2023

AIR POLLUTION IN THE SLOVAK REPUBLIC

Emissions and Air Quality Division
SLOVAK HYDROMETEOROLOGICAL INSTITUTE

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

The text has not undergone linguistic proofereading.

CONTENT

FOREWORD

Each person inhales about 14 kg of air per day, while drinking only 2 kg of water and consuming 1.5 kg of food. From this fact alone, it is clear that air quality is one of the factors that significantly affects human health. In addition, it also has a significant impact on the state of ecosystems. Air quality is assessed by concentrations of selected pollutants in the air. Research shows that adverse health effects are caused not only by short-term heavy exposure to pollutants in the environment, but also by long-term human exposure to poor air quality.

Like many other processes in the atmosphere, air quality is highly variable over time and space. It is almost impossible to monitor the local and short-term deterioration in air quality to which people are often exposed. Individuals themselves must avoid local and random phenomena that have a negative impact on air quality and therefore on their health. Avoiding smoking and smoky rooms, using respirators for demolition work, limiting roasting on open fires and using dry, good-quality fuel, and not staying in close proximity to car exhausts are just a few examples that should be observed.

Air quality can also be deteriorated more widely – for example, on streets, in communities and regions by sources that are relatively constant (industrial sources), recurring (traffic) or temperature-dependent (local heating sites). Unlike random, local and short-term events, air quality in these cases can be assessed by monitoring from a network of stations that measure concentrations of air pollutants. The Slovak Hydrometeorological Institute (SHMÚ) operates a National Air Quality Monitoring Network consisting of 52 stationary stations, which measure concentrations of basic pollutants such as ozone, PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, benzene, heavy metals and benzo(a)pyrene using very precise methods. Such monitoring is much needed to know the current state of air quality, to obtain trends and to develop policies and measures to improve air quality. In areas not covered by SHMÚ monitoring stations, air quality is assessed by numerical modelling on a high-performance supercomputer.

The presented annual Report on Air Quality in Slovakia contains in a clear and coherent structure the results of monitoring and modelling of air quality and a proposal for the definition of air quality management areas in 2024. As in recent years, high concentrations of PM_{10}, $PM_{2.5}$ and benzo(a)pyrene caused by local heating in the winter period remain the most serious problem in Slovakia. In summer, some locations experience higher ozone concentrations and exceedances of the target values.

The Report on Air Quality in the Slovak Republic is one of the results of the systematic and professional work of all the staff of the Air Quality Division of the SHMÚ – the only expert workplace in Slovakia, where experts in monitoring, modelling and chemical analysis of pollutants in the air work together.

The Ministry of the Environment of the Slovak Republic, by Act No. 146/2023 Coll. on air protection, as amended, in order to provide information to the public on air quality, authorised 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 the authorised organisation, fulfils the obligations arising from §14 paragraph (1) letter e) of the above-mentioned Act and submits to the lay and professional public a report containing all the details as required by Act No. 146/2023 Coll. on air protection, as amended.

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.

Processes that affect air pollutants include transport in both horizontal and vertical directions (advection, convection), chemical reactions (e.g., oxidation of NO from road traffic to NO_2, ozone formation), changes in composition (e.g., condensation when hot flue gases escaping from smokestacks are cooled), and dry, wet, and hidden deposition. Dry deposition is the trapping of pollutants on the ground surface or on vegetation. 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 and in mountain 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. The frequent occurrence of inversions in these areas is a factor that complicates pollutant dispersion in the atmosphere and is one of the reasons for the occurrence of high concentrations of these pollutants in the air in winter. 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 the Slovak Republic 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 the Záhorie region, southeast wind prevails over the northwest, in Danube lowlands it is opposite case. Northern air convection dominates in middle Považie, Ponitrie regions 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 area) 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 characterised 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, Galanta and Senec area) 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 High and Low Tatras and from the south by the Slovak Ore Mountains.

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 longlasting 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 2023

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. Decree MoE SR No. 250/2023 Coll. on air quality), 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 Decree of MoE SR No. 250/2023 Coll. on air quality, 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 2023, for SO_2, NO_2, NO_X, PM_{10}, $PM_{2.5}$, benzene, polycyclic aromatic hydrocarbons and CO

In order to take a more targeted approach to tackling air quality problems, Slovakia is divided into zones and agglomerations. The zones are made up of NUTS-3 regions, with the exception of the Bratislava and Košice NUTS-3 regions, which in both cases consist of a zone and an agglomeration.

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 [km²]	Population*
Bratislava region	(Bratislavský kraj)	2 053	732 757
Trnava region	(Trnavský kraj)	4 146	566 114
Trenčín region	(Trenčiansky kraj)	4 502	568 102
Nitra region	(Nitriansky kraj)	6 344	668 301
Žilina region	(Žilinský kraj)	6 809	687 174
Banská Bystrica region	(Banskobystrický kraj)	9 454	614 356
Prešov region	(Prešovský kraj)	8 973	808 810
Košice region	(Košický kraj)	6 754	779 073

**As of 31. 12. 2023*
Source: Statistical Office of the SR

1.1.2 Country breakdown into zones and agglomerations in 2023 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 household 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[1]. Road traffic 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 measures to improve the situation.

The tropospheric ozone problem is regional in nature, with a significant share of transport from the stratosphere and a significant share of transboundary transport. Road traffic in major cities is a source of ozone precursors, but nitrogen oxides also cause ozone titration (the chemical reaction of ozone with nitrogen oxides in which ozone decomposes) near the most congested roads. The ozone target value for the protection of human health tends to be exceeded in several places in the Slovak Republic, especially in the more photochemically active years. The possibilities for improving the situation by local measures are limited.

[1] *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

The beginning of the measurement of air pollutants in Slovakia dates back to the second half of the 1950s. Systematic monitoring began to be carried out in 1967, when the first law on air protection came into force (Act No. 35/1967 Coll. on measures against air pollution). The measurements, which initially included only SO_2 and dust fallout in Bratislava, Košice and the surrounding area, were gradually supplemented by other pollutants and locations. Legislation has changed over time – expanding the substances monitored and tightening the limit values. An example of a modification is the reduction of the limit value for the annual average concentration of $PM_{2.5}$, which has been changed to 20 $\mu g \cdot m^{-3}$ (from the original 25 $\mu g \cdot m^{-3}$) from 2020. The current form of legislation in the Slovak Republic is an implementation of EU legislation. In April 2024, a new Directive of the European Parliament and of the Council on Air Quality and Cleaner Air in Europe (COM/2022/542[2]) was approved with ambitious targets for 2030 and the fulfilment of the EU's vision of zero air pollution by 2050. The aim of monitoring is to best characterise air quality with a view to protecting public health. The structure of the monitoring network has been designed so that individual stations represent pollution levels in the most polluted areas – in the past, these were mainly locations close to large industrial sources of air pollution. These stations are still part of the monitoring network today, as are sites burdened by emissions from road transport. The monitoring plan is further extended to locations where the dominant source of air pollution is domestic heating, as these sources are currently among the most problematic and most influential on air quality in Slovakia.

Locations sufficiently distant from sources of anthropogenic air pollution are also covered by monitoring. Monitoring stations located in these areas are called regional (rural) background stations and represent outdoor air pollution. Since pollutants can remain in the air for several days depending on their properties (e.g. sedimentation rate, chemical reactivity), they can be transported over long distances (referred to as long-range transport) by air mass flow, and high concentrations of pollutants can occur even in apparently clean mountain areas. In recent years, episodes of long-range transport of dust from arid areas have been recorded. 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.

The network of measuring stations – named the National Monitoring Network for Air Quality (NMSKO) – began to be built in the Czecho-Slovak Republic in 1991[3]. Currently, it includes continuous measurements using automatic instruments and manual measurements based on sampling and chemical analyses at the SHMÚ Testing Laboratory and other external laboratories. Manual monitoring covers the measurement of concentrations of heavy metals, volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) in the air, as well as air quality monitoring and precipitation quality analysis at regional background stations with the EMEP (Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe) monitoring programme. The distribution of the NMSKO network monitoring stations and their measurement programme in 2023 is shown in **Fig. 2.1**.

A detailed list of the monitoring instruments at each station and the methods used by the instruments can be found in "Annex A - Measurement stations of monitoring air quality networks – 2023".

In 1979, the UNECE Convention on Long-range Transboundary Air Pollution (hereinafter the Convention) was signed in Geneva. Eight protocols have been signed under the Convention so far. The first of these is the Protocol on the Long-term Financing of the Cooperative Programme for Monitoring and Evaluation of Long-range Transmission of Air Pollutants in Europe (EMEP) (Geneva, 1984).

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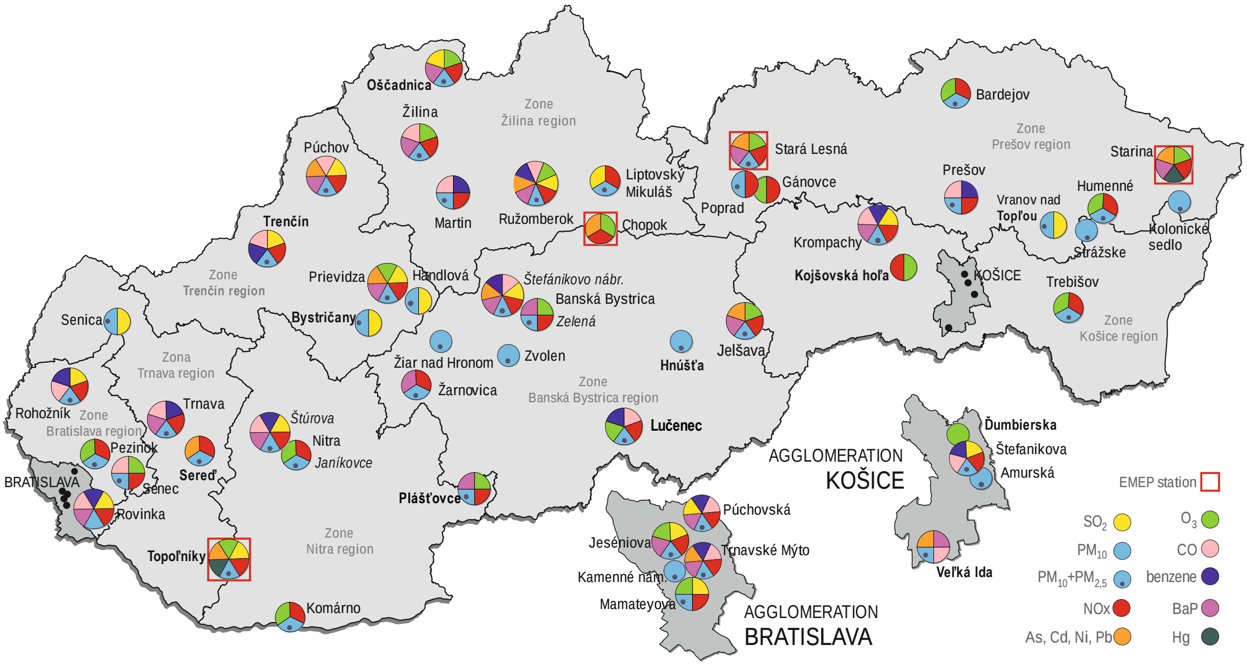
[2] *https://www.europarl.europa.eu/news/sk/press-room/20240419IPR20587/znecistenie-ovzdusia-parlament-prijal-zakon-pre-vyssiu-kvalitu-ovzdusia*

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

The aim of EMEP is to monitor, model and assess the long-range transport of pollutants in Europe and to develop the basis for a strategy to reduce emissions at international level. The EMEP monitoring network currently has about 180 regional stations, including four Slovak EMEP stations, which are part of NMSKO. The first EMEP station on the territory of Slovakia was established at Chopok near the meteorological observatory of the SHMÚ at an altitude of 2008 m. Air quality measurements started to be carried out here as early as 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 air, particulate matter, ozone, and in 1994 measurements of volatile organic compounds began to be carried out in cooperation with the EMEP International Chemical Coordination Centre – the Norwegian Institute for Air Research in Kjeller. Later, measurements of heavy metals 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 2023.*



The monitoring programme of the air quality stations in the NMSKO network is presented in **Tab. 2.1**. The table contains information on the air quality monitoring stations belonging to the NMSKO by agglomeration and zone:

- station characteristics according to the dominant sources of air pollution (traffic, background, industrial), the type of area monitored (urban, suburban, rural/regional) and the geographical coordinates;
- monitoring programme. Automatic continuous monitoring instruments provide hourly average concentrations of PM_{10}, $PM_{2.5}$, nitrogen oxides, sulphur dioxide, ozone, carbon monoxide, benzene and mercury. The SHMÚ test laboratory analyses heavy metals and polycyclic aromatic hydrocarbons as part of manual monitoring, resulting in 24-hour average values. Exceptions are the EMEP stations whose monitoring programme is described in **Tab. 2.2** and **Tab. 2.3**.

Tab. 2.1 National air quality monitoring network (NMSKO).

AGGLOMERATION Zone	Station	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
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[4]	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	Pezinok, Obrancov mieru	U	B	x	x	x		x					
	Rovinka	S	B	x		x	x		x	x			x
	Rohožník, Senická	S	T	x	x	x	x		x	x			
	Senec, Boldocká	U	T	x	x	x		x	x				
	4 stations in total			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	S	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 Žarnovica replaced AMS Žarnovica, Dolná*

AGGLOMERATION Zone	Station	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
Trenčín region	Prievidza, Malonecpalská	U	B	x	x	x	x	x				x	x
	Bystričany, Rozvodňa SSE	S	B	x	x		x						
	Handlová, Morovianska cesta	U	B	x	x		x						
	Trenčín, Hasičská	U	T	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	2
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	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	20

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

The air quality monitoring programme at EMEP stations in 2023 is shown in **Tab. 2.2**. Ozone is measured continuously. The sampling interval for heavy metals is every third day at Topoľníky and Stará Lesná, and weekly at Starina and Chopok. VOCs are sampled at weekly intervals. Other substances are sampled at 24-hour intervals.

Tab. 2.2 *EMEP station monitoring programme – 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,	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 ions and alkali metal cations) is analysed from samples taken at EMEP stations according to the monitoring programme listed in **Tab. 2.3** either on a daily basis (Chopok, Starina) or on a weekly basis (Topoľníky, Stará Lesná), the quality of precipitation is monitored at the Bratislava, Jeséniova station at an interval of 14 days. The analyses result in average weekly or monthly concentrations depending on the sampling interval.

Rainfall sampling intervals for heavy metal analysis are monthly, except at the Starina EMEP station where weekly samples are collected. Two types of rain gauges are used for precipitation collection: "wet-only" and "bulk". "Wet-only" is a rain gauge that captures only precipitation – wet deposition is assessed on the basis of the samples collected in this way. "Bulk" (i.e. 'whole') takes both dry and wet deposition. This type of sampling is carried out at Chopok, where, due to inclement weather, open-container sampling of precipitation is done.

Tab. 2.3 *Precipitation measurement programme at EMEP stations and at the Bratislava, Jeséniova station.*

	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. The minimum required monitoring coverage[6] was met. Monitoring of sulphur dioxide was provided continuously, by the reference method, at all 20 stations. The required number of valid measurements (90%) was achieved at 18 monitoring stations.

- **Oxides of nitrogen NO_2 a NO_X**

This pollutant was monitored at 40 stations. The minimum required monitoring coverage[6] was met. Nitrogen oxides were monitored continuously by the reference method at all 40 stations. The required number of valid measurements (90%) was achieved at 36 monitoring stations. The monitoring station Žarnovica, Dolná ceased measurement on 11 October 2023 and was replaced by AMS Žarnovica on 5 December 2023. The required number of valid measurements was not met at AMS Rovinka, AMS Plášťovce and AMS Kojšovská hoľa.

- **Particulate matter PM_{10}**

This pollutant was monitored at 48 stations. The minimum required monitoring coverage[6] was met. Monitoring of PM_{10} was provided by the equivalent, continuous method of oscillation microbalance (TEOM instruments) and the beta absorption method (BAM instruments). The required number of valid measurements (90%) was achieved at 47 monitoring stations. The monitoring station Žarnovica, Dolna ceased measurements on 11 October 2023 and was replaced by AMS Žarnovica on 5 December 2023[6].

[6] *number and location according to Annex No. 8 to Decree of the MoE of the Slovak Republic No. 250/2023 Coll. on air quality*

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

  This pollutant was monitored at 47 stations. The minimum required monitoring coverage[6] was met. $PM_{2.5}$ monitoring was provided by the same method as PM_{10} measurements, by TEOM and BAM instruments. The required number of valid measurements (90%) was achieved at 46 monitoring stations. The monitoring station Žarnovica, Dolná ceased measurement on 11 October 2023 and was replaced by AMS Žarnovica on 5 December 2023.

- **Carbon monoxide CO**

  This pollutant was monitored at 18 monitoring stations. The minimum required monitoring coverage[6] has been met. Carbon monoxide was monitored continuously, by the referee method, at 18 stations. The required number of valid measurements (90%) was achieved at 16 monitoring stations. The required number of valid measurements was not met at AMS Trnava and AMS Rovinka. CO concentrations are below the lower limit for the assessment thus the number of monitoring sites is sufficient.

- **Ozone O_3**

  Ozone was monitored at 24 monitoring stations. The minimum required monitoring coverage[6] was met. Ozone was monitored continuously, using the reference method, at all 24 stations. The required recovery of valid measured data (90%) was achieved at 19 monitoring stations.

- **Benzene C_6H_6**

  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. The required recovery of valid measured data (90%) was achieved by all monitoring stations.

- **Mercury Hg**

  Total gaseous mercury was monitored at two EMEP stations (Topoľníky and Starina). Monitoring of mercury was provided continuously by the method of differential Zeeman atomic absorption spectrometry, the proportion of valid measured data exceeded 90% at the monitoring station at Starina. The proportion of valid data at the EMEP station Topoľníky is 52% due to technical reasons. Despite the outage, the measurement is representative for a year-long assessment, as concentrations fluctuate only slightly during the year.

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

  Heavy metals were monitored at 12 monitoring stations. Samples for heavy metals analysis are collected at the urban stations every other day for 24 hours on a nitrocellulose filter, then analysed at the SHMÚ Testing Laboratory by gas chromatography. In 2023, samples for analysis of heavy metals (Pb, As, Cd, Ni) were collected at one suburban, seven urban and four EMEP monitoring stations.

- **Polyaromatic hydrocarbons – BaP**

  In 2023, monitoring of benzo(a)pyrene was ensured at 20 monitoring stations. Sampling was carried out 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] has been met.

- **VOC**

  Volatile organic compounds, C_2–C_8 or so-called light hydrocarbons, started to be sampled at the Starina station in the autumn of 1994. Starina is one of the few European stations included in the EMEP network with regular monitoring of volatile organic compounds.

- **EC/OC**

  In autumn 2021, monitoring of the organic and elemental carbon fraction of $PM_{2.5}$ began at Stará Lesná in accordance with the EMEP monitoring strategy.

- **Air quality monitoring at EMEP stations**

  At all four EMEP stations air quality measurements (**Tab. 2.2**) were carried out 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 stations (**Tab. 2.3**) in accordance with the EMEP monitoring strategy according to the approved monitoring programme.

In addition to the air quality monitoring stations in the NMSKO network, monitoring stations operated by operators of large air pollution sources (VZZO) are also established in the territory of the Slovak Republic for the purpose of monitoring air pollution levels. The decision on the establishment of VZZO stations is issued by the District Office in the seat of the region. The VZZO monitoring stations data that have passed the functional tests (**Tab. 2.4**) serve as supplementary data to the measurements in the NMSKO network for the assessment of air quality, provided that they have been obtained by a reference or equivalent method. Concentrations of those pollutants that are monitored at VZZO by a different method (Annex A) are nevertheless important information in 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	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 related to environmental pollution have accompanied the technological progress of mankind since ancient times. Both environmental burdens and environmental disasters associated with threats to human life and health have stimulated the collective action of people in the search for solutions in this area. Since pollutants can spread over long distances through the air, coordinated action by as many countries as possible in monitoring and assessing air quality has proved to be an essential basis for taking measures and has been reflected in international conventions and European legislation, subsequently implemented in Slovak legislation.

Air quality assessment according to the requirements of §4 of Act No. 146/2023 Coll. on air protection, as amended, (hereinafter referred to as the Air Protection Act) is carried out by the SHMÚ using methods of measurement, calculation, prediction or estimation.

Chapter **3** presents the processed results of air quality monitoring. The assessment of air quality 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** treats the results of measurements of monitoring stations with the EMEP monitoring programme according to limit values for the protection of vegetation. The EMEP programme also includes an analysis of atmospheric precipitation quality.

3.2 AIR QUALITY ASSESMENT CRITERIA

Air quality (according to Section 4 (§3) of the Air Protection Act) is considered good if the level of air pollution is below the limit value, the target value and the exposure reduction commitment.

The limit value (in accordance with Section 5 (§3) of the Air Protection Act) is a 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 may not be exceeded from that time onwards; limit values and the conditions for their legal force are laid down for sulphur dioxide, nitrogen dioxide, carbon monoxide, lead, benzene, PM_{10} and $PM_{2.5}$ (by implementing regulation pursuant to §62(a) of the Air Protection Act).

The target value is (in accordance with Section 8 (§3) of the Air Protection Act) the level of air pollution which is intended to prevent, avoid or reduce harmful effects on human health or the environment as a whole; the target value is set for concentrations of ozone, arsenic, cadmium, nickel and benzo(a)pyrene and is to be attained at a given time, where practicable (by means of an implementing regulation pursuant to §62(a) of the Air Protection Act).

The alert threshold (according to Section 15 (§3) of the Air Protection Act) is the level of air pollution above which there is already a risk of harm to human health from short-term exposure; if the alert threshold is exceeded, a severe smog warning must be issued immediately. Alert thresholds are established for sulphur dioxide, nitrogen dioxide, ozone and PM_{10} (by implementing regulation pursuant to §62(d) of the above-mentioned Act).

The critical level for the purpose of air quality assessment is (according to Section 7 (§3) of the Air Protection Act) the level of air pollution determined on the basis of scientific knowledge, above which direct adverse effects on vegetation, such as trees and plants, or natural ecosystems, but not on humans, may occur; the critical level is determined for sulphur dioxide and nitrogen oxides (by the implementing regulation according to §62(a) of the above-mentioned Act).

The air quality assessment regime is determined on the basis of air pollution levels. Agglomerations and zones shall be assigned to the air quality assessment regime according to criteria expressed as air pollution level assessment thresholds specifically established by implementing regulation pursuant to §62(b) for the protection of health, the protection of vegetation and natural ecosystem.

The upper assessment threshold, for determining the air quality assessment regime (according to Section 6 (§4, a) of the Air Protection Act), is the established level of air pollution below which a combination of continuous measurements and modelling techniques or even indicative measurements can be used to assess air quality.

The lower assessment threshold, for determining the air quality assessment regime (according to Section 6 (§4, b) of the Air Protection Act), is the level of air pollution below which modelling or objective estimation techniques may 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 limits for the assessment 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 the protection of vegetation for As, Cd, Ni and benzo(a)pyrene (BaP). The values given in Tab. 3.1 and Tab. 3.2 are based on Slovak legislation (Annex 1 to Decree No. 250/2023 Coll.[7]).

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	1 h	350	(24)				
SO_2	Human health	24 h	125	(3)	75	(3)	50	(3)
SO_2	Vegetation	1y, winter season	20	(-)	12	(-)	8	(-)
NO_2	Human health	1 h	200	(18)	140	(18)	100	(18)
NO_2	Human health	1 y	40	(-)	32	(-)	26	(-)
NO_X	Vegetation	1 y	30	(-)	24	(-)	19,5	(-)
PM_{10}	Human health	24 h	50	(35)	35	(35)	25	(35)
PM_{10}	Human health	1 y	40	(-)	28	(-)	20	(-)
Pb	Human health	1 y	0,5	(-)	0,35	(-)	0,25	(-)
CO	Human health	8 h (maximum)	10 000	(-)	7 000	(-)	5 000	(-)
Benzene	Human health	1 y	5	(-)	3,5	(-)	2	(-)
$PM_{2.5}$	Human health	1 y	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.*

	Assessment thresholds [ng·m⁻³]		Averaging period	Target value [ng·m⁻³]
	Upper	Lower		
As	3.6	2.4	1y	6
Cd	3	2	1y	5
Ni	14	10	1y	20
BaP	0.6	0.4	1y	1

[7] *https://www.slov-lex.sk/pravne-predpisy/SK/ZZ/2023/250/20230701*

As part of the European Green Deal, the European Union has developed the Zero Pollution Action Plan[8], which sets out a vision for 2050. Its aim is to reduce air pollution to a level that is no longer considered harmful to health and natural ecosystems by that year. The Action Plan includes new EU limit and target values for many pollutants. **Tab. 3.3** shows the limit and target values according to Slovak legislation (2023), the new EU limit and target values to be achieved by 1 January 2030, and the WHO recommendations (2021).

Tab. 3.3 *Comparison of limit values, target values and WHO recommendations.*

Pollutant	Averaging period	Limit/target value according to Slovak legislation (y. 2023)[a]		EU limit/target value, to be achieved by 1 January 2030[b]		WHO recommendations (y. 2021)[c]	
		Concentration	shall not exceed per year more than	Concentration	shall not exceed per year more than	Concentration	shall not exceed per year more than
$PM_{2.5}$	24 hours	-	-	25 µg·m⁻³	18 times	15 µg·m⁻³	3 – 4 times
	calendar year	20 µg·m⁻³	-	10 µg·m⁻³	-	5 µg·m⁻³	-
PM_{10}	24 hours	50 µg·m⁻³	35 times	45 µg·m⁻³	18 times	45 µg·m⁻³	3 – 4 times
	calendar year	40 µg·m⁻³	-	20 µg·m⁻³	-	15 µg·m⁻³	-
O_3	the highest daily 8-hour mean value	120 µg·m⁻³	18 times*	120 µg·m⁻³	18 times*	100 µg·m⁻³	3 – 4 times
NO_2	1 hour	200 µg·m⁻³	18 times	200 µg/m³	1 times	-	-
	24 hours	-	-	50 µg·m⁻³	18 times	25 µg·m⁻³	3 – 4 times
	calendar year	40 µg·m⁻³	-	20 µg·m⁻³	-	10 µg·m⁻³	
SO_2	1 hour	350 µg·m⁻³	24 times	350 µg·m⁻³	1 time	-	-
	24 hours	125 µg·m⁻³	3 times	50 µg·m⁻³	18 times	40 µg·m⁻³	3 – 4 times
	calendar year	-	-	20 µg·m⁻³	-	-	-
CO	the highest daily 8-hour mean value	10 mg·m⁻³ (10 000 µg·m⁻³)	-	10 mg/m³ (10 000 µg·m⁻³)	-	-	-
	24 hours	-	-	4 mg·m⁻³ (4 000 µg·m⁻³)	18 times	4 mg·m⁻³	3 – 4 times

a) Decree No. 250/2023 Coll.: https://www.slov-lex.sk/pravne-predpisy/SK/ZZ/2023/250/20230701
b) https://eur-lex.europa.eu/resource.html?uri=cellar:2ae4a0cc-55f8-11ed-92ed-01aa75ed71a1.0009.02/DOC_2&format=PDF
c) https://www.who.int/news-room/feature-stories/detail/what-are-the-who-air-quality-guidelines
** per calendar year averaged over three years*

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

3.3 AIR QUALITY MONITORING RESULTS – LOCAL AIR POLLUTION

Tab. 3.4 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. 3.4 *Percentage of valid data in 2023.*

AGLOMERATION / Zone	Station	SO_2	NO_2	PM_{10}	$PM_{2.5}$	CO	Benzene	O_3	Hg
BRATISLAVA	Bratislava, Kamenné nám.			100	99				
	Bratislava, Trnavské mýto		95	98	98	95	99		
	Bratislava, Jeséniova	95	95	99	99			93	
	Bratislava, Mamateyova	95	95	98	98			93	
	Bratislava, Púchovská	92	93	100	100	93	96		
KOŠICE	Košice, Štefánikova	93	95	98	98	94	99		
	Košice, Amurská			99	99				
	Košice, Ďumbierska							97	
	Veľká Ida, Letná			99	99	93			
Banská Bystrica region	Banská Bystrica, Štefánik. nábr.	92	94	98	98	94	96		
	Banská Bystrica, Zelená		93	99	99			98	
	Jelšava, Jesenského		94	99	97			91	
	Hnúšťa, Hlavná			98	98				
	Lučenec, Gemerská cesta		93	98	98	95	98	95	
	Zvolen, J. Alexyho			99	99				
	Žarnovica[1)]		7	7	7				
	Žarnovica, Dolná[1)]		74	77	76				
	Žiar n/H, Jilemnického			98	98				
Bratislava region	Pezinok, Obrancov mieru		95	99	98			96	
	Rohožník, Senická	94	92	98	98	91	99		
	Rovinka	90	80	92		89	94		
	Senec, Boldocká		93	98	98	94		99	
Košice region	Kojšovská hoľa		*87					*87	
	Trebišov, T. G. Masaryka		96	99	99			99	
	Strážske, Mierová			99	99				
	Krompachy, SNP	94	96	99	99	95	99		
Nitra region	Nitra, Janíkovce		91	94	94			78	
	Nitra, Štúrova	92	93	98	98	92	92		
	Komárno, Vnútorná Okružná		95	99	99			98	
	Plášťovce		*88	99	97			100	
Prešov region	Gánovce, Meteo. st.		96					82	
	Humenné, Nám. Slobody		95	98	99			94	
	Prešov, Arm. gen. L. Svobodu		96	99	99	95	100		
	Vranov n/T, M. R. Štefánika	94		98	98				
	Stará Lesná, AÚ SAV, EMEP		95	99	99			66	
	Starina, Vodná nádrž, EMEP		95					94	98
	Kolonické sedlo, Hvezdáreň			99	99				
	Poprad, Železničná		96	99	99				
	Bardejov, Pod Vinbargom		96	99	99			99	
Trenčín region	Prievidza, Malonecpalská	91	91	99	99			94	
	Bystričany, Rozvodňa SSE	90		99	99				
	Handlová, Morovianska cesta	96		99	99				
	Púchov, 1. mája	92	96	99	98	95			
	Trenčín, Hasičská	95	95	94	94	96	93		
Trnava region	Senica, Hviezdoslavova	92		98	97				
	Trnava, Kollárova		96	99	99	89	99		
	Topoľníky, Aszód, EMEP	94	96	98	97			100	52
	Sereď, Vinárska		95	99	99				

AGLOMERATION / Zone	Station	SO_2	NO_2	PM_{10}	$PM_{2.5}$	CO	Benzene	O_3	Hg
Žilina region	Chopok, EMEP		95					93	
	Liptovský Mikuláš, Školská	95	96	99	99				
	Martin, Jesenského		95	99	99	95	99		
	Oščadnica	95	95	99	99			99	
	Ružomberok, Riadok	94	95	99	99	96	94	95	
	Žilina, Obežná		93	99	99	95		95	

≥ 90% of valid measurements

1) *monitoring station Žarnovica, Dolná ceased measurement on 11. 10. 2023 and was replaced by AMS Žarnovica on 5. 12. 2023*

An assessment of air pollution according to the limit values 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 2023 shows **Tab. 3.5**. According to the preliminary processing of the *CAMS* model outputs, a few exceedances (days with average daily PM_{10} concentration > 50 $\mu g \cdot m^{-3}$) can be attributed to natural sources (e.g. transport of Saharan dust). EU legislation allows the Member State to subtract these days from the total number of exceedances once the methodology for the subtraction has been approved[9].

Tab. 3.5 *Assessment of air pollution according to the limit values for health protection in 2023.*

AGLOMERATION Zone	Pollutant / Averaging period / Parameter	SO_2 1 h number of exceedances	SO_2 24 h number of exceedances	NO_2 1 h number of exceedances	NO_2 1 year average	PM_{10} 24 h number of exceedances	PM_{10} 1 year average	$PM_{2.5}$ 1 year average	CO 8 h 1) average	Benzene 1 year average
	Limit value [$\mu g \cdot m^{-3}$]	350	125	200	40	50	40	20	10 000	5
	Maximum number of exceedances	24	3	18		35				
BRATISLAVA	Bratislava, Kamenné nám.					0	17	11		
	Bratislava, Trnavské mýto			0	30	7	21	13	1 035	0.32
	Bratislava, Jeséniova	0	0	0	8	0	15	11		
	Bratislava, Mamateyova	0	0	0	16	0	14	10		
	Bratislava, Púchovská	0	0	0	13	3	18	10	742	0.38
KOŠICE	Košice, Štefánikova	0	0	0	22	13	24	16	1 437	0.88
	Košice, Amurská					5	20	15		
	Veľká Ida, Letná					36	30	20	2 962	
Banská Bystrica region	Banská Bystrica, Štefánik. nábr.	0	0	0	22	18	24	13	1 696	0.49
	Banská Bystrica, Zelená			0	8	1	14	11		
	Jelšava, Jesenského			0	7	42	28	20		
	Hnúšťa, Hlavná					1	19	13		
	Lučenec, Gemerská cesta			0	14	9	21	15	1 267	0.34
	Zvolen, J. Alexyho					4	17	13		
	Žarnovica 2			0	11	15	21	19		
	Žiar n/H, Jilemnického					0	14	10		
Bratislava region	Pezinok, Obrancov mieru			0	9	0	14	10		
	Rohožník, Senická cesta	0	0	0	12	3	18	12	1 383	0.59
	Rovinka	0	0	0	12	1	16		718	0.68
	Senec, Boldocká			0	19	5	20	13	1 539	
Košice region	Kojšovská hoľa			0	2					
	Trebišov, T. G. Masaryka			0	10	4	19	14		
	Strážske, Mierová					3	19	14		
	Krompachy, SNP	0	0	0	14	17	22	17	1 706	1.07
Nitra region	Nitra, Janíkovce			0	10	1	16	12		
	Nitra, Štúrova	0	0	0	22	3	21	12	895	0.20
	Komárno, Vnútorná Okružná			0	13	1	18	12		
	Plášťovce			0	7	34	22	20		

9 *https://www.shmu.sk/sk/?page=2816*

AGLOMERATION Zone		Protection of human health								
	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	7					
	Humenné, Nám. slobody			0	8	4	19	17		
	Prešov, Arm. gen. L. Svobodu			0	34	10	23	16	1 337	0.55
	Vranov n/T, M. R. Štefánika	0	0			4	18	13		
	Stará Lesná, AÚ SAV, EMEP			0	4	0	11	8		
	Starina, Vodná nádrž, EMEP			0	3					
	Kolonické sedlo, Hvezdáreň					0	14	10		
	Poprad, Železnicná			0	14	1	16	12		
	Bardejov, Pod Vinbargom			0	10	4	17	13		
Trenčín region	Prievidza, Malonecpalská	0	0	0	19	4	16	12		
	Bystričany, Rozvodňa SSE	0	0			5	17	12		
	Handlová, Morovianska cesta	0	0			1	15	10		
	Púchov, 1. mája	0	0	0	9	6	19	14	1 433	
	Trenčín, Hasičská	0	0	0	23	6	19	12	1 144	0.60
Trnava region	Senica, Hviezdoslavova	0	0			4	18	13		
	Trnava, Kollárova			0	27	2	19	14	1 178	0.67
	Topoľníky, Aszód, EMEP	0	0	0	5	0	13	13		
	Sereď, Vinárska			0	12	3	17	11		
Žilina region	Chopok, EMEP			0	2					
	Liptovský Mikuláš, Školská	0	0	0	12	8	17	12		
	Martin, Jesenského			0	16	11	20	15	1 752	0.47
	Oščadnica	0	0	0	6	8	18	15		
	Ružomberok, Riadok	0	0	0	17	15	19	15	2 690	0.79
	Žilina, Obežná			0	18	13	20	15	1 346	

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

1) *maximum 8-h concentration*

2) *monitoring station Žarnovica, Dolná ceased measurement on 11. 10. 2023 and was replaced by AMS Žarnovica on 5. 12. 2023*

The limit value for the average daily concentration of PM_{10} (the average daily concentration of PM_{10} must not exceed 50 µg·m^{-3} more than 35 times per calendar year) was exceeded at only two monitoring stations in 2023 – Veľká Ida, Letná and Jelšava, Jesenského.

Tab. 3.6 *Average annual concentrations of heavy metals (As, Cd, Ni and Pb) in 2023.*

AGLOMERATION 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		0.2	0.1	0.8	3.3
Slovakia	Banská Bystrica, Štefánikovo nábrežie		0.4	0.3	0.8	5.8
	Jelšava, Jesenského		0.4	0.2	1.2	5.8
	Ružomberok, Riadok		0.9	0.1	1.3	2.6
	Veľká Ida, Letná		0.5	0.5	1.9	14.7
	Prievidza, Malonecpalská		0.6	0.1	0.7	2.5
	Sereď, Vinárska		0.2	0.1	0.7	15.7
	Púchov, 1. mája		0.2	0.2	0.8	2.9

Tab. 3.7 shows the average annual concentrations of benzo(a)pyrene (BaP) in air as measured in 2018 – 2023. BaP concentrations exceeded the target value at 10 stations. Although the measurements in Žarnovica did not reach the required proportion of valid data (90%) due to station relocation, their distribution during the year allows to assume with high probability that the target value would be exceeded also at this location. The proportion of valid data was 82%, the outage was during the heating season, a year-round measurement would probably have resulted an even higher value of the annual average concentration in Žarnovica.

Tab. 3.7 *Average annual concentrations of benzo(a)pyrene in 2018 – 2023.*

AGLOMERATION Zone			2018	2019	2020	2021	2022	2023
	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	*0.3
	Bratislava, Trnavské Mýto		0.9	0.4	0.5	0.5	0.5	0.3
	Bratislava, Púchovská					0.9	0.4	0.4
KOŠICE	Veľká Ida, Letná		5.8	4.5	4.6	6.1	5.4	4.9
Banská Bystrica region	Banská Bystrica, Štefánikovo nábrežie		2.1	1.7	1.6	1.7	1.4	1.2
	Banská Bystrica, Zelená			1.1	1.2	1.3	0.9	0.9
	Jelšava, Jesenského		3.9	4.0	3.0	2.8	2.7	3.4
	Žarnovica, Dolná					2.2	2.7	**2.0
Bratislava region	Rovinka				0.4	0.6	0.5	***0.4
Košice region	Krompachy, SNP			2.7	2.1	2.2	2.2	2.1
Nitra region	Nitra, Štúrova		0.9	0.8	0.6	0.8	0.6	0.5
	Plášťovce					2.2	2.4	2.7
Prešov region	Starina, Vodná nádrž, EMEP		1.2	0.4	0.3	0.4	0.2	0.3
	Stará Lesná, AÚ SAV, EMEP			0.4	0.3	0.4	0.3	0.3
Trenčín region	Prievidza, Malonecpalská			1.4	1.2	1.1	0.9	1.1
	Púchov, 1. mája					4.7	2.0	1.2
Trnava region	Trnava, Kollárova		0.9	0.7	0.5	0.6	0.5	0.5
Žilina region	Žilina, Obežná		6.0	2.0	1.9	1.9	1.9	1.2
	Ružomberok, Riadok				4.5	2.3	2.2	2.0
	Oščadnica					12.0	2.5	1.9

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

* *Bratislava, Jeséniova - outage due to technical problems from March to July, 60% of valid measurements*

** *Žarnovica - station relocation, outage in November and fewer measurements in December, 82% of valid measurements*

*** *Rovinka - outage in March and fewer measurements in the summer months, 81% of valid measurements in total*

3.3.1 Assessment of air quality based on upper and lower assessment thresholds

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 threshold for the assessment of the level of air pollution. Where sufficient data are available, exceedances of the upper and lower thresholds for the assessment of the level of air pollution shall be determined on the basis of concentrations measured over the last five years. An air pollution assessment threshold shall be considered to have been exceeded if there has been an exceedance 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 air pollution assessment thresholds may be determined by combining the results of measurement campaigns of shorter duration carried out over a one-year period at locations likely to have the highest levels of air pollution with the results obtained from emission inventories and modelling (Decree No. 250/2023 Coll. of the MoE SR on air quality). The classification of monitoring stations according to the upper and lower thresholds for the assessment is presented in **Tab. 3.8** and **Tab. 3.9*****.***

Tab. 3.8 Classification of AMS according to upper resp. lower assessment thresholds (UAT resp. LAT) for determining the air quality assessment regime in 2019 – 2023.

AGLOMERATION Zone	Station	UAT and LAT with regard to the protection of human health																							
		SO_2			NO_2						PM_{10}						$PM_{2.5}$			CO			Benzene		
		24-h average			1-h average			annual average			24-h average			annual average			annual average			8-h 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								
	Žarnovica**																								
	Lučenec, Gemerská cesta						x			x		x			x			x				x			x
	Žiar nad Hronom, Jilemnického											x				x		x							
Bratislava region	Pezinok			x			x			x		x				x		x				x			
	Rovinka			x			x			x	x				x							x			x
	Rohožník, Senická cesta ***			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, Morovianska 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

AGLOMERATION Zone	Station	UAT and LAT with regard to the protection of human health																							
		SO_2			NO_2						PM_{10}						$PM_{2.5}$			CO			Benzene		
		24-h average			1-h average			annual average			24-h average			annual average			annual average			8-h 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
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			

* *stations indicate regional background level*
** *AMS Žarnovica, Dolná ceased measurement on 11. 10. 2023 and was replaced by AMS Žarnovica on 5. 12. 2023*
*** *the monitoring station was relocated from Malacky to Rohožník in 2022*

Tab. 3.9 *AMS stations monitoring heavy metals and benzo(a)pyrene according to upper (UAT) and lower assessment threshold (LAT) for the air quality assessment method in 2019 – 2023.*

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			x			x	x		
Nitra, Štúrova														x	
Plášťovce													x		
Starina, Vodná nádrž, EMEP															x
Stará Lesná, EMEP															x
Prievidza, Malonecpalská						x			x			x	x		
Púchov, 1. mája													x		
Trnava, Kollárova														x	
Žilina, Obežná													x		
Ružomberok, Riadok			x			x			x			x	x		
Oščadnica													x		
Sereď, Vinárska			x			x			x			x			

Tab. 3.10 shows the average annual tropospheric ozone concentrations in 2010 – 2023 compared to the photochemically extremely active year 2003.

Tab. 3.10 *Annual average concentrations of ground-level ozone [µg·m^{-3}] in years 2003, 2010 – 2023.*

Station	2003	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Bratislava, Jeséniova	71	61	63	65	62	60	71	56	64	68	66	61	62	65	65
Bratislava, Mamateyova	53	46	51	53	48	46	54	36	51	54	54	49	50	50	50
Košice, Ďumbierska	68	63	73	62	61	55	57	55	55	63	56	46	49	53	50
Banská Bystrica, Zelená		56	60	66	66	58	48	45	57	56	47	48	54	57	52
Jelšava, Jesenského	55	44	-	-	41	36	45	48	49	49	45	39	41	38	45
Kojšovská hoľa	91	90	87	83	78	75	61	81	80	82	78	72	74	79	76
Nitra, Janíkovce		53	-	62	58	52	63	43	60	60	54	56	58	59	61
Humenné, Nám. slobody	66	53	53	55	60	40	41	50	52	51	54	49	49	51	49
Stará Lesná, AÚ SAV, EMEP	67	67	65	63	71	56	66	58	63	67	59	57	47	49	49
Gánovce, Meteo. st.	68	63	64	66	67	58	66	38	53	56	57	51	53	54	52
Starina, Vodná nádrž, EMEP	73	51	59	60	64	55	64	58	60	64	62	54	57	55	53
Prievidza, Malonecpalská		49	51	52	50	53	54	39	51	52	49	46	47	41	47
Topoľníky, Aszód, EMEP	67	55	-	59	64	51	51	49	47	54	55	24	49	54	52
Chopok, EMEP	109	87	96	93	96	52	88	91	98	95	90	91	89	91	89
Žilina, Obežná	48	47	48	49	53	42	36	43	38	44	44	36	38	36	37
Ružomberok, Riadok								37	37	36	36	35	40	37	40
Bardejov, Pod Vinbargom													44	45	42
Trebišov, T. G. Masaryka													49	49	49
Plášťovce													49	47	46
Komárno, Vnútorná Okružná													47	46	53
Senec, Boldocká													35	49	48
Pezinok, Obrancov mieru														58	58
Lučenec, Gemerská cesta														42	41
Oščadnica														48	50
Average	65	59	61	63	63	53	58	52	57	59	57	51	50	52	52

≥ 90% of valid measurements

Decree of MoE of the Slovak Republic No. 250/2023 Coll. on air quality establishes the target value for ozone for the protection of human health as follows: *the highest daily 8-hour mean value shall not exceed 120 µg/m^3 for more than 25 days per calendar year in an average of three years*.* The number of days exceeding the ground-level ozone objective value is shown in **Tab. 3.11**.

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

Station	2021	2022	2023	Average 2021 – 2023
Bratislava, Jeséniova	23	37	23	28
Bratislava, Mamateyova	15	25	18	19
Košice, Ďumbierska	0	7	4	4
Banská Bystrica, Zelená	3	9	0	4
Jelšava, Jesenského	2	*7	1	2
Kojšovská hoľa	4	16	*17	10
Nitra, Janíkovce	15	31	21	22
Humenné, Nám. Slobody	1	5	2	3
Stará Lesná, AÚ SAV, EMEP	0	0	*0	0
Gánovce, Meteo. st.	0	2	0	1

Station	2021	2022	2023	Average 2021 – 2023
Starina, Vodná nádrž, EMEP	0	1	1	1
Prievidza, Malonecpalská	3	*3	4	4
Topoľníky, Aszód, EMEP	3	9	2	5
Chopok, EMEP	22	34	34	30
Žilina, Obežná	0	3	1	1
Ružomberok, Riadok	0	0	1	1
Bardejov, Pod Vinbargom	0	3	1	1
Trebišov, T. G. Masaryka	2	5	3	3
Plášťovce	19	21	13	18
Komárno, Vnútorná Okružná	7	11	16	11
Senec, Boldocká	*2	11	3	7
Pezinok, Obrancov mieru		21	16	19
Lučenec, Gemerská cesta		6	0	3
Oščadnica		8	6	7

≥ 90% of valid measurements *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. 3.12**. 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 2019 – 2023 exceeded 18 000 µg·m^{-3}).

Tab. 3.12 *Ground-level ozone AOT40 values for vegetation protection (May – July). The AOT40 target value is 18 000 µg·m^{-3}.*

Station	2019	2020	2021	2022	2023	Average 2019 – 2023
Bratislava, Jeséniova	20 609	12 501	19 274	23 763	20 177	19 265
Bratislava, Mamateyova	19 340	10 655	17 655	20 072	16 292	16 803
Košice, Ďumbierska	11 752	3 269	7 368	12 662	11 835	9 377
Banská Bystrica, Zelená	8 298	7 723	15 869	*19 716	9 226	12 166
Jelšava, Jesenského	12 361	5 191	10 186	*17 622	10 530	11 178
Kojšovská hoľa	12 202	4 995	13 260	19 435	13 249	12 628
Nitra, Janíkovce	13 313	12 741	18 931	24 322	18 824	17 626
Humenné, Nám. slobody	13 326	5 981	12 578	16 047	9 520	11 490
Stará Lesná, AÚ SAV, EMEP	8 666	7 890	2 491	6 210		6 314
Gánovce, Meteo. st.	8 954	3 251	6 707	11 317	4 596	6 965
Starina, Vodná nádrž, EMEP	11 601	5 072	11 737	9 560	5 857	8 765
Prievidza, Malonecpalská	8 301	6 198	11 799	*15 529	8 582	10 082
Topoľníky, Aszód, EMEP	17 690	-	13 176	16 686	12 739	12 058
Chopok, EMEP	23 711	15 957	23 654	26 536	24 179	22 807
Žilina, Obežná	11 800	559	4 794	5 338	5 114	5 521
Ružomberok, Riadok	5 307	1 999	*8 041	2 935	7 890	4 533
Bardejov, Pod Vinbargom			10 607	12 711	7 413	10 244
Trebišov, T. G. Masaryka			12 369	15 806	10 425	12 867
Plášťovce*			*24 211	19 720	15 043	17 381
Komárno, Vnútorná Okružná*			*17 818	12 824	21 701	17 262
Senec, Boldocká*			-	14 893	8 930	11 911
Pezinok, Obrancov mieru				19 368	11 931	15 650
Lučnec, Gemerská cesta				14 834	9 478	12 156
Oščadnica				14 893	8 930	11 911

** a given year is not included in the average, due to lack of data in the summer period*
Exceedance of the target value is marked in red.

According to the evaluation of the measurements of the monitoring stations of the other operators (industrial stations outside NMSKO), the limit value for PM_{10} was not exceeded at any site (**Tab. 3.13**).

Tab. 3.13 *Air pollution assessment according to limit values for the protection of human health in 2023 from industrial stations of other operators – large air pollution sources (VZZO).*

AGLOMERATION Zone	Pollutant / Averaging period / Limit value [µg·m⁻³] / (Maximum number of exceedances)	Health protection						
	Pollutant	SO_2		NO_2		PM_{10}		CO
	Averaging period	1 h	24 h	1 h	1 year	24 h	1 year	8 h 1)
	Limit value [µg·m⁻³]	350	125	200	40	50	40	10 000
	(Maximum number of exceedances)	(24)	(3)	(18)		(35)		
BRATISLAVA	Bratislava, Pod. Biskupice (Slovnaft, a.s.)	1	1	0	14	2	18	1 063
	Bratislava, Vlčie Hrdlo (Slovnaft, a.s.)	1	0	0	14	1	16	737
KOŠICE	Košice, Poľov (U.S. Steel, s.r.o.)					1	13	
	Košice, Haniska (U.S. Steel, s.r.o.)					3	17	
Bratislava region	Rovinka (Slovnaft, a.s.)	0	0	0	11	0	17	703
Košice region	Veľká Ida (U.S. Steel, s.r.o.)					8	23	
	Leles (Slovenské elektrárne, a.s.)	0	0	0	7	0	10	
Nitra region	Trnovec nad Váhom (Duslo, a.s.)	0	0	0	4	0	18	
Trenčín region	Oslany (Slovenské elektrárne, a.s.)	0	0	0	10	5	18	
Žilina region	Ružomberok (Mondi a.s. - Supra)					14	22	

1) *maximum 8-hour concentration.*

3.3.2 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 in agglomeration and zone in 2023

In the Annexes *Air quality assessment of NUTS-3 regions*, the results of measurements with respect to the limit and target values for individual pollutants for the protection of human health in individual zones and agglomerations are presented. The assessment of air quality is a complex problem for which mathematical modelling methods are used in addition to monitoring. These provide additional information on the spatial distribution of air pollutant concentrations as well as on the relationship with pollutant emission sources (where input information is available). The assessment of air quality using mathematical modelling is presented in Chapter **45**.

3.3.3 Air quality assessment according to limit and target values for human health protection concerning Pb, As, Cd, Ni and O_3, in agglomeration Bratislava and zone Slovakia in 2023

- **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 largest daily 8-h mean value does not exceed 120 $\mu g \cdot m^{-3}$ for more than 25 days per calendar year in an average of three consecutive years) 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 this location, 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 2023, there was a 3-hour exceedance of the information threshold for O_3 at AMS Bratislava, Jeséniova and a 5-hour exceedance at AMS Bratislava, Mamateyova. The warning threshold for O_3 was not exceeded.

- **Zone Slovakia**

  For Pb, As, Cd, Ni and O_3 the zone defines the territory of the Slovak Republic except 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 monitoring station Chopok, EMEP. The station is located at an altitude of 2 008 m a. s. l., where, in addition to horizontal long-range transport, transport from the lower stratosphere contributes to higher tropospheric ozone concentrations. In 2023, the information threshold for O_3 was exceeded at AMS Pezinok, Obrancov mieru for 2 hours and at AMS Komárno, Vnútorná Okružná for 3 hours. The warning threshold for O_3 was not exceeded.

3.3.4 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 (alert, respectively) threshold for ground-level ozone is exceeded if the hourly average concentration exceeds 180 $\mu g \cdot m^{-3}$ (240 $\mu g \cdot m^{-3}$, respectively). 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 an announcement of cancellation of either a smog situation or the alert warning against a severe smog situation occurs shall be met if the concentration does not exceed the relevant threshold and this condition persists:

- continuously for 24 hours and, on the basis of the air pollution trend and the meteorological forecast, it is not reasonable to expect the relevant threshold value to 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 rules for the application of the smog warning system are laid down by Decree of the MoE of the Slovak Republic No. 250/2023 Coll. on air quality.

The warning threshold for SO_2 and NO_2 has not been exceeded since 2013. Ground-level ozone concentration exceeded the information threshold in 2023 at AMS Bratislava, Jeséniova, AMS Bratislava Mamateyova, AMS Pezinok and AMS Komárno.

The number of smog announcement for PM_{10} was slightly lower in 2023 compared to 2022. 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 (three for Jelšava and Ružomberok and one each for Martin and Krompachy). In cases where an improvement in the dispersion situation could be expected on the basis of the meteorological forecast or the nature of the pollution, no announcement or warning was issued.

In 2023, three smog situation notifications for O_3 were issued (19 June for the Komárno district, 21 June for Bratislava and 22 August for Bratislava and the Pezinok district). There was no exceedance of the O_3 alert threshold in the Slovak Republic.

The duration of exceedances of the information and alert thresholds for PM_{10} and O_3 in 2023 compared to 2022 is shown in **Tab. 3.14**.

Tab. 3.14 *Duration of exceedances (in hours) of the information threshold (IT) and alert threshold (AT) for individual pollutants.*

AGLOMERATION Zone	Pollutant	O_3				PM_{10}			
	Year	2022	2022	2023	2023	2022	2022	2023	2023
	Information/alert threshold	IT	AT	IT	AT	IT	AT	IT	AT
	Averaging period	1 h	3 h conse-cutively	1 h	3 h conse-cutively	12 h	12 h	12 h	12 h
	Limit value [μg·m⁻³]	180	240	180	240	100	150	100	150
BRATISLAVA	Bratislava, Kamenné nám.					0	0	0	0
	Bratislava, Trnavské mýto					0	0	0	0
	Bratislava, Jeséniova	1	0	3	0	0	0	0	0
	Bratislava, Mamateyova	0	0	5	0	8	0	0	0
	Bratislava, Púchovská					0	0	0	0
KOŠICE	Košice, Štefánikova					24	0	28	0
	Košice, Amurská					0	0	0	0
	Košice, Ďumbierska	0	0	0	0				
	Veľká Ida, Letná					72	0	15	0
Banská Bystrica region	Banská Bystrica, Štefánik. nábr.					33	0	52	8
	Banská Bystrica, Zelená	0	0	0	0	0	0	0	0
	Jelšava, Jesenského	0	0	0	0	85	0	28	0
	Hnúšťa, Hlavná					0	0	0	0
	Lučenec, Gemerská cesta	0	0	0	0	0	0	0	0
	Zvolen, J. Alexyho					0	0	0	0
	Žarnovica, Dolná					14	0	0	0
	Žiar n/H, Jilemnického					0	0	0	0
Bratislava region	Pezinok, Obrancov mieru	0	0	2	0	0	0	0	0
	Rohožník, Senická					0	0	0	0
	Rovinka					0	0	11	0
	Senec, Boldocká	0	0	0	0	9	0	22	6
Košice region	Kojšovská hoľa	0	0	0	0				
	Trebišov, T. G. Masaryka	0	0	0	0	6	0	0	0
	Strážske, Mierová					0	0	0	0
	Krompachy, SNP					15	0	20	0
Nitra region	Nitra, Janíkovce	0	0	0	0	0	0	0	0
	Nitra, Štúrova					0	0	0	0
	Komárno, Vnútorná Okružná	0	0	3	0	9	0	10	0
	Plášťovce	0	0	0	0	17	0	24	6
Prešov region	Gánovce, Meteo. st.	0	0	0	0				
	Humenné, Nám. Slobody	0	0	0	0	0	0	2	0
	Prešov, Arm. gen. L. Svobodu					6	0	20	0
	Vranov n/T, M. R. Štefánika					0	0	10	0
	Stará Lesná, AÚ SAV, EMEP	0	0	0	0	0	0	0	0
	Starina, Vodná nádrž, EMEP	0	0	0	0	0	0	0	0
	Kolonické sedlo, Hvezdáreň					0	0	0	0
	Poprad, Železničná					0	0	0	0
	Bardejov, Pod Vinbargom	0	0	0	0	0	0	0	0
Trenčín region	Prievidza, Malonecpalská	0	0	0	0	0	0	0	0
	Bystričany, Rozvodňa SSE					0	0	0	0
	Handlová, Morovianska cesta					6	0	0	0
	Púchov, 1. mája					13	0	0	0
	Trenčín, Hasičská					0	0	0	0
Trnava region	Senica, Hviezdoslavova					0	0	0	0
	Trnava, Kollárova					0	0	0	0
	Topoľníky, Aszód, EMEP	0	0	0	0	13	4	0	0
	Sereď, Vinárska					0	0	0	0
Žilina region	Chopok, EMEP	0	0	0	0	0	0	0	0
	Liptovský Mikuláš, Školská					4	0	24	11
	Martin, Jesenského					6	0	47	0
	Oščadnica	0	0	0	0	19	0	9	0
	Ružomberok, Riadok	0	0	0	0	15	1	86	15
	Žilina, Obežná	0	0	0	0	38	12	0	0

The highest number of hours with exceedances of the information threshold for PM_{10} was recorded in 2023 at the Ružomberok, Riadok monitoring station (86), with exceedances measured at this station during January, February, and December. The highest number of exceedances at Ružomberok was measured in February (59).

3.3.5 Summary

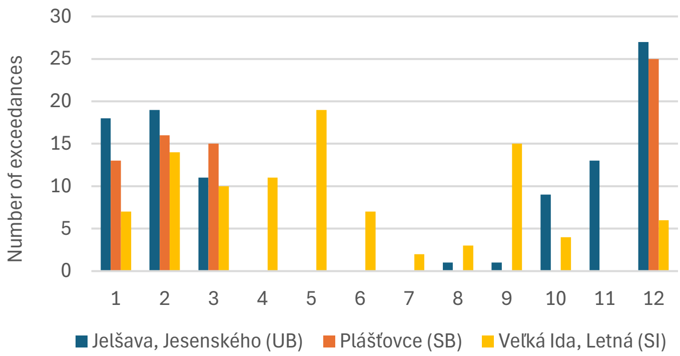
The year 2023 was generally positively influenced by meteorological conditions – it was unusually heavy on rainfall and demands on household heating were not high. Measured pollutant levels were therefore on average lower than in previous years.

The highest concentrations were measured in February, due to a combination of the influence of unfavourable dispersion conditions under the repeated influence of anticyclone and relatively low temperatures in the first half of the month.

- **PM_{10}**

Exceedances of the limit value for the protection of human health for 24-h concentrations occurred at two AMS (Jelšava, Jesenského and Veľká Ida, Letná), with the highest number of exceedances recorded in February and December (**Fig. 3.1**). Interestingly, although most of the average daily PM_{10} concentrations above 50 μg·m^{-3} were recorded in February (**Fig. 3.2**) under the influence of cold days with higher heating requirements and unfavourable dispersion conditions, in Jelšava and Plášťovce most such days were in December. Overall, however, the limit value was not exceeded in Plášťovce. The highest proportion of exceedances was in the Košice agglomeration (including the industrial AMS Veľká Ida) and the zone Banská Bystrica region (**Fig. 3.3**). Several other episodes with higher values of the average daily concentration of PM_{10} were probably caused by *long-distance transport of dust* from dry areas.

Fig. 3.1 *Number of days in the months of 2023 with an average daily PM_{10} concentration > 50 μg·m^{-3} at the AMS where the limit value was exceeded in 2022 or 2023.*



In 2023, there were no exceedances of the limit value of 40 μg·m^{-3} for the annual mean PM_{10} concentration at any monitoring station. The highest values of this indicator were recorded at Veľká Ida, Letná (30 μg·m^{-3}; in 2022: 37 μg·m^{-3}) and Jelšava, Jesenského (28 μg·m^{-3}; in 2022: 30 μg·m^{-3}).

Fig. 3.2 *Number of days with average daily PM_{10} concentrations > 50 μg·m^{-3} at all AMS in all months.*

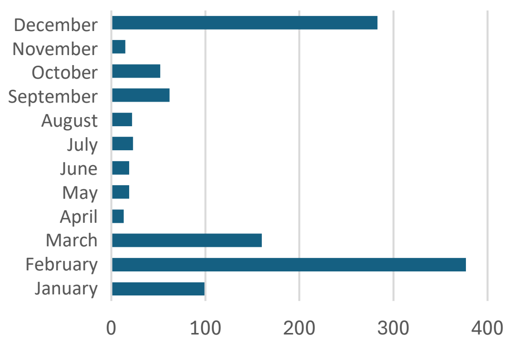
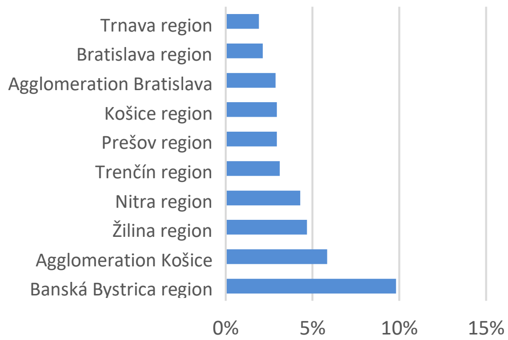
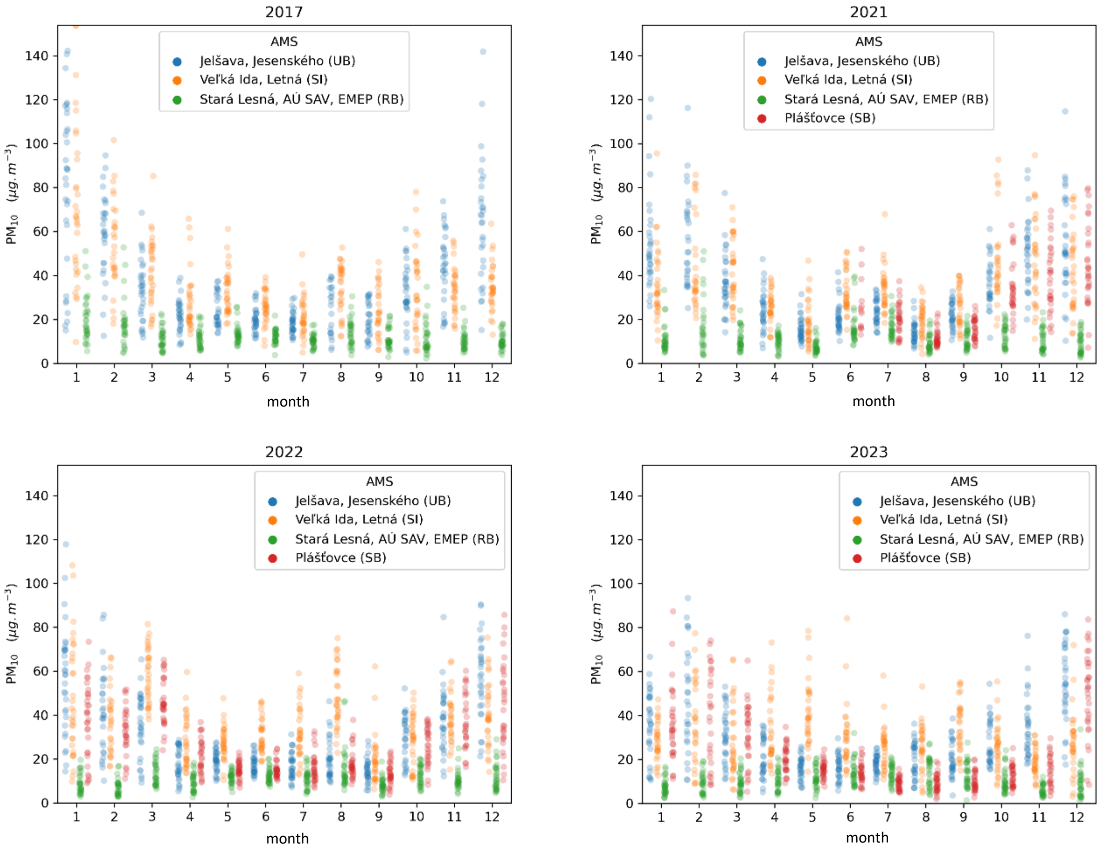


Fig. 3.3 *Relative number of exceedances of the daily limit value for PM_{10} to all measurements in the zone/agglomeration.*



A comparison of the average daily concentrations at stations that recorded exceedances of the limit value for PM_{10} in 2017 and 2021 – 2023 is illustrated in **Fig. 3.4**.

Fig. 3.4 *Comparison of average daily PM_{10} concentrations at selected stations in 2017 and 2021 – 2023.*



$PM_{2.5}$

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. In 2023, the limit value for $PM_{2.5}$ was not exceeded. In 2022, the limit value was exceeded at three automatic air quality monitoring stations: Veľká Ida, Letná; Jelšava, Jesenského and Plášťovce.

The health effects of PM air pollution depend on both the size and composition of the particulate matter, with the smaller the particles, the more severe the consequences for human health. European and Slovak legislation therefore shifts the focus of attention to $PM_{2.5}$. The indicator that reflects the trend in the exposure of the population to $PM_{2.5}$ air concentrations is the $PM_{2.5}$ Average Exposure Indicator (AEI). It is defined as a three-year moving average of $PM_{2.5}$ annual averages from selected urban and suburban background stations. For example, the AEI 2023 is calculated as the average of the three annual average concentrations from these stations in 2021, 2022 and 2023. **Tab. 3.15** shows the values of this indicator since 2010, which is the reference year for the AEI. According to Annex 4 to Decree No. 250/2023 Coll., the national exposure reduction target for $PM_{2.5}$ is set at 18 μg·m^{-3}, which was to be achieved by 2020. This has been achieved. The national exposure reduction target for $PM_{2.5}$ in 2023 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 is to be achieved
Concentration in 2010 in µg·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 µg·m^{-3}	

Exposure concentration reduction obligation for $PM_{2.5}$

Exposure concentration reduction obligation applicable from 2015	20 µg·m^{-3}

Tab. 3.15 shows the evolution of the $PM_{2.5}$ Average Exposure Indicator over the last fourteen years. Its decline in 2021 can probably be explained by the emissions decrease in Slovakia and in neighbouring countries.

Tab. 3.15 *$PM_{2.5}$ Average Exposure Indicator (AEI) in 2010 – 2023.*

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
AEI [µg·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	15.2

- **SO_2**

In contrast to PM, NO_2, CO and benzo(a)pyrene, large industrial sources are the main contributors to SO_2 emissions. During the winter months, the impact of household heating with high sulphur coal may be reflected in the level of air pollution. However, high concentrations of SO_2 have not been recorded in Slovakia, indicating that this is probably a less used method of heating in Slovakia. Measured concentrations have been below the limit value for a long time. In 2023, there were no exceedances of the SO_2 alert threshold at monitoring stations in Slovakia.

The critical level for the protection of vegetation is 20 µg·m^{-3} per calendar year and winter period. This level has not been exceeded during 2023 at any of the EMEP stations, neither for the calendar year nor for the winter period. All values were below the lower assessment threshold for determining the air quality assessment regime with respect to vegetation protection.

- **NO_2**

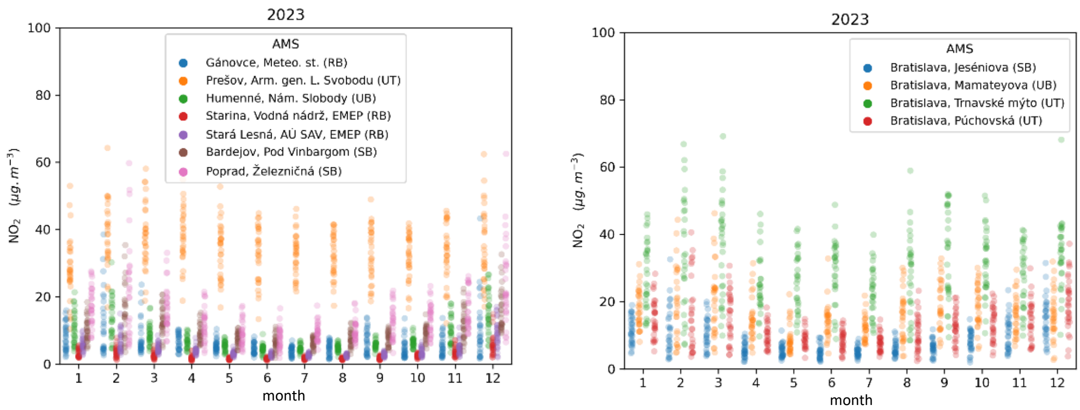
NO_2 is formed in the air by the oxidation of NO emitted from road traffic and various industrial sources. Therefore, as the distance from the source increases – for example, from the road – the NO/NO_2 fraction changes significantly in favour of NO_2.

In 2023, the annual limit value of 40 µg·m^{-3} for NO_2 was not exceeded at any monitoring station. The last exceedance was measured in 2018 at the monitoring stations Prešov, Arm. gen. L. Svobodu and Bratislava, Trnavské Mýto. In Slovakia, there was also no exceedance of the alert threshold for NO_2 in 2023.

The highest annual average was recorded by two traffic stations – Prešov, Arm. gen. L. Svobodu (34 µg·m^{-3}) and Bratislava, Trnavské Mýto (30 µg·m^{-3}). **Fig. 3.5** illustrates a comparison of the values measured at these two AMS and the remaining stations in Bratislava and the Prešov region in each month of 2023. The AMS in Prešov has significantly the highest NO_2 values in the Prešov region all year round, with higher concentrations also occurring in February and December at the suburban background station in Poprad, and to a lesser extent in Bardejov. This will be due to a combination of influences, with unfavourable dispersion conditions of several anticyclonic situations in February.

Comparing the NO_2 concentrations measured in Bratislava, it can be seen (Fig. 3.5) that although the values at the traffic station at Trnavské Mýto are, as expected, the highest, the traffic station at Púchovská Street has lower values than the urban background station at Mamateyova Street, which is perhaps episodically influenced by the refinery.

Fig. 3.5 *Comparison of average daily NO_2 concentrations in the Prešov region and in the Bratislava agglomeration.*

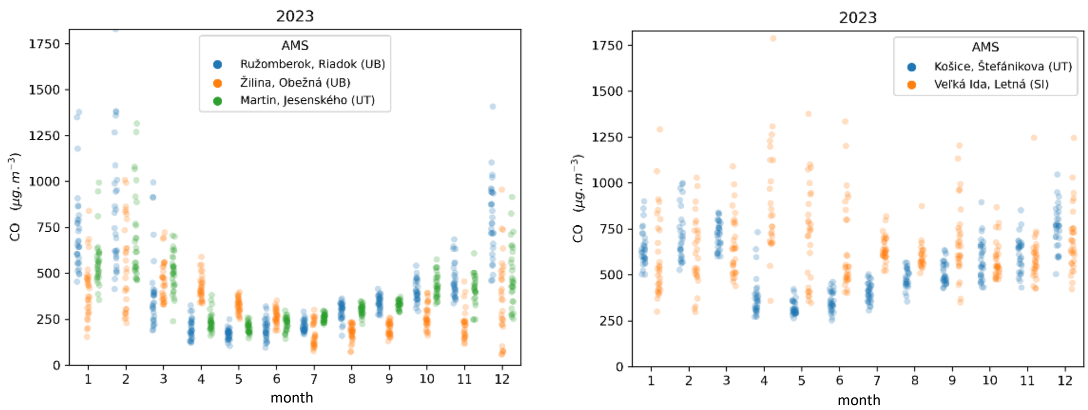


The critical level of air pollution for the protection of vegetation (30 $\mu g \cdot m^{-3}$ per calendar year expressed as NO_x) was not exceeded at any of the EMEP stations in 2023. The values were well below the lower assessment threshold (for determining the air quality assessment regime) designed to protect vegetation and natural ecosystems.

CO

Sources of CO emissions are combustion processes in industry, power engineering, household heating and road traffic. None of the monitoring stations in Slovakia exceeded the limit value for CO in 2023, and the level of air pollution for the previous period 2012 – 2023 is below the lower assessment threshold for determining the air quality assessment regime. In Fig. 3.6 we can compare the pattern of average daily concentrations in the Košice agglomeration and in the zone Žilina region, with higher concentrations at AMS Veľká Ida, Letná distributed approximately evenly throughout the year, while at AMS Ružomberok, Riadok the maximum occurs in the winter months.

Fig. 3.6 *Average daily CO concentrations in the zone Žilina region and in the Košice agglomeration.*

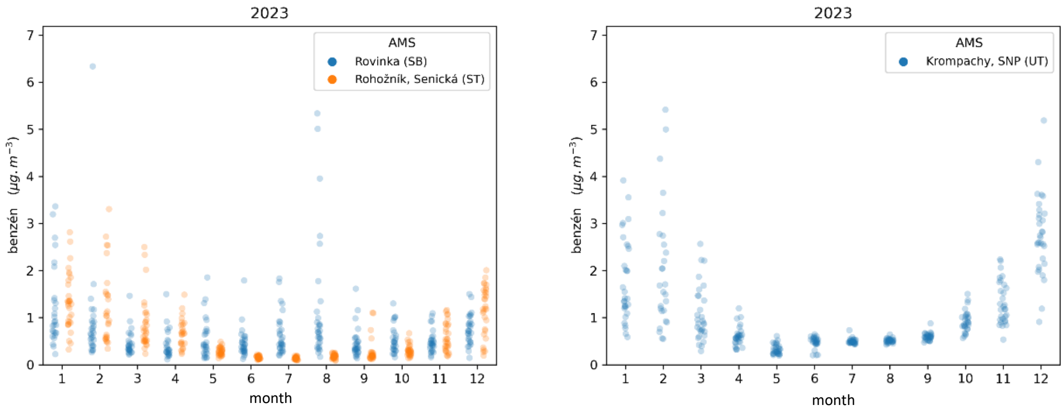


Benzene

The values of annual average benzene concentrations were well below the limit value of 5 µg·m^{-3}.

Fig. 3.7 illustrates benzene concentrations in individual months of 2023 in the zone Bratislava region and in Krompachy (the zone Košice region), where the annual average was the highest (1.1 µg·m^{-3}). The concentrations measured in Krompachy have a characteristic pattern indicating the influence of heating. In addition to road traffic, the AMS in Rovinka may also be affected episodically by the nearby refinery, but the limit value was not exceeded in this case either.

Fig. 3.7 Comparison of average daily benzene concentrations in the zones Bratislava and Košice region.



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 chemistry of its formation and decomposition in the atmosphere also complicates the situation – ozone is formed in the presence of solar radiation from, for example, nitric oxide (from road traffic) and volatile organic hydrocarbons (from various combustion processes, paints and dissolvents, but also from biogenic sources) or CO (from road traffic or industrial sources). The amount of ozone formed depends on the concentration ratio of its precursors. However, in the presence of nitric oxide, ozone also decomposes (so-called ozone titration), which is why ozone concentrations are usually lower near busy roads.

Fig. 3.8 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 (tropospheric) ozone is formed from photochemical reactions of, for example, nitric oxide or carbon monoxide and volatile organic compounds. The reaction depends on the intensity of solar radiation. At high mountain altitudes (e.g. Chopok), ozone concentrations are highest.

The target value for ground-level ozone was exceeded by measurements at two stations: Bratislava, Jeséniova and Chopok, EMEP.

When comparing the course of measured values, it can be seen that while in the high-mountain location at Chopok the values are higher all year round with a slight maximum in summer, in Bratislava the maximum is much more pronounced in the summer months (**Fig. 3.8**).

In 2023, the information threshold for ozone was exceeded at 4 AMS: Bratislava, Jeséniova; Bratislava, Mamateyova; Pezinok, Obrancov mieru and Komárno, Vnútorná Okružná (**Tab. 3.14**).

Since 2022, ozone has also been measured at the traffic stations in Lučenec and Senec, but the values are lower here due to the aforementioned titration of ozone by nitric oxide from road traffic (**Fig. 3.9**).

Fig. 3.8 *Comparison of average daily concentrations of ground-level ozone in the Žilina region and Bratislava*

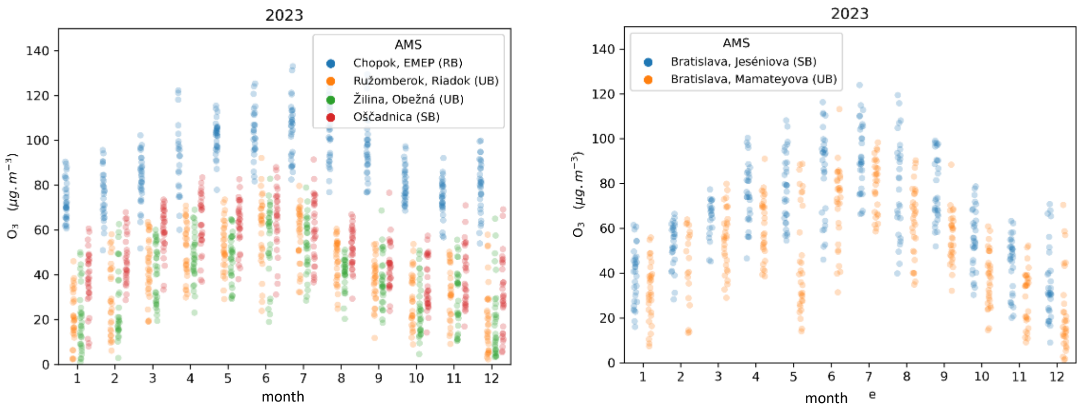
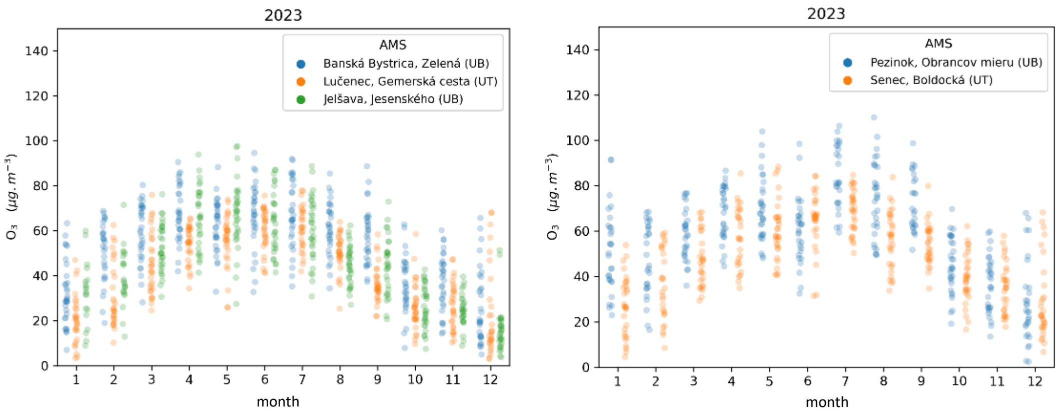


Fig. 3.9 *Comparison of average daily concentrations of ground-level ozone at urban traffic stations in Lučenec and Senec with values at urban background locations in the zones of Banská Bystrica and Bratislava region.*



Pb, As, Ni, Cd

Neither the limit value nor the target value was exceeded in 2023.

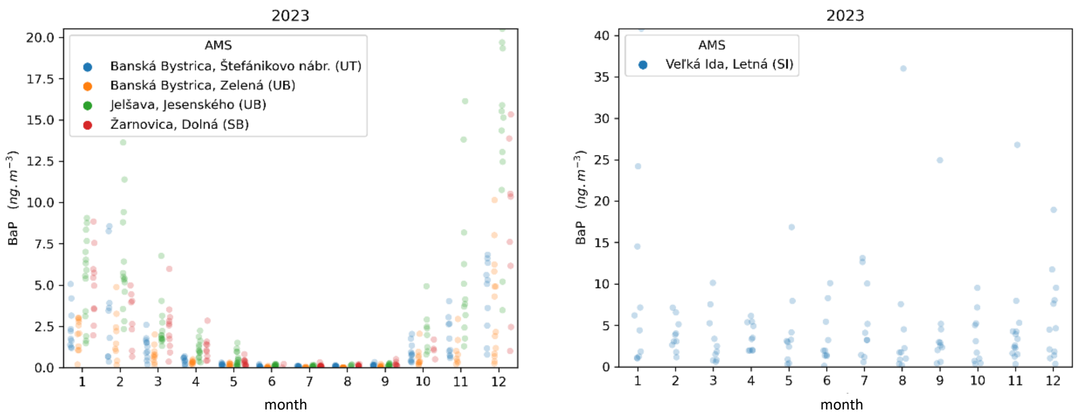
The annual average concentrations of heavy metals measured at NMSKO stations are mostly only a fraction of their target or limit values (**Tab. 3.6**).

BaP

Benzo(a)pyrene and other polycyclic aromatic hydrocarbons were monitored at 20 stations in 2023, of which the target value for the annual average concentration of BaP was exceeded at the following 10 stations: Veľká Ida, Letná; Jelšava, Jesenského; Plášťovce; Krompachy, SNP; Ružomberok, Riadok; Oščadnica; Púchov, 1. mája; Žilina, Obežná; Banská Bystrica, Štefánikovo nábrežie; Prievidza, Malonecpalská. Measurements at the first four AMS exceeded the target value more than twice, Veľká Ida even four times (**Tab. 3.7**). Although the AMS in Žarnovica had an outage mainly during December due to station relocation, it is very likely that with sufficient measurements the target value would have been exceeded at this station as well. In most locations, local heating is the decisive source of BaP air pollution, in Veľká Ida the contribution of the metallurgical complex plays a large role, while households heating with solid fuel or various types of waste also contributes to some extent to the pollution.

Fig. 3.10 compares the average daily BaP concentrations measured at the locations with the highest hourly values. However, it is important to note the difference in scale – the maximum values measured in Veľká Ida are almost double the concentrations measured in Jelšava or Žarnovica. In Veľká Ida, BaP is mainly influenced by industry (coke production), to a lesser extent by household heating. This is indicated by the annual pattern of values, in which there is no summer minimum – high values have been recorded throughout the year. On the contrary, all stations in the Banská Bystrica region are characterised by very low values outside the heating season and high values measured in the winter months. This pattern is typical for all monitoring stations in other regions, except for Veľká Ida.

Fig. 3.10 *Comparison of average daily BaP concentrations in the zone Banská Bystrica region (left) and at the monitoring station Veľká Ida, Letná (right) in 2023.*



3.4 REGIONAL MONITORING

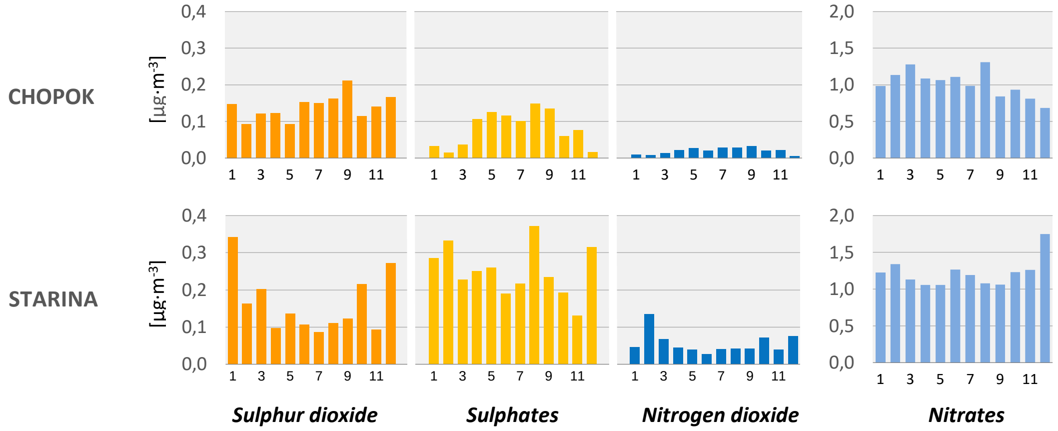
Regional air pollution is the pollution of the boundary layer of the atmosphere of a natural landscape type, at a sufficient distance from local industrial and urban sources. The boundary layer of the atmosphere is the layer in which pollution is mixed from the earth's surface up to the height of about 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, the results from the EMEP regional monitoring stations are presented, 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 2023, the average concentrations per calendar year were 0.28 µg $SO_2 \cdot m^{-3}$ at Chopok and 0.33 µg $SO_2 \cdot m^{-3}$ at Starina. Also, for the winter period, the concentrations at Chopok (0.29 µg $SO_2 \cdot m^{-3}$) and Starina (0.43 µg $SO_2 \cdot m^{-3}$) were at a low level and met the legislative limits. The limit values are laid down in the Decree of the Ministry of Environment of the Slovak Republic No. 250/2023 Coll. on air quality in Annex 1. The annual average concentrations of sulphur dioxide and sulphates are presented in **Tab. 3.16**. The values are converted to mass of sulphur. **Fig. 3.11** illustrates the monthly course of sulphur and nitrogen compounds.

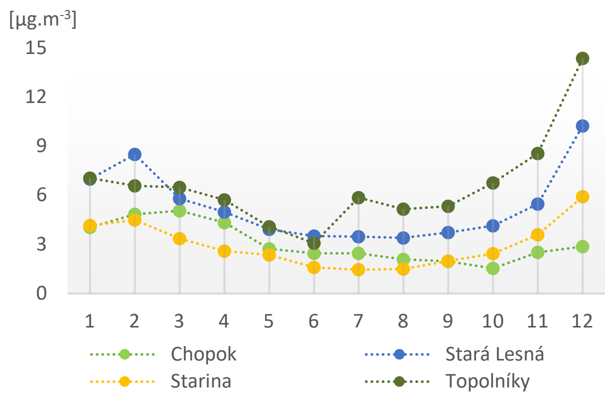
Fig. 3.11 *Average monthly concentrations of air pollutants – 2023 (converted to sulphur and nitrogen, respectively).*



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 $NO_X \cdot m^{-3}$ for the calendar year, which is listed in Annex 1 of the Decree of the Ministry of the Environment of the Slovak Republic on air quality No. 250/2023 Col. At the Chopok regional stations (3.07 µg $NO_X \cdot m^{-3}$), Stará Lesná (5.35 µg $NO_X \cdot m^{-3}$), Starina (2.96 µg $NO_X \cdot m^{-3}$) and Topoľníky (6.59 µg $NO_X \cdot m^{-3}$) the limit value has not been exceeded. **Fig. 3.12** shows the monthly average concentrations of nitrogen oxides. At the stations Stará Lesná and Topoľníky, significantly higher monthly concentrations were achieved in December, with a maximum 14 µg $NO_X \cdot m^{-3}$ in Topoľníky, and this value is well below the critical level for vegetation protection for a calendar year. The annual average concentrations of nitrous oxide and nitrate are shown in **Tab. 3.16**. The values are converted to mass of nitrogen. Nitrate was more abundant in gaseous than in particulate form ($NO_3^-{}_{(s)}/HNO_{3(g)}$) in 2023, accounting for 6.4% of the total TSP at Chopok and 9.6% of the PM_{10} at Starina.

Fig. 3.12 *Average monthly NO_X concentrations in air – 2023.*



Tab. 3.16 *Average annual concentrations of pollutants [µg·m⁻³] in air at EMEP stations – 2023.*

	SO_2	SO_4^{2-}	NO_2	NO_3^-	HNO_3	Cl^-	NH_3	NH_4^+	Na^+	K^+	Mg^{2+}	Ca^{2+}
Chopok	0.14	0.08	1.02	0.02	0.08	0.02	-	-	-	-	-	-
Starina	0.16	0.25	1.21	0.06	0.09	0.03	0.78	0.24	0.11	0.09	0.02	0.12

SO_2, SO_4^{2-} – converted to mass of sulphur, NO_X, NO_3^-, HNO_3, NH_3, $NH^+{}_4^+$ – converted to mass of 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 cations, sodium, potassium, calcium and magnesium ions 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. 3.16**. For ammonium ions the annual concentration was 0.47 µg $N \cdot m^{-3}$ and for ammonia 0.78 µg $N \cdot m^{-3}$.

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 2023 are presented in **Tab. 3.17**.

Tab. 3.17 *Average annual concentrations of PM_{10}, TSP, EC/OC, O_3 [$\mu g \cdot m^{-3}$] and heavy metals [$ng \cdot m^{-3}$] in air at EMEP stations – 2023.*

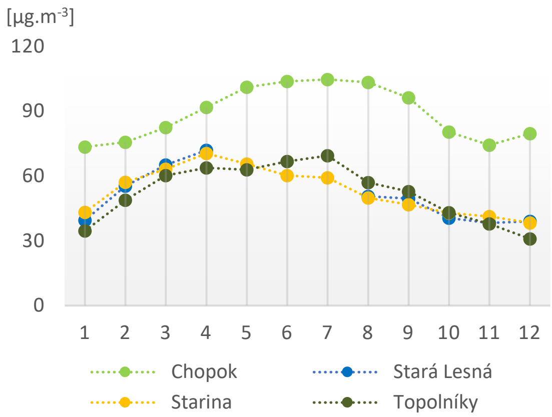
	PM_{10}/TSP[1]	Pb	Cu	Cd	Ni	Cr	Zn	As	Hg[2]	EC/OC	O_3
Chopok[1]	7	0.68	0.38	0.03	0.24	0.38	3.63	0.12	-	-	89
Topoľníky	11	2.66	1.03	0.07	0.19	0.33	10.30	0.23	*1.03	-	52
Starina	10	1.41	0.65	0.08	0.13	0.25	7.17	0.13	1.19	-	53
Stará Lesná	9	1.47	0.89	0.06	0.18	0.38	6.91	0.18	-	1.8/0.29	*49

[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.*
** the required percentage of valid data has not been met*

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 2023, the annual average ozone concentration was 89 $\mu g \cdot m^{-3}$ at Chopok, 52 $\mu g \cdot m^{-3}$ at Topoľníky, 49 $\mu g \cdot m^{-3}$ at Stará Lesná (the requirement for percentage of valid data >90% in 2023 was not met here) and 53 $\mu g \cdot m^{-3}$ at Starina (**Tab. 3.17**). **Fig. 3.13** 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.). The AOT40 target value for vegetation protection was exceeded at the station Chopok.

Fig. 3.13 *Average monthly O_3 concentrations in air – 2023.*



Volatile Organic Compounds

Volatile organic compounds C2 – C8 (so called light hydrocarbons) started to be sampled at the Starina station in 1994. The concentrations of individual compounds vary throughout the year. The lower hydrocarbons (ethane, ethene, propane and propene) have a seasonal pattern, with high values occurring in winter. In contrast, the highest concentrations of isoprene are measured in the summer months. This is due to the fact that it is a chemical whose emissions are biogenic in nature, produced by plants. The production of isoprene emissions increases with increasing temperature. Benzene and its derivatives are not seasonal, and their concentrations are constant throughout the year.

Tab. 3.18 *Annual average concentrations of volatile organic compounds [ppb] at EMEP station Starina – 2023.*

ethane	ethane	etín	propane	propene	i-butane	butene	2-metylbutane	pentane
1.77	0.74	0.03	1.12	0.34	0.34	0.75	0.13	LOD*
hexane	Isoprene	**Σ butenes**	**Σ pentenes**	benzene	toluene	m+p-xylene	o-xylene	
0.43	0.19	0.12	LOD*	0.44	0.30	LOD*	LOD*	

** LOD – below the detection limit of the analytical method*

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. 3.19 Annual weighted averages of pollutant concentrations in atmospheric precipitation – 2023.

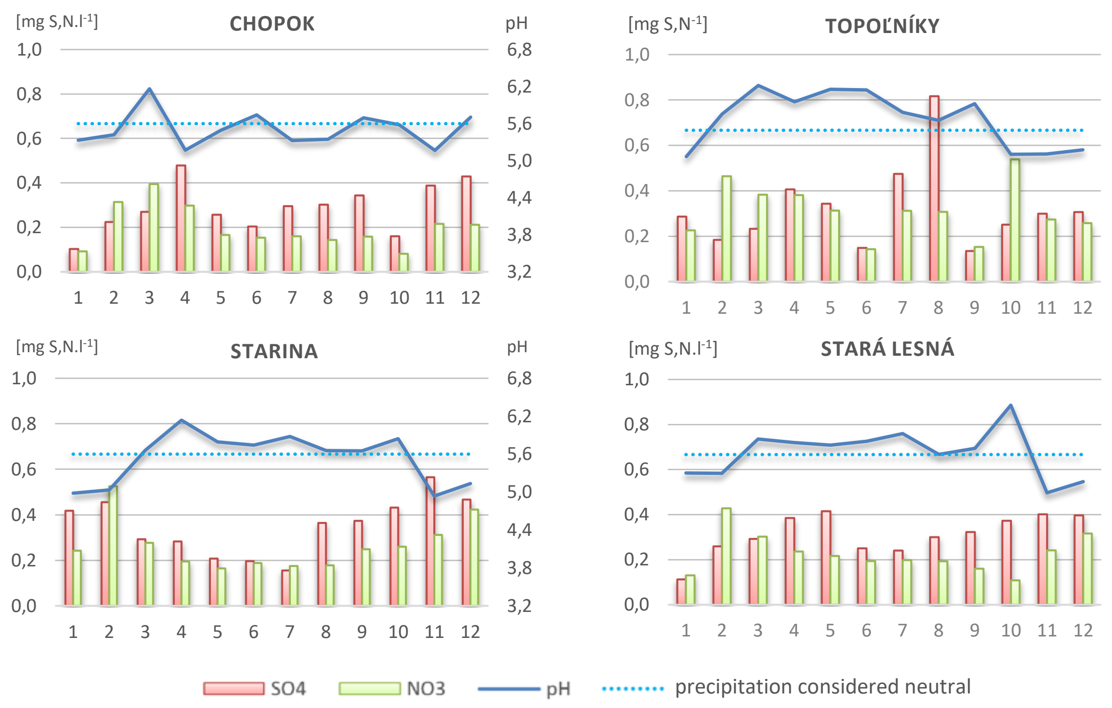
	Precip. [mm]	pH	Cond. [µS·cm⁻¹]	SO_4^{2-} [mg·l⁻¹]	NO_3^- [mg·l⁻¹]	NH_4^+ [mg·l⁻¹]	Cl^- [mg·l⁻¹]	Na^+ [mg·l⁻¹]	K^+ [mg·l⁻¹]	Mg^{2+} [mg·l⁻¹]	Ca^{2+} [mg·l⁻¹]
Chopok	1 370	5,43	8,31	0,27	0,18	0,34	0,25	0,14	0,05	0,03	0,17
Topoľníky	804	5,48	10,61	0,35	0,31	0,44	0,30	0,18	0,10	0,04	0,35
Starina	550	5,37	9,62	0,34	0,25	0,38	0,31	0,20	0,17	0,05	0,31
Stará Lesná	598	5,53	8,44	0,31	0,20	0,37	0,27	0,16	0,07	0,03	0,25
Bratislava, Jeséniova	655	6,00	9,95	0,34	0,28	0,62	0,21	0,44	0,11	0,03	0,20

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

Main ions, pH, conductivity

Higher precipitation was recorded at all regional stations in 2023 compared to 2022. Annual mean pH values at EMEP stations ranged from 5.37 at Starina to 5.53 at Topoľníky. The highest annual mean pH value of 6.0 was measured in Bratislava, which corresponds with higher NH_4^+ ion concentrations at this station, while ammonium cations have a high neutralizing capacity in precipitation in Slovakia (**Tab. 3.19**, **Fig. 3.14**)[10]. The conductivity of atmospheric precipitations is a reflection of the amount of dissociated ions present in the precipitations. The highest conductivity 10.61 µS·cm⁻¹ was recorded at station Topoľníky. The average annual concentrations of sulphate in precipitation water (**Tab. 3.19**, **Fig. 3.14**) converted to mass of sulphur, were in the range 0.27 – 0.35 mg·l⁻¹ at the EMEP stations. The lowest concentrations were measured at Chopok, the differences in concentrations were negligible.

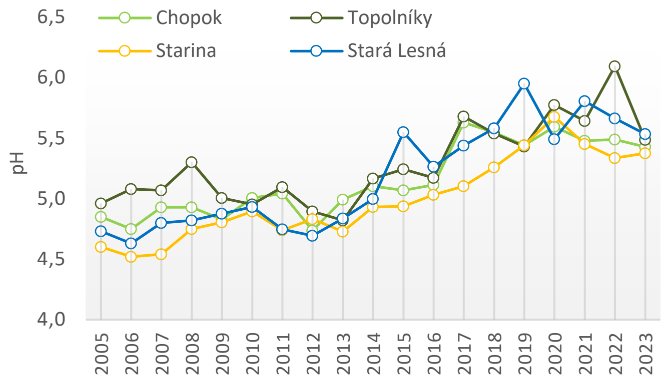
Fig. 3.14 Atmospheric precipitation – 2023.



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

Nitrates showed a concentration range at EMEP stations converted to mass of nitrogen from 0.18 – 0.31 mg·l⁻¹ (**Tab. 3.19**, **Fig. 3.14**). The lowest annual average weighted concentrations were measured at AMS Chopok, the highest at AMS Topoľníky.

Fig. 3.15 pH in atmospheric precipitation.



Ammonium ions are the most abundant cations in precipitation in Slovakia. Their concentration range at EMEP stations was 0.34 – 0.44 mg·l⁻¹ (**Tab. 3.19**). The lower end of the range is being represented in the long term by Chopok and the upper by Topoľníky, as it was also in 2023. Trends of annual mean pH values of atmospheric precipitation at EMEP stations since 2005 are shown in **Fig. 3.15**.

Heavy metals in atmospheric precipitation

Monitoring of heavy metals in precipitation is carried out on the basis of the monitoring strategy of the CCC of EMEP (Chemical Coordinating Centre of EMEP). Heavy metals – lead, copper, cadmium, nickel, chromium, chromium, zinc and arsenic – are monitored at first level stations. At the monitoring station Bratislava, Jeséniova the same range of heavy metals is being measured. The results of annual weighted averages of heavy metal concentrations in atmospheric precipitation for 2023 are presented in **Tab. 3.20**. In 2023, significantly lower concentrations of all monitored heavy metals were measured in precipitation compared to previous measurements after 2020 (**Tab. 3.17**). This may be due to the roughly one-third greater annual rainfall and, in particular, the uneven occurrence of rainfall in favour of convective rainfall with high totals over a short period of time[11].

Tab. 3.20 Annual weighted averages of heavy metal concentrations in atmospheric precipitation at EMEP stations – 2023.

	Precip [mm]	Pb [µg·l⁻¹]	Cd [µg·l⁻¹]	Cr [µg·l⁻¹]	As [µg·l⁻¹]	Cu [µg·l⁻¹]	Zn [µg·l⁻¹]	Ni [µg·l⁻¹]
Chopok	1 634	0.54	0.04	0.14	0.12	0.72	13.53	0.17
Topoľníky	662	0.54	0.05	0.15	0.10	0.47	16.48	0.24
Starina	850	0.45	0.04	0.17	0.05	0.86	11.54	0.29
Stará Lesná	983	0.53	0.03	0.14	0.11	0.83	6.52	0.21
Bratislava, Jeséniova	957	0.32	0.03	0.14	0.13	1.24	9.26	0.22

[11] *https://www.shmu.sk/sk/?page=1&id=klimat_operativneudaje2&identif=11813&rok=2023&obdobie=1981-2010*

4 RESULTS OF AIR QUALITY MATHEMATICAL MODELLING

The Act No. 146/2023 Coll. on air protection 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 those from the 2020 Air Quality Reports and previous reports.

4.1 BRIEF CHARACTERISTICS OF MODELS USED

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

The *Community Multiscale Air Quality Modelling System* - CMAQ[12], 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 × 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[13] 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 × 1 km was used.

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

[13] *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[14]. 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[15] (7%), the ventilation index[16] (19%), altitude (63.6%), land use[17] (9.6%)[18] were used as proxy spatial fields. After subsequent adjustment of the results using the IDW-R method and comparison with measurements, we get RMSE = 0.2 $\mu g \cdot m^{-3}$ and BIAS = 0.0 $\mu g \cdot m^{-3}$.

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.

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 regions. 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.

[14] *https://www.ceip.at/status-of-reporting-and-review-results - IIR by individual years and countries.*
[15] *This model included emissions from local heating plants without considering background concentrations.*
[16] *The height of mixing multiplied by average wind velocity in layers under this height.*
[17] *CORINE Land Cover 2018 https://www.eea.europa.eu/data-and-maps/data/external/corine-land-cover-2018*
[18] *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 2023.*

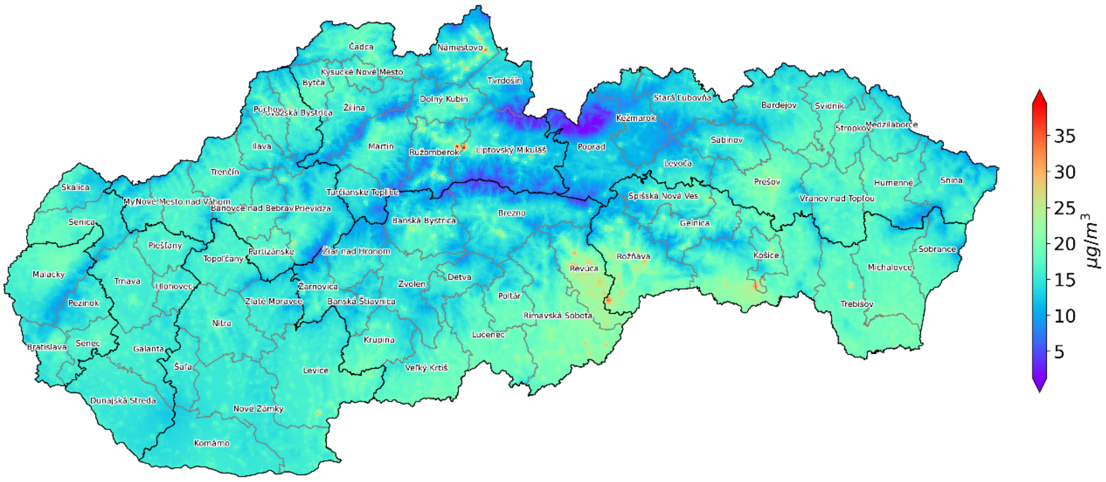
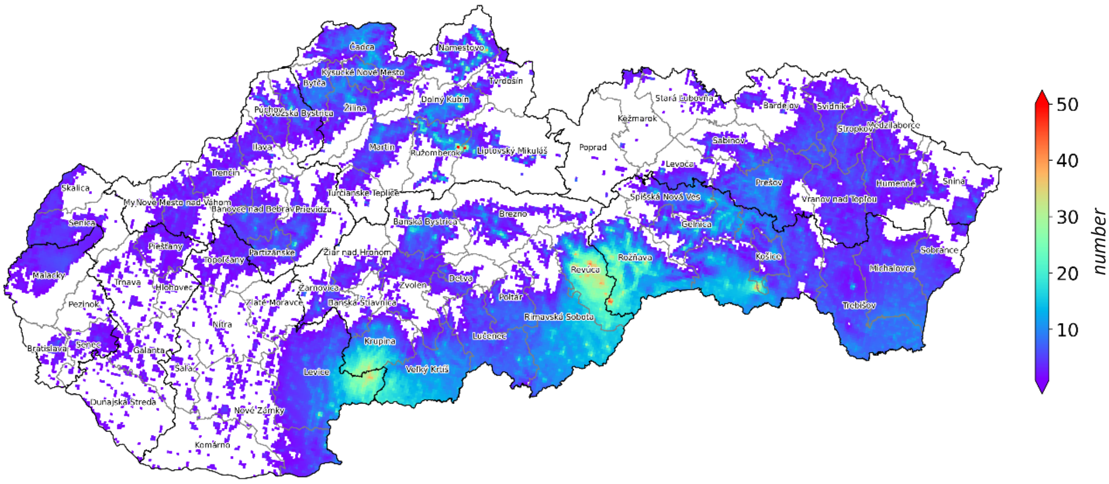


Fig. 4.2 *Number of days exceeding the limit value for the 24-hour PM_{10} concentration (50 $\mu g \cdot m^{-3}$) in 2023. Only areas with a non-zero number of exceedances are shown.*



■ **$PM_{2.5}$**

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[19].

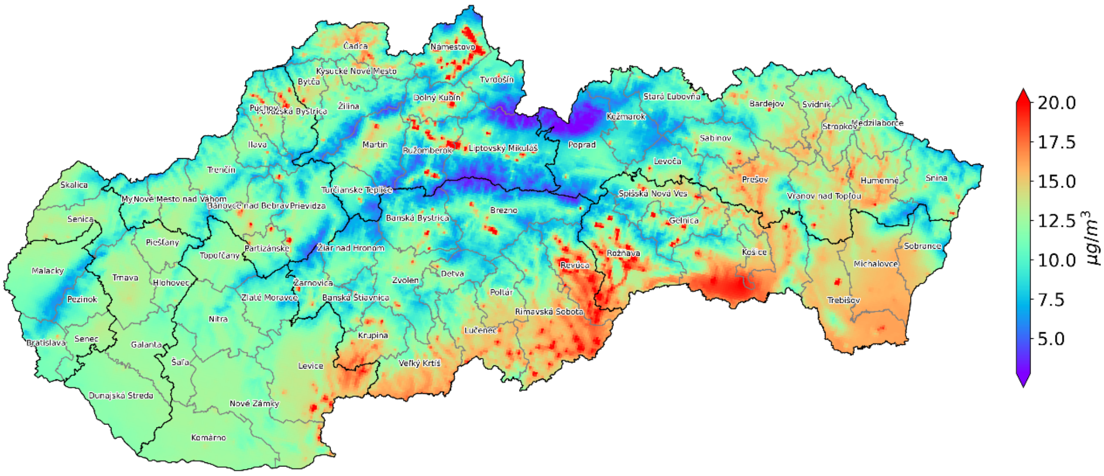
The spatial distribution of $PM_{2.5}$ concentrations in Slovakia was calculated by the RIO model, while the outputs from the AtmoStreet model (12.1%), ventilation index (21%) and altitude (66.7%) were used as additional spatial data.

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 = 0.0 $\mu g \cdot m^{-3}$ when compared with the measurements. The resulting annual mean concentrations of $PM_{2.5}$ are shown in **Fig. 4.3**.

In 2023, 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. Similarly to PM_{10}, the highest $PM_{2.5}$ concentrations, are in locations with a high share of solid fuels used for local heating, in closed mountain valleys.

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

Fig. 4.3 *Annual mean concentration $PM_{2.5}$ [$\mu g \cdot m^{-3}$] in the year 2023.*

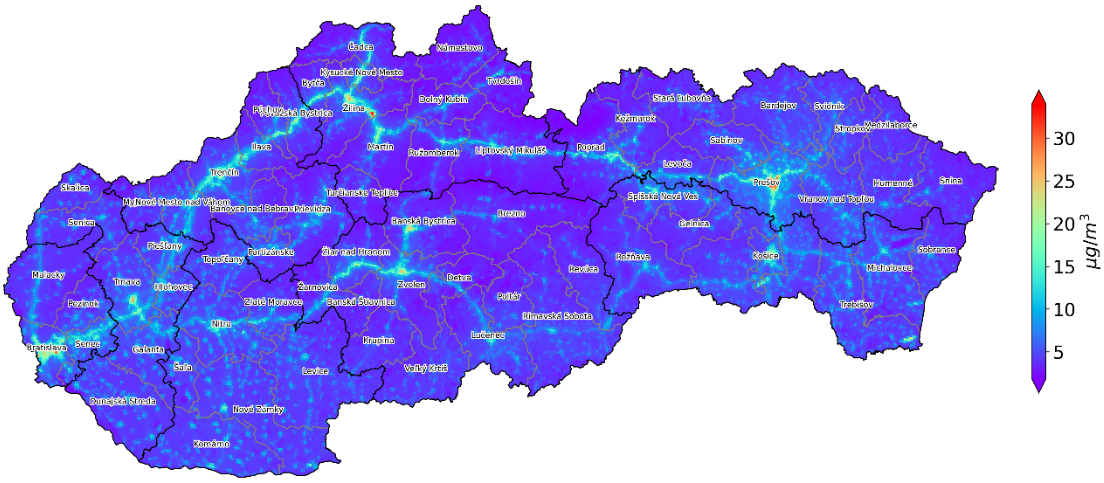


NO₂

Although the contribution of 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 (47%), altitude (8%) and land use[20] (44%). After subsequent modification of the model by the IDW-R method and comparison with measurements, we get RMSE = 1.8 $\mu g \cdot m^{-3}$ and BIAS = 0.0 $\mu g \cdot m^{-3}$. 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 2023. 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 2023.*



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[20] *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 (18.3%), altitude (51.7%), ventilation index (30%) 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 = 0.4 $\mu g \cdot m^{-3}$ and BIAS = 0 $\mu g \cdot m^{-3}$. 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 2021 – 2023 (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 2021 – 2023 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 2019 – 2023 (according to Decree of MoE SR No. 250/2023 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 2023.*

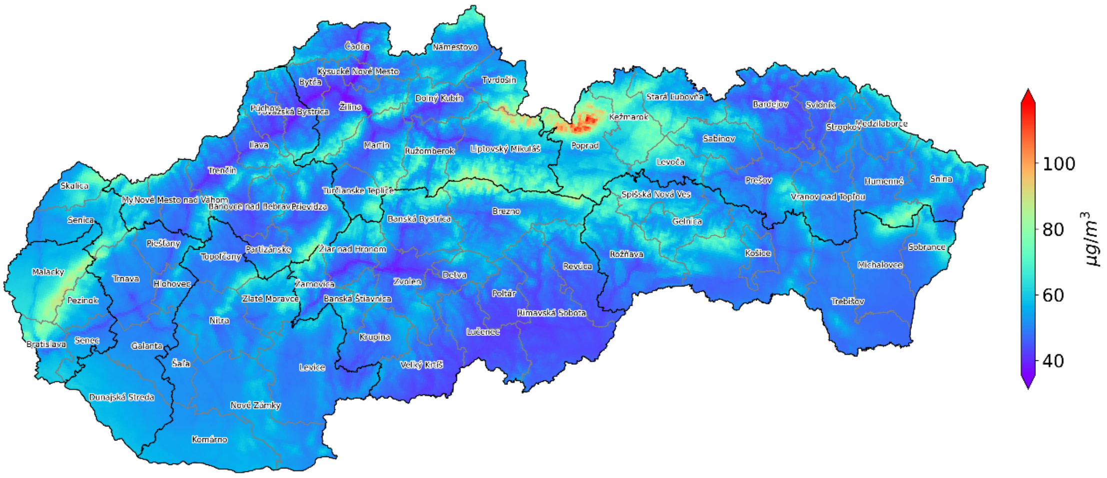


Fig. 4.6 *Number of days, in which eight-hour mean concentration of surface ozone exceeded value 120 $\mu g \cdot m^{-3}$ (mean during years 2021 – 2023).*

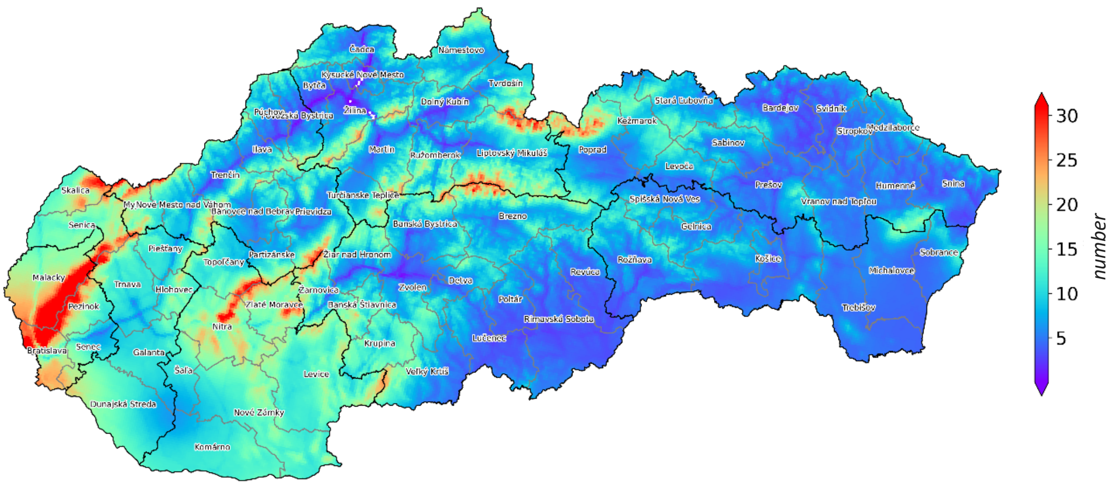
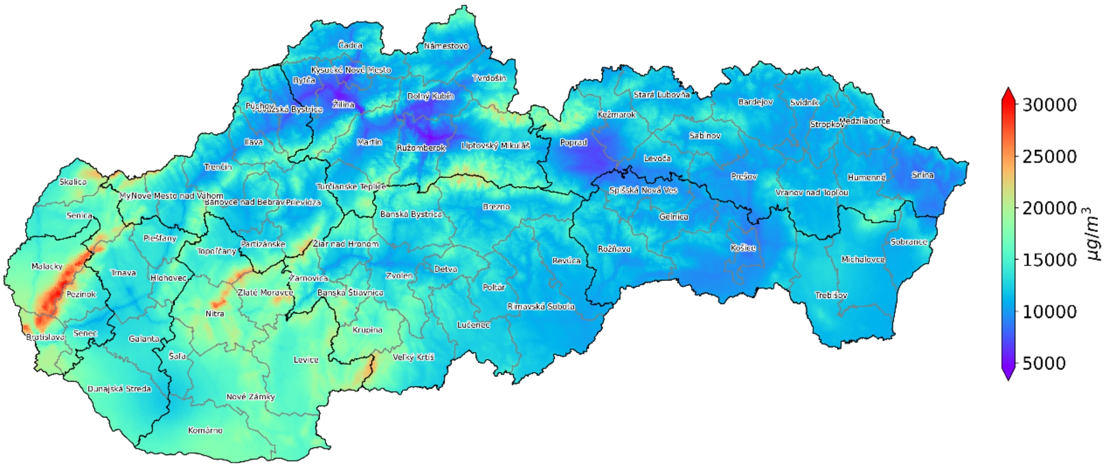


Fig. 4.7 Mean values of AOT40 during period of five years (2019 – 2023).



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 2023, 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 decomposed 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 characterise 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. 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), and Slovenské elektrárne, a. s. (Nováky power plant, closure in December 2023). SO_2 emissions have decreased significantly compared to the past. For example, the contribution of Slovalco, a. s. (Žiar nad Hronom), a significant producer of SO_2 emissions in the past, is negligible due to the curtailment of production.

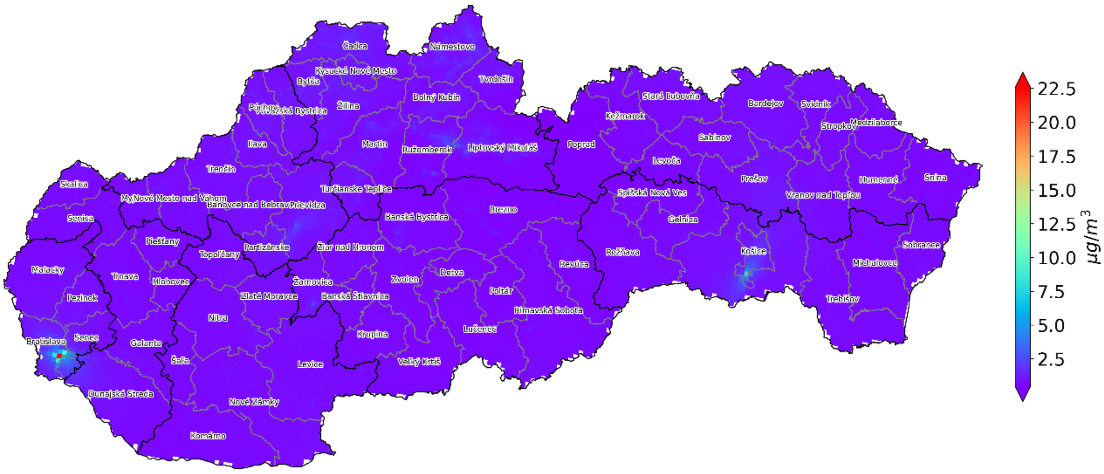
Furthermore, SO_2 emissions from local heating and emissions from road transport (which in the case of SO_2 represent less than 1% of total emissions) were also included in the simulation. Outside the Slovak Republic, emissions from the TNO-MAC III[21] database were used. Another necessary characteristic is changes in emissions during the year, which were determined based on the nature and type of source (year-round operation, seasonal operation, energy, local heating, etc.). However, in the case of large

[21] *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*

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.

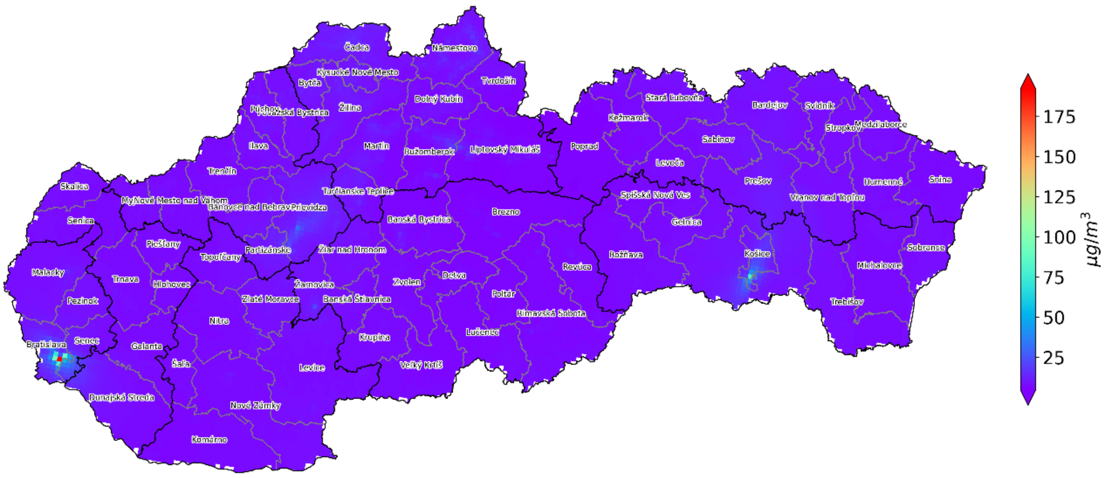
Measured annual mean concentrations of SO_2 have been low in recent years It seems, that at such low values the level of sensitivity of measured instruments (analysers) SO_2 was reached, therefore in case of annual mean concentrations of SO_2 the model is not calibrated with values of measured concentrations. 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 exposure of significant point sources.

Fig. 4.8 *Annual mean concentrations of SO_2 [$\mu g \cdot m^{-3}$] in the year 2023.*



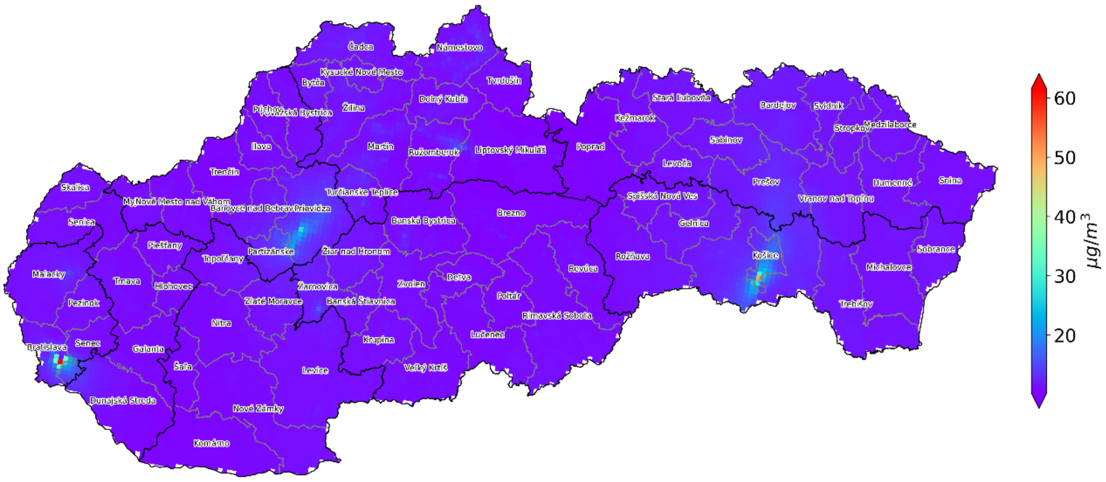
Hourly mean SO_2 concentrations should not exceed 350 $\mu g \cdot m^{-3}$ more than 24 times in a calendar year. Therefore, the 99.7 percentile of the hourly values is calculated (this percentile corresponds roughly to the 25th highest hourly concentration). Interestingly, in the case of the 99.7 hourly 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 = 6.1 $\mu g \cdot m^{-3}$ and BIAS = –0.3 $\mu g \cdot m^{-3}$). 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 2023.*



The daily mean SO_2 concentration should not exceed 125 $\mu g \cdot m^{-3}$ 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 $\mu g \cdot m^{-3}$ and BIAS = 2.84 $\mu g \cdot m^{-3}$). 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 2023.*



■ CO

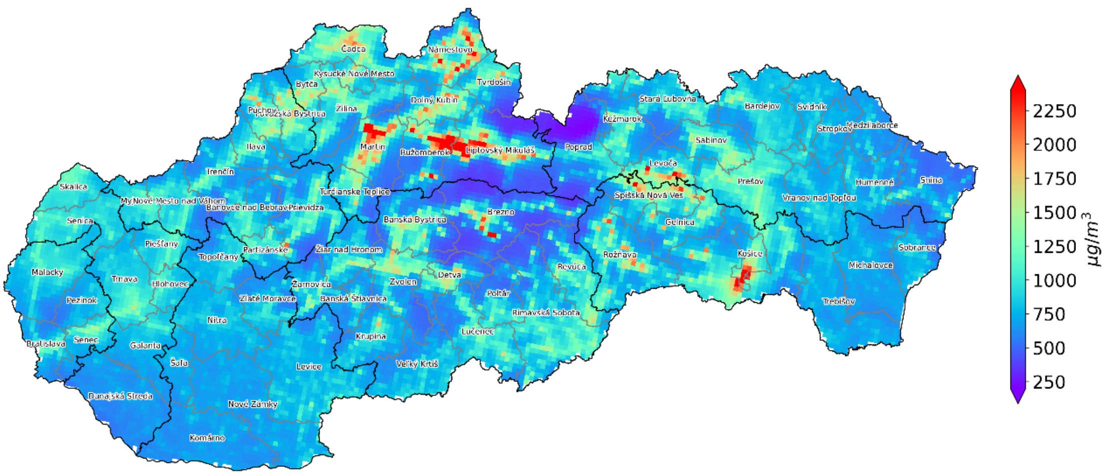
The spatial distribution of CO concentrations in Slovakia was calculated by the CMAQ model, using meteorological data from the ALADIN model.

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 agricuture (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 2023 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 = 138 µg·m^{-3} a BIAS = –40 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.

This pollutant is not a concern in terms of exceeding the limit value for the protection of human health.

Fig. 4.11 *Maximum daily 8-hour moving concentrations of CO [µg·m^{-3}] in year 2023.*

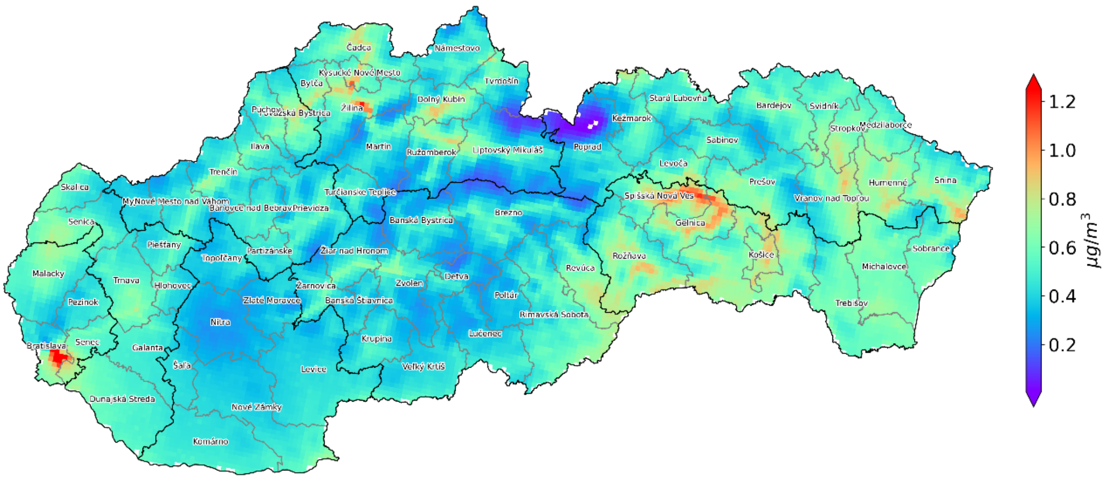


■ **Benzene**

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[22] database were used. Annual mean concentrations of benzene in year 2023 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 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 2023.*



■ **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 household heating in total benzo(a)pyrene emissions is close to 70%, while in 2017 (when there was a January with subnormal temperature[23]), for example, the share was more than 80%[24]. 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 2023, the highest annual mean concentration of benzo(a)pyrene among monitoring stations in Slovakia was recorded here again, namely 4.9 ng·m^{-3}. Note that this station is in a village, where local heating 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 2023 at this station was 3.4 ng·m^{-3}, with a target value of 1 ng·m^{-3}.

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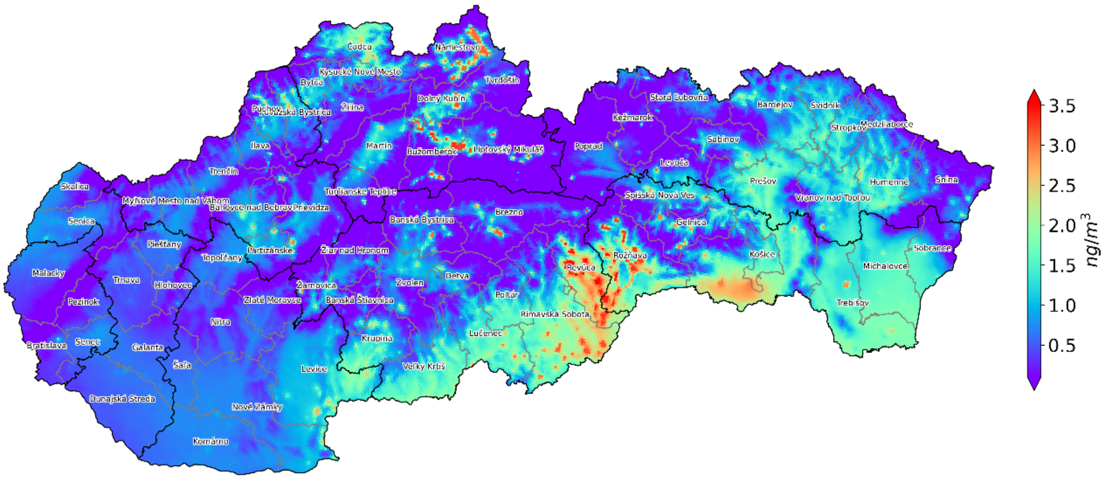
[22] *Kuenen, J.J.P., Visschedijk, A.J.H., Jozwicka, M., Denier van der Gon, H.A.C., 2014. TNOMACC_ II emission inventory; a multi-year (2003-2009) consistent high-resolution European emission inventory for air quality modelling. Atmos. Chem. Phys. 14, 10963–10976. https://doi.org/10.5194/acp-14-10963-2014*

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

[24] *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*

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[25]. 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 = 0.1 ng·m^{-3} and BIAS = –0.01 ng·m^{-3}. The target value 1 ng·m^{-3} for the annual mean concentration of benzo(a)pyrene 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 over-estimate benzo(a)pyrene concentrations particularly around Košice and the East Slovak 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 2023.*



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 × 1 km area (or 2 × 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 × 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.

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

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 a*ir 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 Slovakia in 2023, especially during the colder part of the year (October – March), with solid fuel household heating 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 areas mentioned above.

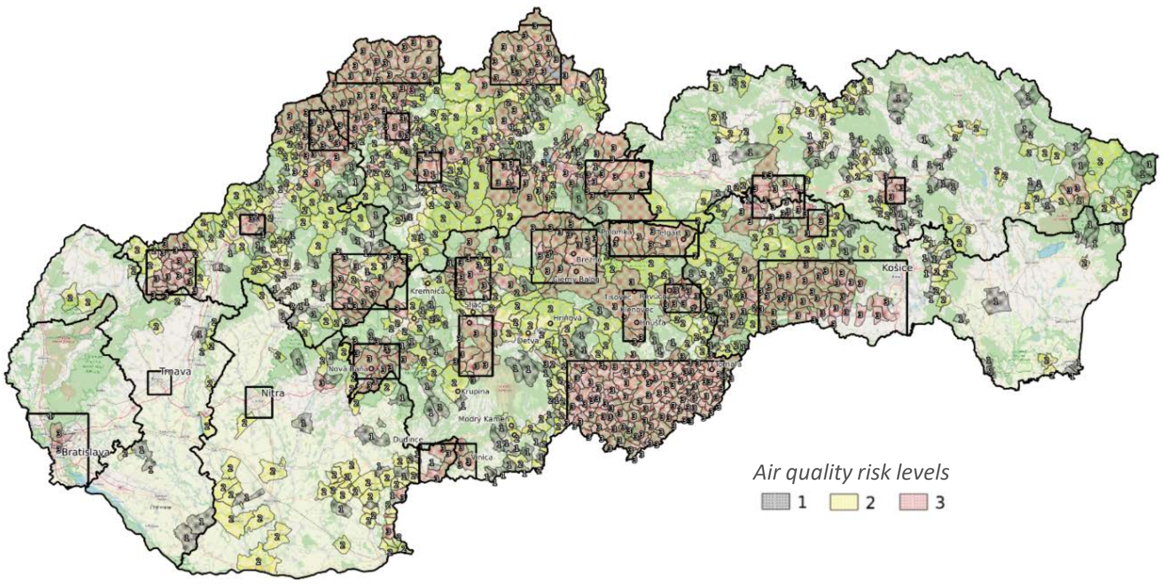
5 AIR QUALITY ASSESSMENT – CONCLUSION

5.1 PROPOSAL FOR THE DEFINITION OF AIR QUALITY MANAGEMENT AREAS IN 2024

Based on the assessment of air quality in zones and agglomerations in 2021 – 2023, the SHMÚ's task is to, according to §8 par. 3 of Act No. 146/2023 Coll. on air protection, as amended, to propose an update of the definition of the a*ir quality management areas* (ORKO) of the Slovak Republic for 2024. 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*, 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*[26], was proposed in 2021 and updated in 2022[27] based on the results of the 2021 Population and Housing Census.

In 2023, a further update of the methodology was made[28] based on the results of high-resolution CALPUFF modelling in selected domains with the assumption of degraded air quality (**Fig. 5.1**).

Fig. 5.1 *Risk municipalities identified by the integrated assessment method for 2024. Selected domains for high-resolution modelling are labelled in black.*



[26] Nemček V., Krajčovičová J., Štefánik, D. 2020, Stanovenie rizikových oblastí kvality ovzdušia ohrozených časticami PM10 z lokálneho vykurovania na Slovensku, Meteorologický časopis, Ročník 23, číslo 1, ISSN 1335-339X, dostupné: http://www.shmu.sk/sk/?page=31, posledný prístup 14.6.24.

[27] 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

[28] Štefánik, D., Krajčovičová, J.: Metóda integrovaného posúdenia obcí vzhľadom na riziko nepriaznivej kvality ovzdušia, Slovenský hydrometeorologický ústav, 2023. https://www.shmu.sk/File/oko/studie_analyzy/Metodika_final_v2ab.pdf

Risk levels from 0 to 3 are assigned to municipalities based on the above-mentioned methodology with risk level 3 indicating the greatest risk of deteriorating air quality. Municipalities, where 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. Zones and agglomerations, with at least one municipality at risk level 3, are required to prepare Air Quality Improvement Plan. Based on this, municipalities at risk level 3 correspond to a*ir quality management areas*. However, in these zones and agglomerations, emission reduction measures must be implemented in all municipalities with a risk level of 2 or 3, ideally also in municipalities with a risk level of 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 refined, either nationwide 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 2023, concentrations of the monitored pollutants decreased on average compared to previous years, probably due to a not very intense heating season and unusually high precipitation totals. Compared to 2022, dust transport episodes from dry areas were also less pronounced in 2023.

As in previous years, there were persistent problems with PM_{10} limit value exceedances and high levels of benzo(a)pyrene.

The highest concentrations of PM and other pollutants were measured at most stations during February. The exceptions were Jelšava and Plášťovce, where most PM_{10} exceedances occurred during December.

The situation in February was interesting – due to the influence of a large and massive anticyclone, which moved from the area over Britain over western, central and eastern Europe over Ukraine and Romania in the period from approximately 6 February to 10 February 2023, unfavourable dispersion conditions in combination with low air temperatures (e.g. in Liptovský Mikuláš, a minimum temperature of –22.3 °C was recorded on 7 February 2023). This period was therefore also characterised by increased household heating demand. On 10 February 2023, at 34 monitoring stations, the average daily PM_{10} concentration exceeded 50 $\mu g \cdot m^{-3}$, with 3 stations exceeding this value twice (Martin; Ružomberok; Banská Bystrica, Štefánikovo nábrežie). After the passage of the occlusion front, our territory was under the influence of a pressure high with unfavourable dispersion conditions in the period from approximately 11 February to 18 February 2023, and although the temperature had already risen, 29 stations still recorded PM_{10} exceedances on 11 February 2023. In the last decade of February, we were again under the influence of a pressure high, but only 2 stations recorded PM_{10} exceedances (the urban background station in Jelšava and the traffic station in Banská Bystrica).

The limit value for the average daily concentration of PM_{10} was exceeded at the monitoring stations Jelšava, Jesenského and Veľká Ida, Letná.

The target value for benzo(a)pyrene was exceeded at 10 monitoring stations: Veľká Ida, Letná; Jelšava, Jesenského; Oščadnica; Plášťovce; Krompachy, SNP; Ružomberok, Riadok; Púchov, 1. mája; Prievidza, Malonecpalská; Žilina, Obežná and Banská Bystrica, Štefánikovo nábrežie. The highest daily values were recorded in December in Jelšava and Oščadnica (21 $ng \cdot m^{-3}$ each) and in August in Veľká Ida (36 $ng \cdot m^{-3}$).

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.

Household heating with solid fuels remains the most notable air pollution problem in Slovakia, especially when using older heating equipment. The situation is worse in localities with non-penetrating dispersion conditions in mountain valleys, with the use of higher emitting heating appliances reflecting the social composition of the population. The economic crisis is in fact complicating the situation as people return to fuelwood heating.

LIST OF ANNEXES