause the most significant concentrations of PM and benzo(a)pyrene. To obtain a more accurate distribution of concentrations in individual cities and to determine local maxima, it is therefore necessary to use high-resolution local models. However, the accuracy of these models is also strongly dependent on the accuracy of the input emission data and their optimal use requires refinement of local emission inventories (local heating sites, road transport). The outputs of high-resolution local models are mainly used in Air Quality Plans for individual zones and agglomerations, including Air Quality Management Areas.

As in recent years, high concentrations of PM_{10}, $PM_{2.5}$ and benzo(a)pyrene are the most significant air pollution problem in 2022, especially during the colder part of the year (October – March), with household heating with solid fuels playing a significant role. The situation is most complicated in mountain valleys, in areas with good availability of firewood and frequent occurrence of adverse dispersion conditions, especially during the heating season. The financial conditions of the local population often do not allow the use of natural gas for heating or the purchase of modern low-emission heating equipment. This also has an impact on air quality in the above areas.

5 AIR QUALITY ASSESSMENT – CONCLUSION

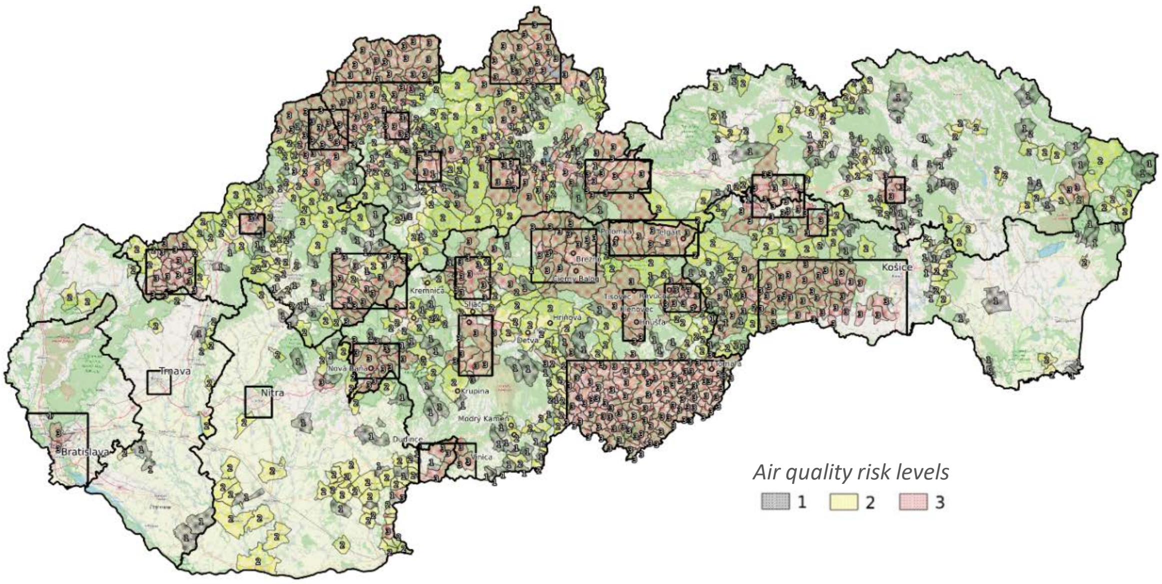
5.1 PROPOSAL FOR THE DEFINITION OF AIR QUALITY MANAGEMENT AREAS IN 2023

Based on the assessment of air quality in zones and agglomerations in 2020 – 2022, the SHMÚ's task is to, according to § 8 par. 3 of Act No. 137/2010 Coll. on Air, as amended, to propose an update of the definition of the air quality management areas of the Slovak Republic for 2023.

Monitoring results play a crucial role in assessing air quality. Since 2021, the results of mathematical modelling are also taken into account in the design of Air Quality Management Areas (ORKO), as the orography reduces the areas represented by individual monitoring station and therefore it is not possible to cover the whole country with measurements. Methodology for identifying municipalities at risk of poor air quality from household heating, based on the article *Determination of air quality risk areas for PM_{10} particles from local heating in Slovakia*, was proposed in 2021 and updated in 2022[23].

In 2023, the current integrated municipal assessment method with regard to the risk of adverse air quality[24] was proposed, which incorporates the rate of household heating with solid fuels, the impact of impaired dispersion conditions in the short and long term, the results of the CMAQ chemical-transport model, the RIO interpolation model, and the results of high-resolution CALPUFF modelling of selected domains with the assumption of impaired air quality (**Fig. 5.1**).

Fig. 5.1 *Risk municipalities identified by the integrated assessment method for 2023. Selected domains for high-resolution modelling are labelled in black.*



Risk levels from 0 to 3 are assigned to municipalities based on the described methodology with risk level 3 indicating the greatest risk of deteriorating air quality. Municipalities in which the limit value for a pollutant has been exceeded either according to high-resolution modelling or according to measurement are automatically assigned risk level 3.

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[23] *D. Štefánik: Určenie rizikových obcí s kvalitou ovzdušia ohrozenou lokálnym vykurovaním a zhoršenými rozptylovými podmienkami. SHMÚ, Bratislava, October 2022 https://www.shmu.sk/File/oko/studie_analyzy/Popis%20met%C3%B3dy%20na%20ur%C4%8Denie%20rizikov%C3%BDch%20oblast%C3%AD.pdf*

[24] *D. Štefánik, J. Krajčovičová: Metóda integrovaného posúdenia obcí vzhľadom na riziko nepriaznivej kvality ovzdušia. SHMÚ, 2023. https://www.shmu.sk/File/oko/studie_analyzy/Metodika_final_v2a.pdf*

Zones and agglomerations containing at least one municipality with risk level 3 are required to prepare Air Quality Improvement Plan. Based on this, municipalities at risk level 3 correspond to Air Quality Management Areas (ORKO). However, measures to reduce emissions must be implemented in all municipalities with risk level 2 or 3 included in the zone, ideally also in municipalities with a risk level 1.

Fig. 5.1 and the *web page* show the municipalities with assigned risk levels and the location of the domains where air quality was modelled with high resolution.

The list of at-risk municipalities will be updated when the input data are better specified, either in full or for individual regions or municipalities. Updates will be made at most once a year, but at least once every 5 years. Similarly, the methodology itself may be updated if necessary.

5.2 SUMMARY

In the 2022 air quality assessment, we also include the results of monitoring at 14 new monitoring sites that have been set up as part of the National Monitoring Network Improvement project. These sites are Lučenec, Žarnovica, Pezinok, Senec, Trebišov, Komárno, Plášťovce, Poprad, Bardejov, Púchov, Sereď, Oščadnica, Liptovský Mikuláš and Bratislava (Púchovská Street).

Monitoring at these stations began during 2021, improving the coverage of the area with monitoring data. However, due to the orography, information on air quality needs to be supplemented by modelling. Using the Integrated Assessment Method, municipalities were assigned risk levels, which characterise the degree of exposure to poor air quality. The list of municipalities is published on the *SHMÚ website*.

In 2022, as in previous years, the problem of high levels of PM_{10}, $PM_{2.5}$ and especially benzo(a)pyrene persisted in Slovakia. The limit value for the average daily concentration of PM_{10} and the average annual concentration of $PM_{2.5}$ were exceeded at the monitoring stations Jelšava, Jesenského; Veľká Ida, Letná and at the new station Plášťovce.

The highest PM values were measured during January at several stations in central and eastern Slovakia, which was probably due to the lower temperature in this area and higher heating requirements.

The target value for benzo(a)pyrene was exceeded at AMS Veľká Ida, Letná; Jelšava, Jesenského; Žarnovica, Dolná; Oščadnica; Plášťovce; Krompachy, SNP; Ružomberok, Riadok; Púchov, 1. mája; Žilina, Obežná and Banská Bystrica, Štefánikovo nábrežie.

Exceedances of the target value for ground-level ozone were measured at the stations Bratislava, Jeséniova and Chopok, EMEP, with the highest values occurring in August.

The most significant problem in terms of air pollution in the Slovak Republic remains the heating of households with solid fuels, especially when using older heating appliances. The situation is worse in localities with unfavourable dispersion conditions in mountain valleys, with the use of heating appliances with higher emissions reflecting the social composition of the population. The economic crisis is probably complicating the situation, as people are returning to heating with firewood.

LIST OF ANNEXES