2024

AIR POLLUTION IN THE SLOVAK REPUBLIC

Emissions and Air Quality Division

SLOVAK HYDROMETEOROLOGICAL INSTITUTE

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CONTENT

FOREWORD

Every day reminds us that the air we breathe is the most vulnerable environment to which we are constantly exposed. Air pollution is one of the most serious environmental risks to human health and is a major environmental factor in premature deaths. According to data from the World Health Organization, long-term exposure to air pollution is responsible for millions of premature deaths worldwide each year. Air pollution threatens not only people with compromised immune systems, but also the healthy population, children, seniors, and people with chronic respiratory and cardiovascular diseases.

Air quality in 2024 was negatively affected by several adverse phenomena. In the spring, there was a significant episode of Saharan dust, which caused a marked increase in PM_{10} concentrations during several days in March and April, well above the long-term average. Although the dust was of natural origin, many people experienced respiratory irritation or worsening of chronic conditions.

The summer months brought a prolonged period of anticyclonic weather with above-average temperatures, minimal precipitation, and weak winds. These conditions promoted the accumulation of secondary aerosol particles in the atmosphere. Combined with global warming and prolonged periods of drought, this led to insufficient removal of pollutants from the air. At the same time, high temperatures stimulated emissions of biogenic volatile organic compounds from vegetation, which, after oxidation in the air, contributed to the formation of secondary organic compounds. Particulate matter of biogenic origin thus posed a significant risk, especially for people suffering from allergies.

Autumn was characterized by frequent temperature inversions, during which pollutants accumulated in the lower layers of the atmosphere. PM_{10} concentrations at several monitoring stations exceeded information thresholds. During this period, regions in western Slovakia, which otherwise usually benefit from more favorable dispersion conditions, were also significantly affected.

The Slovak Hydrometeorological Institute (SHMÚ) operates 52 automated stations in the National Air Quality Monitoring Network, providing continuous time-series and spatially resolved measurements of air pollutants across Slovakia. Numerical air-quality modelling on a high-performance computing system complements the network by filling observational gaps and supporting the interpretation of monitoring results.

This year's Report on Air Quality in the Slovak Republic summarizes the results of measurements and modeling, assesses risk areas and periods, and provides proposals for defining air quality management areas for 2025. It shows that although long-term trends in some areas are favorable, individual episodes and meteorological fluctuations can quickly change the overall picture. It reminds us that air quality is dynamic and vulnerable—and that protecting it requires constant attention and cooperation from all stakeholders.

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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 on several conditions:

- the quantity of emissions
- spatial distribution of air pollution sources
- meteorological conditions
- 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 NO2, 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.

Well-ventilated areas may have lower concentrations of pollutants, despite the presence of nearby sources of air pollution.

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 2024

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 2024 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.

Agglomerations:

- Agglomeration Bratislava – territory of the capital city of the Slovak Republic, Bratislava),
- Agglomeration Košice – territory of the Košice city and municipalities Bočiar, Haniska, Sokoľany and Veľká Ida).

Zones:

- Banská Bystrica region (Banskobystrický kraj),
- Bratislava region (Bratislavský kraj)[1],
- Košice region (Košický kraj)[2],
- Nitra region (Nitriansky kraj),
- Prešov region (Prešovský kraj),
- Trenčín region (Trenčiansky kraj),
- Trnava region (Trnavský kraj)
- Žilina region (Žilinský kraj)

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 individual Slovak regions (NUTS 3)*

	Area [km^2]	**Population***
Bratislava region (Bratislavský kraj)	2 053	736 385
Trnava region (Trnavský kraj)	4 146	565 900
Trenčín region (Trenčiansky kraj)	4 502	565 572
Nitra region (Nitriansky kraj)	6 344	665 600
Žilina region (Žilinský kraj)	6 809	686 063
Banská Bystrica region (Banskobystrický kraj)	9 454	611 124
Prešov region (Prešovský kraj)	8 973	810 008
Košice region (Košický kraj)	6 754	778 799

**As of 31. 12. 2024*
Source: Statistical Office of the SR

1.1.2 Country breakdown into zones and agglomerations in 2024 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 neighboring 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[3]. **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] *does not include the territory of Bratislava*
[2] *does not include the territory of the Košice agglomeration*
[3] *EMEP Status Report 1/2024, Transboundary particulate matter, photo-oxidants, acidifying and eutrophying components https://emep.int/publ/reports/2024/EMEP_Status_Report_1_2024.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 SO2 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/2022/5422) 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 19913. 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 2024 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 – 2024".

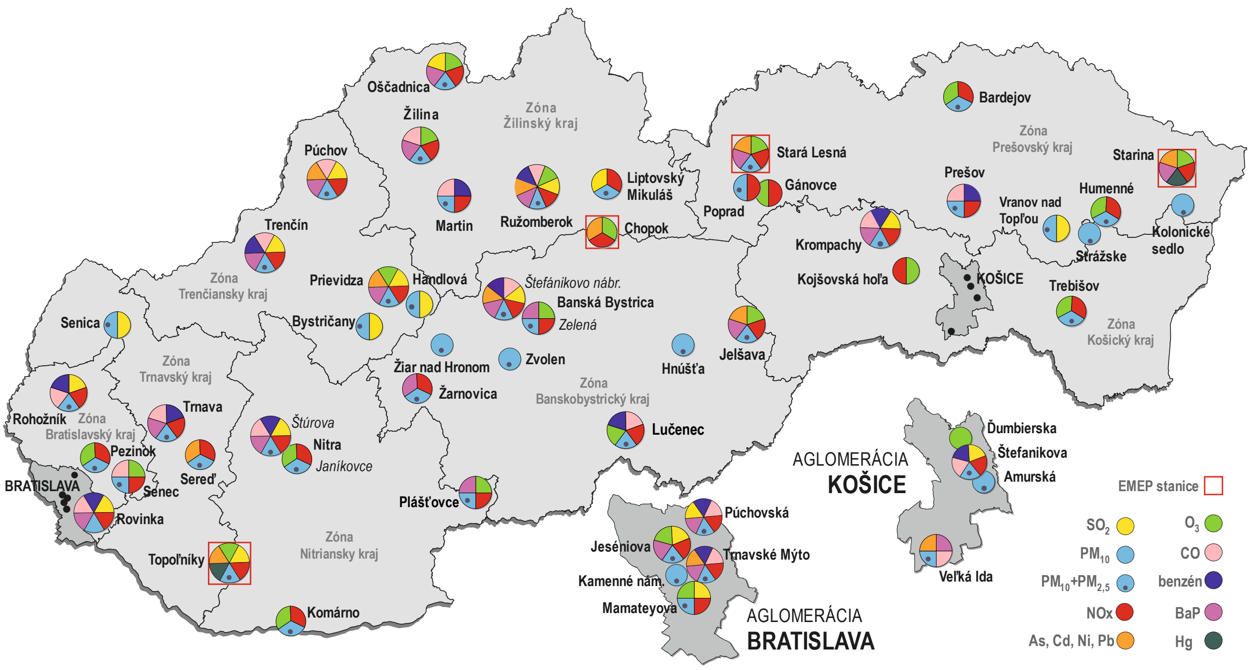
In 1979, the UNECE Convention on Long-range Transboundary Air Pollution (hereinafter the Convention) was signed in Geneva. Eight protocols have been signed under the Convention so far. The first of these is the Protocol on the Long-term Financing of the Cooperative Programme for Monitoring and Evaluation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

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.

Pollutants can persist in the air for several days, depending on various properties, such as sedimentation rate and chemical reactivity. Due to the influence of air flow, these substances can be transported over considerable distances, which is referred to as long-range transport. As a result, even seemingly clean mountain areas can be affected by high concentrations of pollutants.

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 2024.*



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,	Sulphur dioxide SO_2	Ozone O_3	Oxid uhoľnatý CO	Benzene	Mercury Hg	Heavy metals As, Cd, Ni, Pb	Polyaromatic hydrocarbons
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	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**
Trenčín region	Prievidza, Malonecpalská	U	B	x	x	x	x	x				x	x
	Bystričany, Rozvodňa SSE	S	B	x	x		x						
	Handlová, Morovnianska cesta	U	B	x	x		x						
	Trenčín, Hasičská	U	T	x	x	x	x		x	x			
	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**

AGGLOMERATION / Zone	Station	Type of area	Type of station	Continuously PM$_{10}$	PM$_{2.5}$	Oxides of nitrogen NO, ...	Sulphur dioxide SO$_2$	Ozone O$_3$	Oxid uhoľnatý CO	Benzene	Mercury Hg	Manually Heavy metals As, Cd, Ni, Pb	Polyaromatic hydrocarbons ...
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			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	4
NMSKO O altogether 53 monitoring stations [4]				48	47	40	20	24	18	14	2	12	21

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

The air quality monitoring programme at EMEP stations in 2024 is shown in **Tab. 2.2**. The sampling intervals are as follows:

- Ozone: measured by a continuous analyzer,
- heavy metals: every three days in Topoľníky and Stará Lesná, weekly in Starina and Chopok,
- VOC: weekly sampling interval,
- Other pollutants: 24-hour sampling interval

Tab. 2.2 *EMEP station monitoring programme – air.*

	Ozón O$_3$	Oxid siričitý SO$_2$	Oxidy dusíka NO$_X$	Sírany SO$_4^{2-}$	Dusičnany NO$_3^-$	Kyselina dusičná HNO$_3$	Chloridy Cl	Amoniak, amónne ióny NH$_3$, NH$_4^+$	Alkalické ióny K$^+$, Na$^+$, Ca^{2+},	VOC	PM$_{10}$ / TSP*	EC/OC	Lead Pb	Arsenic As	Cadmium Cd	Nickel Ni	Chromium Cr	Copper 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*

Precipitation quality (pH, conductivity, sulfates, nitrates, chlorides, ammonium ions and alkali metal cations) is analysed from samples taken at EMEP stations according to the monitoring programme listed in **Tab. 2.2.**

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

[4] *52 stationary stations and one mobile station in Rovinka*

deposition. This type of sampling is carried out at Chopok, where, due to inclement weather, opencontainer sampling of precipitation is done.

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

	pH	Conductivity	Sulfates (SO_4^{2-})	Nitrates (NO_3^-)	Chlorides (Cl^-)	Ammonium ions (NH_4^+)	Alkaline ions (K^+, Na^+, Ca^{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[5] 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 and 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 39 monitoring stations. The required number of valid measurements was not met at AMS Rovinka, AMS Martin, Jesenského.

- **Particulate matter PM_{10}**

This pollutant was monitored at 48 stations. The minimum required monitoring coverage[6] was met. The required number of valid measured data (90%) was achieved at all 48 monitoring stations.

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

$PM_{2.5}$ were monitored at 47 stations. The minimum required monitoring coverage[6] was met. $PM_{2.5}$ monitoring was ensured by the same method as PM_{10} measurements, with TEOM instruments. The required number of valid measured data (90%) was achieved at all monitoring stations.

- **Carbon monoxide CO**

This pollutant was monitored at 18 monitoring stations. The minimum required monitoring scope[6] was met. Carbon monoxide monitoring was ensured continuously, using the reference method at 18 stations. The required number of valid measured data (90%) was achieved at 16 monitoring stations. The required number of valid measurements was not met at AMS Trnava and AMS Ružomberok. CO concentrations are below the lower limit for assessment, so the number of monitoring sites is sufficient.

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

- **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% with 35% time coverage) was achieved by all monitoring stations.

- **Mercury Hg**

  Total gaseous mercury was monitored at two EMEP stations (Topoľníky and Starina). The proportion of valid measured data did not exceed 90% at any monitoring station. Despite the outage, the measurement can be considered representative for the entire year, 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 2024, 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 2024, monitoring of benzo(a)pyrene was mensured at 21 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 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
Bratislavský region	Senec	Rovinka (Slovnaft, a.s.)	S	B	17°13'34"	48°06'05"	133
Košický 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
Nitriansky region	Šaľa	Trnovec nad Váhom (Duslo, a.s.)	S	B	17°55'43"	48°08'60"	117
Trenčiansky region	Prievidza	Oslany (Slovenské elektrárne, a.s.)	S	B	18°28´12"	48°37´60"	228
Žilinský 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

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.

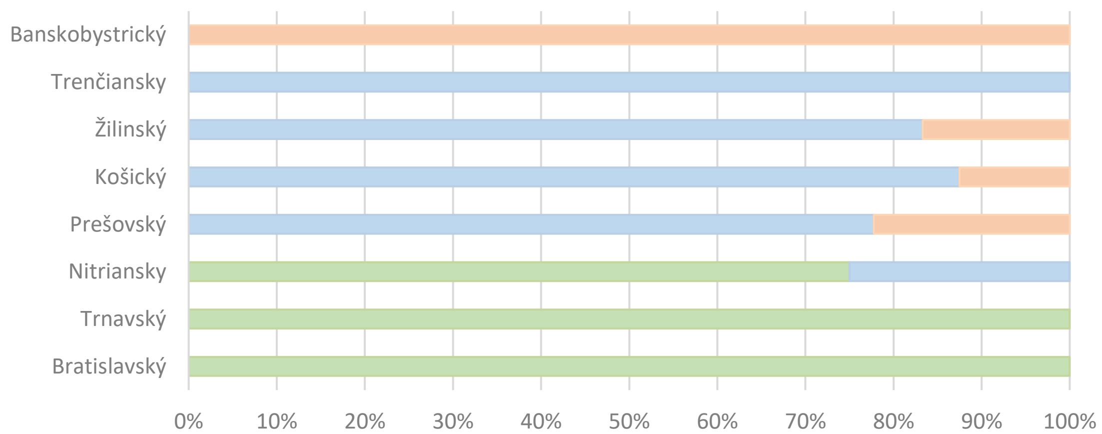
Chapter 3.4 treats the results of measurements of monitoring stations with the EMEP monitoring programme according to limit values for the protection of vegetation. The EMEP programme also includes an analysis of atmospheric precipitation quality.

3.1.1 *Meteorological conditions – ventilation index*

In addition to emission sources, air quality is also influenced by meteorological conditions, such as dispersion conditions and precipitation. One way to quantify dispersion conditions is through the ventilation index, defined as the product of the mixing height and the average wind speed within the mixing layer. The mixing layer is the part of the atmosphere in contact with the Earth's surface, where mechanical and thermal mixing of air occurs. The more intense the turbulence, the higher the mixing layer. A higher ventilation index indicates better dispersion conditions.

Ventilation index values at locations with monitoring stations in different regions were calculated using outputs from the ALADIN meteorological model, which has a spatial resolution of 2 × 2 km. These values vary over time (daily and seasonally) and across space (e.g., due to orography). On average, the lowest values—and therefore the poorest dispersion conditions—are observed at monitoring stations in the Banská Bystrica region (see Fig. 3.1).

Fig. 3.1 *Dispersion conditions based on the average relative value of the ventilation index in regions for 2024*



green – good dispersion conditions; blue – partially deteriorated, red - deteriorated

3.2 AIR QUALITY ASSESSMENT 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.[6]

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[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	1h	350	(24)				
SO_2	Human health	24h	125	(3)	75	(3)	50	(3)
SO_2	Vegetation	1y, winter season	20	(-)	12	(-)	8	(-)
NO_2	Human health	1h	200	(18)	140	(18)	100	(18)
NO_2	Human health	1r	40	(-)	32	(-)	26	(-)
NO_X	Vegetation	1r	30	(-)	24	(-)	19,5	(-)
PM_{10}	Human health	24h	50	(35)	35	(35)	25	(35)
PM_{10}	Human health	1r	40	(-)	28	(-)	20	(-)
Pb	Human health	1r	0,5	(-)	0,35	(-)	0,25	(-)
CO	Human health	8h (maximum)	10 000	(-)	7 000	(-)	5 000	(-)
Benzén	Human health	1r	5	(-)	3,5	(-)	2	(-)
$PM_{2,5}$	Human health	1r	20**		17		12	

* *permitted number of exceedances is listed in brackets*

** *limit value for $PM_{2,5}$ until 1.1.2020: 25 $\mu g \cdot m^{-3}$, limit value for $PM_{2.5}$ since 1.1.2020: 20 $\mu g \cdot m^{-3}$*

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

	Assessment thresholds [ng·m⁻³] Upper	Lower	Averaging period	Target value [ng·m⁻³]
As	3,6	2,4	1r	6
Cd	3	2	1r	5
Ni	14	10	1r	20
BaP	0,4	0,6	1r	1

[6] *Limit value (§3 paragraph 5 of the Air Protection Act)*
Target value (§3 paragraph 8 of the Air Protection Act)
Warning threshold (§3 paragraph 15 of the Air Protection Act)
Critical level for the purposes of air quality assessment (pursuant to §3 paragraph 7 of the Air Protection Act)
The air quality assessment regime is determined on the basis of the level of air pollution. Agglomerations and zones are included in the air quality assessment regime according to criteria expressed as limits for the assessment of the level of air pollution separately established by the implementing regulation pursuant to § 62 letter b) for the protection of health, vegetation and natural ecosystems.
Upper limit (pursuant to §4 paragraph 6 letter a) of the Air Protection Act
Lower limit (pursuant to §4 paragraph 6 letter b) of the Air Protection Act

[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 interval	Limit/target value according to Slovak legislation (250/2023[a])		EU Limit/target value, to be achieved by 1. januára 2030[b]		WHO recommendations (y. 2021)[c]	
		Concentration	shall not exceed per year more than	Concentration	shall not exceed per year more than	Concentration [μg·m⁻³]	shall not exceed per year more than
$PM_{2,5}$	24 hours	-	-	**25** μg·m⁻³	(18)	15 μg·m⁻³	(3 – 4)
	calendar year	20 μg·m⁻³	-	**10** μg·m⁻³	-	5 μg·m⁻³	-
PM_{10}	24 hours	50 μg·m⁻³	(35)	**45** μg·m⁻³	(18)	45 μg·m⁻³	(3 – 4)
	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)*	120 μg·m⁻³	(18)*	100 μg·m⁻³	(3 – 4)
NO_2	1 hours	200 μg·m⁻³	(18)	200 μg·m⁻³	(**3**)	-	-
	24 hours	-	-	**50** μg·m⁻³	(18)	25 μg·m⁻³	(3 – 4)
	calendar year	40 μg·m⁻³	-	**20** μg·m⁻³	-	10 μg·m⁻³	
SO_2	1 hours	350 μg·m⁻³	(24)	350 μg·m⁻³	(**3**)	-	-
	24 hours	125 μg·m⁻³	(3)	**50** μg·m⁻³	(18)	40 μg·m⁻³	(3 – 4)
	calendar year	-	-	**20** μg·m⁻³	-	-	-
CO	the highest daily 8-hour mean value	10 mg·m⁻³	-	10 mg/m³	-	-	-
	24 hours	-	-	**4 mg·m⁻³**	**(18)**	4 mg·m⁻³	(3 – 4)

[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.

Tab. 3.4 Percentage of valid data in 2024.

AGGLOMERATION / Zone	Station	SO_2	NO_2	PM_{10}	$PM_{2,5}$	CO	Benzene	O_3
BRATISLAVA	Bratislava, Kamenné nám.			97	97			
	Bratislava, Trnavské Mýto		97	99	99	95	88	
	Bratislava, Jeséniova	91	90	92	92			90
	Bratislava, Mamateyova	95	95	96	97			94
	Bratislava, Púchovská	96	94	99	99	96	71	
Bratislava region	Rohožník, Senická cesta	96	96	99	99	95	78	
	Rovinka, mobil AMS	90	92	96		91	73	
	Senec, Boldocká		96	99	99	96		99
	Kojšovská hoľa		95	98				96
Trnava region	Senica, Hviezdoslavova	92		97	96			
	Trnava, Kollárova		91	98	98	65	73	
	Topoľníky, Aszód, EMEP	95	93	97	97			95
	Sereď, Vinárska		96	99	99			
Nitra region	Nitra, Janíkovce		95	97	98			90
	Nitra, Štúrova	94	95	98	93	96	72	
	Komárno, Vnútorná Okružná		96	98	98			97
	Plášťovce		96	99	99			99
Trenčín region	Prievidza, Malonecpalská	82	96	100	100			96
	Bystričany, Rozvodňa SSE	84		98	98			
	Handlová, Morovnianska cesta	96		98	99			
	Púchov, 1.mája	96	96	98	99	96		
	Trenčín, Hasičská	96	97	98	98	96	85	
Banská Bystrica region	Banská Bystrica, Štefánikovo nábr.	94	97	99	99	94	90	
	Banská Bystrica, Zelená		97	99	100			95
	Jelšava, Jesenského		95	99	98			96
	Hnúšťa, Hlavná			99	98			
	Lučenec, Gemerská cesta		93	96	95	94	86	95
	Zvolen, J. Alexyho			99	98			
	Žarnovica		96	99	99			
	Žiar nad Hronom, Jilemnického			99	98			
Žilina region	Chopok, EMEP		99					95
	Liptovský Mikuláš, Školská	96	96	100	100			
	Martin, Jesenského		67	99	99	96	96	
	Oščadnica	97	96	99	99			98
	Ružomberok, Riadok	95	96	99	99	83	91	95
	Žilina, Obežná		96	97	98	95		94
Prešov region	Gánovce, Meteo. st.		96	99				95
	Humenné, Nám. slobody		96	99	99			95
	Prešov, arm. gen. L. Svobodu		96	99	99	96	97	
	Vranov nad Top., M.R.Štefánika	96		99	99			
	Stará Lesná, AÚ SAV, EMEP		96	99	99			98
	Starina, Vodná nádrž, EMEP		96					96
	Kolonické sedlo			99	99			
	Poprad, Železničná		96	99	99			
	Bardejov, Pod Vinbargom		97	99	99			100
KOŠICE	Košice, Štefánikova	94	97	99	99	94	90	
	Košice, Amurská			99	99			
	Košice, Ďumbierska							99
	Veľká Ida, Letná			99	99	96		
Košice region	Kojšovská hoľa		95	98				96

AGGLOMERATION / Zone	Station	SO_2	NO_2	PM_{10}	$PM_{2,5}$	CO	Benzene	O_3
	Trebišov, T. G. Masaryka		97	99	99			99
	Strážske, Mierová			100	100			
	Krompachy, SNP	95	96	99	99	96	97	

≥ 90 % of valid measurements

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 stations and pollutants in 2024 shows **Tab. 3.5**

Tab. 3.5 *Assessment of air pollution according to the limit values for health protection in 2024.*

AGGLOMERATION 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				
BRATISLAVA	Bratislava, Kamenné nám.					6	19	12		
	Bratislava, Trnavské mýto			0	28	12	22	13	1 146	0.3
	Bratislava, Jeséniova	0	0	0	6	7	18	12		
	Bratislava, Mamateyova	1	0	0	15	3	18	12		
	Bratislava, Púchovská	0	0	0	12	13	21	11	844	0.2
Bratislava region	Pezinok, Obrancov mieru			0	9	7	17	14		
	Rohožník, Senická cesta	0	0	0	11	7	21	11	1 687	0.4
	Rovinka	0	0	0	11	4	17		1 146	0.7
	Senec, Boldocká			0	18	8	20	12	1 200	
Trnava region	Senica, Hviezdoslavova	0	0			6	19	12		
	Trnava, Kollárova			0	24	6	21	13	2 331	0.3
	Topoľníky, Aszód, EMEP	0	0	0	4	7	17	12		
	Sereď, Vinárska			0	11	7	18	13		
Nitra region	Nitra, Janíkovce			0	9	6	18	15		
	Nitra, Štúrova	0	0	0	24	9	23	13	1 328	0.4
	Komárno, Vnútorná Okružná			0	12	11	20	14		
	Plášťovce			0	7	43	28	22		
Trenčín region	Prievidza, Malonecpalská	0	0	0	12	7	18	13		
	Bystričany, Rozvodňa SSE	0	0			7	18	12		
	Handlová, Morovnianska cesta	0	0			6	17	12		
	Púchov, 1. mája	0	0	0	9	12	21	17	1 353	
	Trenčín, Hasičská	0	0	0	20	15	22	13	2 319	0.5
Banská Bystrica region	Banská Bystrica, Štefánik. nábr.	0	0	0	23	22	26	15	1 360	0.2
	Banská Bystrica, Zelená			0	7	4	17	11		
	Jelšava, Jesenského			0	6	53	30	20		
	Hnúšťa, Hlavná					8	21	14		
	Lučenec, Gemerská cesta			0	13	22	25	17	1 423	0.2
	Zvolen, J. Alexyho					5	19	14		
	Žarnovica			0	11	24	24	20		
	Žiar n/H, Jilemnického					3	16	10		
Žilina region	Chopok, EMEP			0	1					
	Liptovský Mikuláš, Školská	0	0	0	11	9	19	13		
	Martin, Jesenského			0	16	16	22	15	1 486	0.3
	Oščadnica	0	0	0	6	12	20	16		
	Ružomberok, Riadok	0	0	0	15	16	21	15	1 916	0.3
	Žilina, Obežná			0	17	17	21	15	1 424	
Prešov region	Gánovce, Meteo. st.			0	6					

AGGLOMERATION Zone	Pollutant	SO_2		NO_2		PM_{10}		$PM_{2.5}$	CO	Benzene
		Protection of human health								
	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				
	Humenné, Nám. slobody			0	8	5	22	17		
	Prešov, Arm. gen. L. Svobodu			0	34	15	26	17	1 515	0.6
	Vranov n/T, M. R. Štefánika	0	0			3	20	15		
	Stará Lesná, AÚ SAV, EMEP			0	4	3	12	8		
	Starina, Vodná nádrž, EMEP			0	3					
	Kolonické sedlo, Hvezdáreň					2	15	11		
	Poprad, Železničná			0	11	3	17	11		
	Bardejov, Pod Vinbargom			0	10	1	18	13		
KOŠICE	Košice, Štefánikova	0	0	0	21	21	26	16	1 997	1.0
	Košice, Amurská					12	23	16		
	Veľká Ida, Letná					**46**	33	20	2 223	
Košice region	Kojšovská hoľa			0	2					
	Trebišov, T. G. Masaryka			0	11	10	22	15		
	Strážske, Mierová					3	21	15		
	Krompachy, SNP	0	0	0	12	13	23	18	1 505	0.9

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

1) maximum 8-h concentration

The limit value for the daily average PM_{10} concentration (the daily average PM_{10} concentration must not exceed 50 µg·m⁻³ more than 35 times per calendar year**) was exceeded** in 2024 at three monitoring stations – **Veľká Ida, Letná; Jelšava, Jesenského**; and **Plášťovce**. The highest number of exceedances was recorded in *January*, *November*, and *December*.

The limit value for the annual average **$PM_{2.5}$** concentration was exceeded in **Plášťovce**.

The limit values for SO_2, NO_2, CO, and benzene were not exceeded.

Tab. 3.6 Average annual concentrations of heavy metals (As, Cd, Ni a Pb) v r. 2024.

AGGLOMERATION Zone	Pollutant [ng·m⁻³] / Target/limit value* [ng·m⁻³]	As	Cd	Ni	Pb
		6,0	5	20	500*
BRATISLAVA	Bratislava, Trnavské mýto	0,2	0,1	1,2	4,2
Slovensko	Banská Bystrica, Štefánikovo nábrežie	0,2	0,2	0,7	5,5
	Jelšava, Jesenského	0,3	0,3	0,5	8,8
	Ružomberok, Riadok	0,2	0,2	0,8	3,3
	Veľká Ida, Letná	1,5	0,5	0,6	15,9
	Prievidza, Malonecpalská	0,1	0,1	1,7	2,7
	Sereď, Vinárska	0,2	0,1	0,5	13,0
	Púchov, 1. mája	0,2	0,2	1,1	3,1

Tab. 3.7 shows the annual average concentrations of benzo(a)pyrene (BaP) in the air based on measurements from 2018 to 2024.

Tab. 3.7 Annual mean concentrations of benzo(a)pyrene in 2018 – 2024.

AGGLOMERATION Zone			2018	2019	2020	2021	2022	2023	2024
	Target value	[$ng \cdot m^{-3}$]	1,0	1,0	1,0	1,0	1,0	1,0	1,0
	Horná medza na hodnotenie	[$ng \cdot m^{-3}$]	0,6	0,6	0,6	0,6	0,6	0,6	0,6
	Dolná medza na hodnotenie	[$ng \cdot m^{-3}$]	0,4	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	0,2
	Bratislava, Trnavské Mýto		0,9	0,4	0,5	0,5	0,5	0,3	0,5
	Bratislava, Púchovská					0,9	0,4	0,4	0,4
Bratislavský kraj	Rovinka				0,4	0,6	0,5	0,4	0,5
Trnavský kraj	Trnava, Kollárova		0,9	0,7	0,5	0,6	0,5	0,5	0,6
Nitriansky kraj	Nitra, Štúrova		0,9	0,8	0,6	0,8	0,6	0,5	0,5
	Plášťovce					2,2	2,4	2,6	*2,2
Trenčiansky kraj	Prievidza, Malonecpalská			1,4	1,2	1,1	0,9	1,1	0,9
	Púchov, 1. mája					4,7	2,0	1,2	1,4
Banskobystrický kraj	Banská Bystrica, Štefánikovo nábrežie		2,1	1,7	1,6	1,7	1,4	1,2	1,0
	Banská Bystrica, Zelená			1,1	1,2	1,3	0,9	0,9	0,7
	Jelšava, Jesenského		3,9	4,0	3,0	2,8	2,7	3,4	3,5
	Žarnovica					2,2	2,7	1,9	2,2
Žilinský kraj	Žilina, Obežná		6,0	2,0	1,9	1,9	1,9	1,2	1,3
	Ružomberok, Riadok				4,5	2,3	2,2	2,0	1,7
	Oščadnica					12,0	2,5	1,9	2,1
	Martin, Jesenského								**1,0
Prešovský kraj	Starina, Vodná nádrž, EMEP		1,2	0,4	0,3	0,4	0,2	0,3	0,2
	Stará Lesná, AÚ SAV, EMEP			0,4	0,3	0,4	0,3	0,2	0,2
KOŠICE	Veľká Ida, Letná		5,8	4,5	4,6	6,1	5,4	4,9	6,2
Košický kraj	Krompachy, SNP			2,7	2,1	2,2	2,2	2,1	1,8

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

* *80 % of valid measurements*

*** Martin, Jesenského – start of BaP measurements in 2024*

The target value for BaP was exceeded at the following stations: Veľká Ida, Letná; Jelšava, Jesenského; Plášťovce; Krompachy, SNP; Ružomberok, Riadok; Oščadnica; Púchov, 1. mája; Žilina, Obežná; and Banská Bystrica, Štefánikovo nábrežie. Measurements in Plášťovce did not reach the required proportion of valid data (90%). Considering that the measurement outage occurred in December, when concentrations were high in previous years, it can be assumed with high probability that the target value would also have been exceeded in Plášťovce. The proportion of valid data in Plášťovce was 80%.

3.3.1 Assessment based on upper and lower assessment thresholds

Between 2020 and 2024, the levels of SO_2, CO, and benzene at all AMS were below the lower assessment threshold for air pollution levels.

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 2020 – 2024.*

AGGLOMERATION/ zone	Station	UAT and LAT with regard to the protection of human health																							
		SO_2			NO_2						PM_{10}						$PM_{2,5}$			CO			Benzén		
		24h average			1h average			annual average			24h average			ročný average			ročný average			8h maximum			annual average		
		> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT
BRATISLAVA	Bratislava, Kamenné nám.											x				x		x							
	Bratislava, Trnavské mýto					x		x			x				x			x				x			x
	Bratislava, Jeséniova			x			x			x		x				x			x						
	Bratislava, Mamateyova			x			x			x		x				x		x							
	Bratislava, Púchovská			x			x			x			x			x			x			x			x
KOŠICE	Košice, Štefánikova			x			x			x	x				x		x					x			x
	Košice, Amurská										x				x			x							
	Veľká Ida, Letná										x			x			x					x			
Banská Bystrica region	Banská Bystrica, Štefánikovo nábr.			x			x			x	x				x		x					x			x
	Banská Bystrica, Zelená						x			x		x				x		x							
	Zvolen, J. Alexyho											x				x		x							
	Jelšava, Jesenského						x			x	x			x			x								
	Hnúšťa, Hlavná										x				x			x							
	Žarnovica						x			x	x				x		x								
	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, Morovnianska cesta			x								x				x		x							
	Púchov, 1. mája			x			x			x		x			x			x				x			
	Trenčín, Hasičská			x			x			x	x				x			x				x			x

AGGLOMERATION/ zone	Station	UAT and LAT with regard to the protection of human health																							
		SO_2			NO_2						PM_{10}						$PM_{2,5}$			CO			Benzén		
		24h average			1h average			annual average			24h average			ročný average			ročný average			8h maximum			annual average		
		> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT	> UAT	≤ UAT; >LAT	≤ LAT
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

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 2020 – 2024.*

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													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		
Martin, Jesenského															
Sereď, Vinárska			x			x			x			x			

Between 2020 and 2024, the levels of the monitored heavy metals at all AMS were below the lower assessment threshold.

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 and 2011 – 2024.*

Stanica	2003	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Bratislava, Jeséniova	71	63	65	62	60	71	56	64	68	66	61	62	65	65	64
Bratislava, Mamateyova	53	51	53	48	46	54	36	51	54	54	49	50	50	50	52
Košice, Ďumbierska	68	73	62	61	55	57	55	55	63	56	46	49	53	50	60
Banská Bystrica, Zelená		60	66	66	58	48	45	57	56	47	48	54	57	52	48
Jelšava, Jesenského	55	-	-	41	36	45	48	49	49	45	39	41	38	45	46
Kojšovská hoľa	91	87	83	78	75	61	81	80	82	78	72	74	79	76	77
Nitra, Janíkovce		-	62	58	52	63	43	60	60	54	56	58	59	61	51
Humenné, Nám. slobody	66	53	55	60	40	41	50	52	51	54	49	49	51	49	48
Stará Lesná, AÚ SAV, EMEP	67	65	63	71	56	66	58	63	67	59	57	47	49	49	60
Gánovce, Meteo. st.	68	64	66	67	58	66	38	53	56	57	51	53	54	52	58
Starina, Vodná nádrž, EMEP	73	59	60	64	55	64	58	60	64	62	54	57	55	53	54
Prievidza, Malonecpalská		51	52	50	53	54	39	51	52	49	46	47	41	47	50
Topoľníky, Aszód, EMEP	67	-	59	64	51	51	49	47	54	55	24	49	54	52	51
Chopok, EMEP	109	96	93	96	52	88	91	98	95	90	91	89	91	89	94
Žilina, Obežná	48	48	49	53	42	36	43	38	44	44	36	38	36	37	38
Ružomberok, Riadok							37	37	36	36	35	40	37	40	40
Bardejov, Pod Vinbargom												44	45	42	44
Trebišov, T. G. Masaryka												49	49	49	50
Plášťovce												49	47	46	45
Komárno, Vnútorná Okružná												47	46	53	57
Senec, Boldocká												35	49	48	50
Pezinok, Obrancov mieru													58	58	58
Lučenec, Gemerská cesta													42	41	44
Oščadnica													48	50	51
Average	**65**	**61**	**63**	**63**	**53**	**58**	**52**	**57**	**59**	**57**	**51**	**50**	**52**	**52**	**54**

≥ 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/m3 for more than 25 days per calendar year in an average of three years*. The number of days exceeding the ground-level ozone target 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	2022	2023	2024	Average 2022 – 2024
Bratislava, Jeséniova	37	23	26	29
Bratislava, Mamateyova	25	18	18	20
Košice, Ďumbierska	7	4	15	9
Banská Bystrica, Zelená	9	0	1	3
Jelšava, Jesenského	*7	1	4	3
Kojšovská hoľa	16	*17	1	9
Nitra, Janíkovce	31	21	18	23
Humenné, Nám. Slobody	5	2	0	2
Stará Lesná, AÚ SAV, EMEP	0	*0	7	4
Gánovce, Meteo. st.	2	0	2	1

Station	2022	2023	2024	Average 2022 – 2024
Starina, Vodná nádrž, EMEP	1	1	0	1
Prievidza, Malonecpalská	*3	4	3	4
Topoľníky, Aszód, EMEP	9	2	1	4
Chopok, EMEP	34	34	53	40
Žilina, Obežná	3	1	0	1
Ružomberok, Riadok	0	1	0	0
Bardejov, Pod Vinbargom	3	1	1	2
Trebišov, T. G. Masaryka	5	3	1	3
Plášťovce	21	13	8	14
Komárno, Vnútorná Okružná	11	16	29	19
Senec, Boldocká	11	3	3	6
Pezinok, Obrancov mieru	21	16	26	21
Lučenec, Gemerská cesta	6	0	5	4
Oščadnica	8	6	10	8

≥ 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 target value for ground-level ozone was exceeded at two stations: **Bratislava, Jeséniova**, and **Chopok, EMEP** (Tab. 3.11).

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	2020	2021	2022	2023	2024	Average 2020 – 2024
Bratislava, Jeséniova	12 501	19 274	23 763	20 177	*16 339	18 929
Bratislava, Mamateyova	10 655	17 655	20 072	16 292	14 805	16 031
Košice, Ďumbierska	3 269	7 368	12 662	11 835	15 866	10 238
Banská Bystrica, Zelená	7 723	15 869	*19 716	9 226	4 695	11 512
Jelšava, Jesenského	5 191	10 186	*17 622	10 530	10 085	10 803
Kojšovská hoľa	4 995	13 260	19 435	13 249	10 471	12 402
Nitra, Janíkovce	12 741	18 931	24 322	18 824	11 372	17 404
Humenné, Nám. slobody	5 981	12 578	16 047	9 520	8 738	10 698
Stará Lesná, AÚ SAV, EMEP	7 890	2 491	6 210	–	12 855	7 427
Gánovce, Meteo. st.	3 251	6 707	11 317	4 596	10 524	7 424
Starina, Vodná nádrž, EMEP	5 072	11 737	9 560	5 857	7 810	8 110
Prievidza, Malonecpalská	6 198	11 799	*15 529	8 582	9 164	10 332
Topoľníky, Aszód, EMEP	–	13 176	16 686	12 739	8 267	10 349
Chopok, EMEP	15 957	23 654	26 536	24 179	22 651	22 902
Žilina, Obežná	559	4 794	5 338	5 114	2 225	3 625
Ružomberok, Riadok	1 999	*8 041	2 935	7 890	4 208	4 338
Bardejov, Pod Vinbargom		10 607	12 711	7 413	11 139	10 488
Trebišov, T. G. Masaryka		12 369	15 806	10 425	11 341	12 562
Plášťovce*		*24 211	19 720	15 043	12 281	15 764
Komárno, Vnútorná Okružná*		*17 818	12 824	21 701	18 013	17 894
Senec, Boldocká*		–	14 893	8 930	9 467	11 117
Pezinok, Obrancov mieru			19 368	11 931	17 345	16 246
Lučenec, Gemerská cesta			14 834	9 478	8 136	11 017
Oščadnica			14 893	8 930	9 467	11 117

** 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. 3.5**).

Tab. 3.13 *Air pollution assessment according to limit values for the protection of human health in 2024 from industrial stations of other operators – large air pollution sources (VZZO).*

AGGLOMERATION Zone	Pollutant / Averaging period / Limit value [µg·m⁻³] / (Maximum number of exceedances)	Health protection SO_2		NO_2		PM_{10}		CO
		1 h 350 (24)	24 h 125 (3)	1 h 200 (18)	1 year 40	24 h 50 (35)	1 year 40	8 h [1] 10 000
BRATISLAVA	Bratislava, Pod. Biskupice (Slovnaft, a.s.)	1	0	0	13	16	21	1228
	Bratislava, Vlčie Hrdlo (Slovnaft, a.s.)	5	0	0	13	6	18	1318
Bratislava region	Rovinka (Slovnaft, a.s.)	1	0	0	11	6	19	1156
Nitra region	Trnovec nad Váhom (Duslo, a.s.)	0	0	0	2	5	15	
Trenčín region	Oslany (Slovenské elektrárne, a.s.)	0	0	0	6	2	14	
Žilina region	Ružomberok (Mondi a.s. - Supra)					16	21	
KOŠICE	Veľká Ida (U.S. Steel, s.r.o.)					22	26	
	Košice, Poľov (U.S. Steel, s.r.o.)					2	15	
	Košice, Haniska (U.S. Steel, s.r.o.)					4	18	
Košice region	Leles (Slovenské elektrárne, a.s.)	0	0	0	4		7	

[1] maximum 8-h 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 2024

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 **4.**

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 2024

- **Agglomeration Bratislava**

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

The target value for ozone (the highest daily 8-h mean value shall not exceed 120 $\mu g \cdot m^{-3}$ for more than 25 days per calendar year on average for three consecutive years) was exceeded at the **Bratislava, Jeséniova** monitoring station. This could be due to several factors - good availability of ozone precursors, higher NO_2/NO ratio in favor of NO_2 in this location, so that ozone is not degraded by nitric oxide from road traffic as much as at busy roads. Long-distance transmission episodes could also have occurred here.

Assessment of O_3 values from the perspective of the smog warning system: In 2024, the information threshold for O_3 was exceeded in Bratislava at the AMS Bratislava, Jeséniova for a duration of 3 hours and at the AMS Bratislava, Mamateyova for a duration of 2 hours. The warning threshold for O_3 was not exceeded, similarly to the previous year.

- **Zone Slovakia**

For Pb, As, Cd, Ni and O3 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.

Evaluation of O_3 values from the perspective of the smog warning system: In 2024, neither the information nor the warning threshold for O_3 was exceeded in the Slovakia zone.

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 $\mu g \cdot m^{-3}$ in 3 consecutive hours, 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 µg·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. The concentration of ground-level ozone exceeded the information threshold on August 16 and 30, 2024 at AMS Bratislava, Jeséniova and AMS Bratislava Mamateyova.

In 2024, notifications of smog situation for PM_{10} were issued for the following municipalities and areas: Bratislava, Jelšava, Ružomberok, Bratislava district, Galanta district, Levice district, Nitra district, Čadca district, Ružomberok district, Lučenec district, Žarnovica district, Košice, Veľká Ida. 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 2024, 2 notifications of smog situation for O_3 were issued for Bratislava and its surroundings. The warning threshold for O_3 in the Slovak Republic was not exceeded.

The duration of exceedances of the information and alert thresholds for PM_{10} and O_3 in 2024 compared to 2023 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.

AGGLOMERATION Zone	Pollutant	O_3				PM_{10}			
	Year	2023	2023	2024	2024	2023	2023	2024	2024
	Information/alert threshold	IT	AT	IT	AT	IT	AT	IT	AT
	Averaging period	1h	3 h po sebe	1h	3 h po sebe	12h	12h	12h	12h
	Threshold value [µg·m⁻³]	180	240	180	240	100	150	100	150
BRATISLAVA	Bratislava, Kamenné nám.					0	0	16	5
	Bratislava, Trnavské mýto					0	0	19	2
	Bratislava, Jeséniova	3	0	3	0	0	0	13	2
	Bratislava, Mamateyova	5	0	2	0	0	0	7	0
	Bratislava, Púchovská					0	0	15	5
Bratislava region	Pezinok, Obrancov mieru	2	0	0	0	0	0	14	4
	Rohožník, Senická					0	0	21	0
	Rovinka					11	0	24	11
	Senec, Boldocká	0	0	0	0	22	6	15	4
Trnava region	Senica, Hviezdoslavova					0	0	12	2
	Trnava, Kollárova					0	0	16	5
	Topoľníky, Aszód, EMEP	0	0	0	0	0	0	14	0
	Sereď, Vinárska					0	0	24	5
Nitra region	Nitra, Janíkovce	0	0	0	0	0	0	22	7
	Nitra, Štúrova					0	0	28	9
	Komárno, Vnútorná Okružná	3	0	0	0	10	0	23	5
	Plášťovce	0	0	0	0	24	6	57	9
Trenčiansky kraj	Prievidza, Malonecpalská	0	0	0	0	0	0	25	7
	Bystričany, Rozvodňa SSE					0	0	24	9
	Handlová, Morovnianska cesta					0	0	23	9
	Púchov, 1. mája					0	0	40	8
	Trenčín, Hasičská					0	0	22	6
Banská Bystrica region	Banská Bystrica, Štefánikovo nábr.					52	8	22	8
	Banská Bystrica, Zelená	0	0	0	0	0	0	17	9
	Jelšava, Jesenského	0	0	0	0	28	0	94	0
	Hnúšťa, Hlavná					0	0	17	6
	Lučenec, Gemerská cesta	0	0	0	0	0	0	18	8
	Zvolen, J. Alexyho					0	0	19	7
	Žarnovica					0	0	34	9
	Žiar n/H, Jilemnického					0	0	20	7
Žilina region	Chopok, EMEP	0	0	0	0	0	0	0	0
	Liptovský Mikuláš, Školská					24	11	44	9
	Martin, Jesenského					47	0	21	9
	Oščadnica	0	0	0	0	9	0	46	0
	Ružomberok, Riadok	0	0	0	0	86	15	37	7
	Žilina, Obežná	0	0	0	0	0	0	29	4
Preš region	Gánovce, Meteo. st.	0	0	0	0			24	0
	Humenné, Nám. Slobody	0	0	0	0	2	0	25	0
	Prešov, Arm. gen. L. Svobodu					20	0	18	0
	Vranov n/T, M. R. Štefánika					10	0	15	0
	Stará Lesná, AÚ SAV, EMEP	0	0	0	0	0	0	26	0
	Starina, Vodná nádrž, EMEP	0	0	0	0	0	0	0	0
	Kolonické sedlo, Hvezdáreň					0	0	14	0
	Poprad, Železničná					0	0	24	4
	Bardejov, Pod Vinbargom	0	0	0	0	0	0	19	0
KOŠICE	Košice, Štefánikova					28	0	21	0
	Košice, Amurská					0	0	16	0
	Košice, Ďumbierska	0	0	0	0			0	0
	Veľká Ida, Letná					15	0	55	0
Koše region	Kojšovská hoľa	0	0	0	0			19	0
	Trebišov, T. G. Masaryka	0	0	0	0	0	0	15	0
	Strážske, Mierová					0	0	16	0
	Krompachy, SNP					20	0	23	10

The most hours with exceeding the information threshold for PM_{10} were recorded in 2024 at the monitoring station in **Jelšava (94).** Compared to 2023, more exceedances were recorded at most stations, but this reflected, in addition to temperature inversions in November and December, a significant episode of Saharan dust transport at the turn of March and April.

3.3.5 National exposure reduction target for $PM_{2.5}$

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 2025 is calculated as the average of the three annual average concentrations from these stations in 2023, 2024 and 2025.

Exposure reduction target relative to the Average Exposure Indicator in 2010		Year by which the exposure reduction target is to be achieved
Initial concentration 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 15 years. Its decrease in 2024 reflects lower annual mean $PM_{2.5}$ values in the last 3 years, especially in 2023. The Slovak Republic also met the target for reducing exposure to $PM_{2.5}$ particles in 2024. According to Annex No. 4 to Decree No. 250/2023 Coll., the national exposure reduction target for $PM_{2.5}$ particles is set at 18 µg·m^{-3}, which was to be achieved by 2020. This was achieved.

Tab. 3.15 *$PM_{2.5}$ Average Exposure Indicator (AEI) in 2010 – 2024.*

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
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	14,2

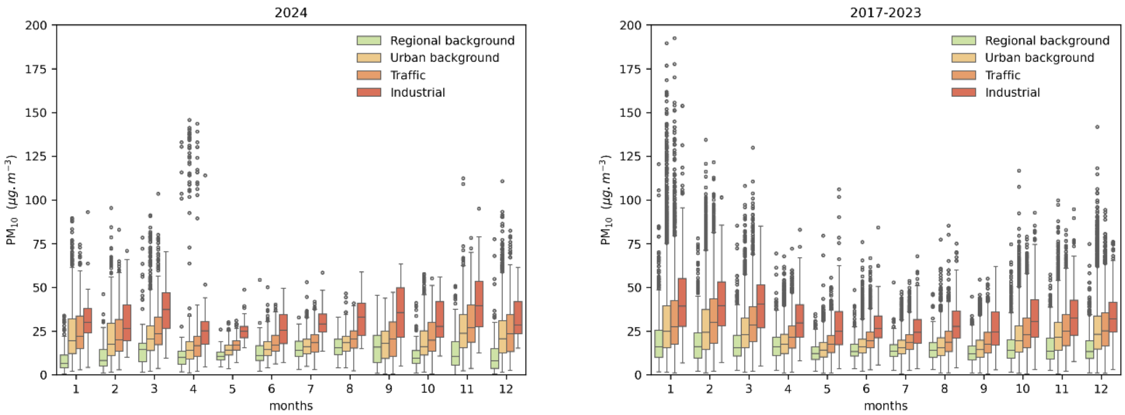
3.3.6 Graphical Presentation of Air Quality Monitoring Results

Graphs comparing monitoring results in 2024 compared to 2023 and 2022, broken down by agglomeration, zone and basic pollutants, are published on the SHMÚ *website.*

- **PM_{10} and $PM_{2,5}$**

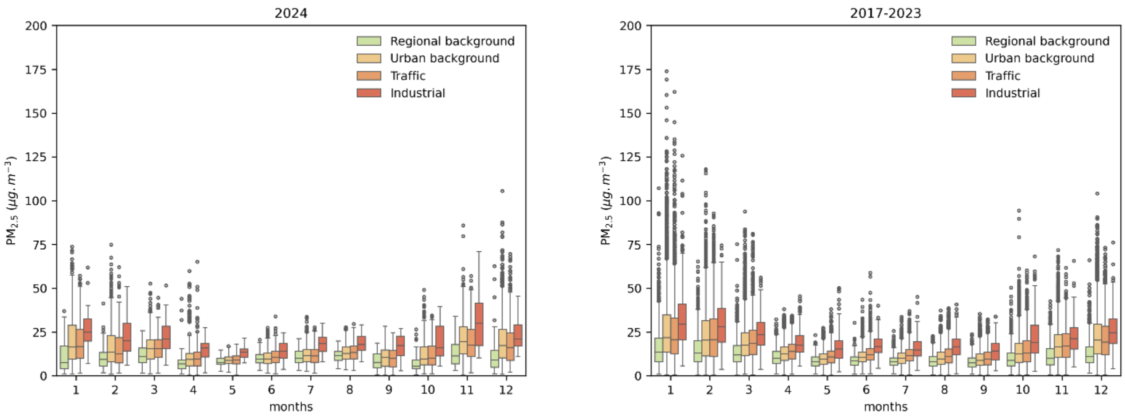
Compared to 2023, when the highest concentrations occurred mainly in a significantly unfavorable February, November and December were particularly problematic in 2024. An *exceptional episode* of Saharan dust transport was recorded in late March to early April, ending with the passage of a cold front through our territory from the west on April 2, 2025. In April 2024 (**Fig. 3.2**), a significant difference was therefore measured between PM_{10} and $PM_{2.5}$, characteristic of the coarse size fraction of desert dust.

Fig. 3.2 *Comparison of PM_{10} in 2024 (left) and in the period 2017 – 2023 (right) at individual types of stations.*



A comparison of the annual course of $PM_{2.5}$ in 2024 and 2017 – 2023 is illustrated in **Fig. 3.3.** Compared to 2024, there are high values especially in January, which is mainly due to the cold January in 2017.

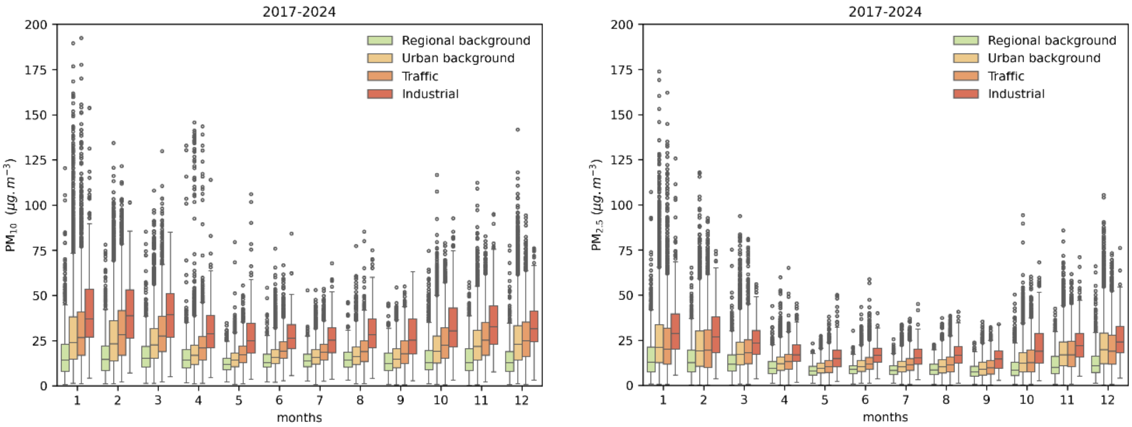
Fig. 3.3 *Comparison of $PM_{2.5}$ concentrations in 2024 (left) and in the period 2017-2023 (right) at individual types of stations.*



In 2024, no monitoring station exceeded the limit value of 40 µg·m^{-3} for the annual mean PM_{10} concentration. The highest values of this indicator were recorded in **Veľká Ida, Letn**á (33 µg·m^{-3}; in 2023 it was 30 µg·m^{-3}) and **Jelšava, Jesenského** (28 µg·m^{-3}, the same as in 2023).

The time series of PM_{10} and $PM_{2.5}$ values since 2017 illustrates the situation with outliers in 2017 (both PM_{10} and $PM_{2.5}$ - fine size fraction from heating), in contrast to 2024, when the outliers in PM_{10} (**Fig. 3.4**) were due to an episode of desert dust transport, which, as already mentioned, was almost not reflected in $PM_{2.5}$ values (**Fig. 3.4**).

Fig. 3.4 Comparison of PM_{10} (left) and $PM_{2.5}$ (right) in 2017 – 2024 at individual station types.



SO₂

Unlike PM, NO_2, CO and benzo(a)pyrene, SO_2 emissions are mainly contributed by large industrial sources. During the winter months, the impact of household heating using coal with high sulfur content may be observed. However, high SO_2 concentrations have not been recorded in Slovakia, indicating that this type of heating is likely a minor practice in the country. Measured concentrations have long remained below the limit value. In 2024, no exceedances of the SO_2 alert threshold were recorded at monitoring stations in Slovakia.

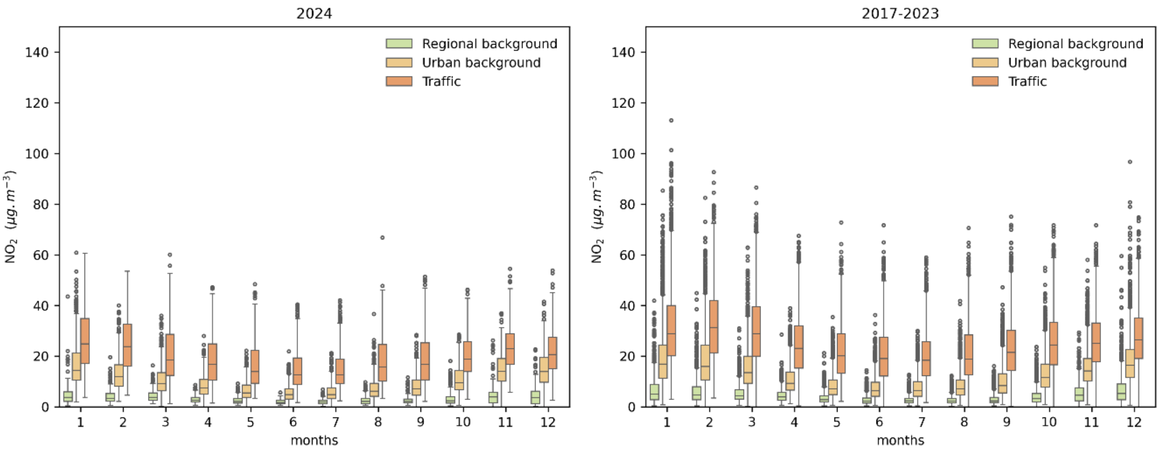
The critical value for vegetation protection is 20 $\mu g \cdot m^{-3}$ for both the calendar year and the winter period. This limit value was not exceeded at any EMEP station throughout 2024, neither for the calendar year nor the winter period. All values were below the lower assessment threshold for outdoor air pollution levels concerning vegetation protection.

NO₂

NO_2 forms in the atmosphere through the oxidation of NO, which is emitted from road traffic and combustion processes in industrial sources. With increasing distance from the source—such as a road—the NO/NO_2 ratio shifts significantly in favor of NO_2.

In 2024, the annual limit value of 40 $\mu g \cdot m^{-3}$ for NO_2 was not exceeded at any monitoring station. The last exceedances were recorded in 2018 at the monitoring stations Prešov, Arm. gen. L. Svobodu, and Bratislava, Trnavské Mýto.The following graphs (**Fig. 3.5**) illustrate the decrease in NO_2 levels in 2024 compared to the long-term average for 2017–2023.

Fig. 3.5 Comparison of NO_2 in 2024 (left) and in the period 2017-2023 (right) at individual types of stations.



No exceedance of the limit value for the protection of vegetation was measured at regional background EMEP stations in 2024. In Slovakia, there was no case of exceeding the warning threshold for NO_2 in 2024.

The highest annual average in 2024 was recorded by the same traffic stations as in 2023 – Prešov, Arm. gen. L. Svobodu (34 µg·m^{-3}) and Bratislava, Trnavské Mýto (28 µg·m^{-3}).

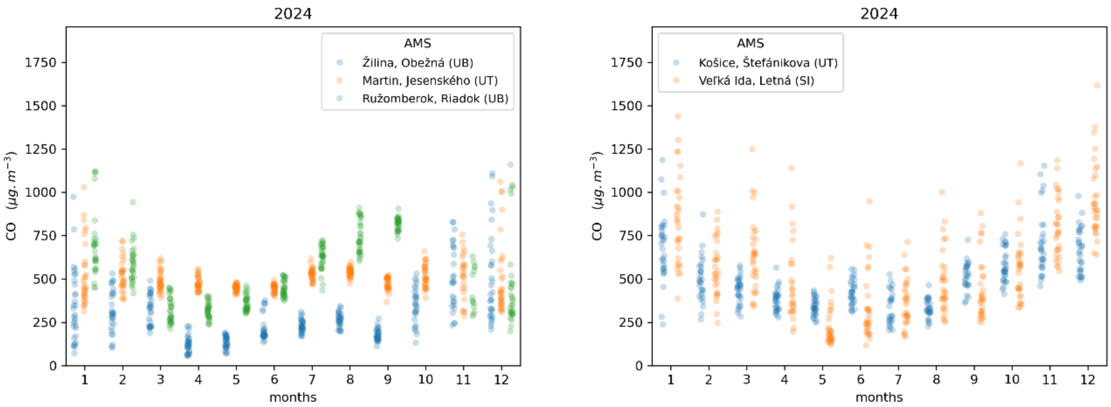
comparison of the values measured at these two AMS and the remaining stations in Bratislava and the Prešov Region in individual months of 2024. The AMS in Prešov has significantly the highest NO_2 values in the Prešov Region throughout the year, while in January, November and December higher concentrations also occurred at the suburban background station in Poprad. NO2 also showed unfavorable dispersion conditions in the last two months of 2024.

The highest annual average in 2024 was recorded by the same traffic stations as in 2023 – Prešov, Arm. gen. L. Svobodu (34 µg·m^{-3}) and Bratislava, Trnavské Mýto (28 µg·m^{-3}). A comparison of the values measured at selected AMS in Bratislava and the Prešov Region during individual months of 2024 shows that the station in Prešov showed the highest NO_2 concentrations within the region throughout the year. In the winter months – especially in January, November and December – increased values were also recorded at the suburban background station in Poprad. Increased NO_2 concentrations at the end of the year were influenced by unfavorable dispersion conditions.

CO

The sources of CO emissions are combustion processes in industry, energy, household heating and road transport. At none of the monitoring stations in Slovakia was the limit value for CO exceeded in 2024, while the air pollution level for the previous period of 2012 - 2024 is below the lower limit for assessing its level. In **Fig. 3.6** we can compare the course of average daily concentrations in the Košice agglomeration and in the Žilina region zone, while at the AMS Veľká Ida, Letná, higher concentrations are distributed approximately evenly throughout the year, at the AMS Ružomberok, Riadok the maximum occurs in the winter months. We do not have a satisfactory explanation for the higher CO values in Ružomberok in August and September. In **Fig. 3.6** we can see a decrease in September concentrations in both Žilina and Martin.

Fig. 3.6 Daily mean CO concentrations in the Žilina region zone and in the Košice agglomeration.

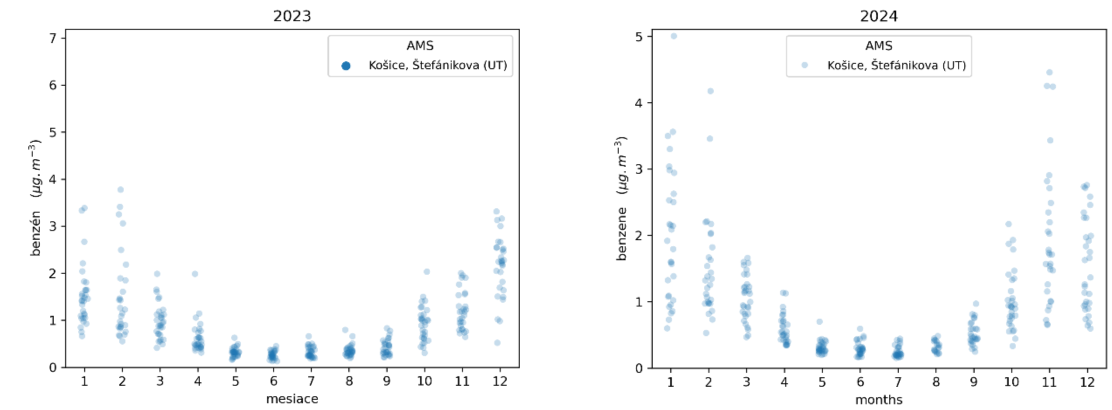


Benzene

Benzene emissions come from road transport, to a lesser extent from industrial sources. The values of average annual benzene concentrations were significantly below the limit value of 5 µg·m $^{-3}$.

Fig. 3.7 illustrates benzene concentrations in individual months in 2023 and 2024 in the Košice agglomeration at the Košice, Štefánikova transport station, where the annual average in 2024 was the highest (1.0 µg·m $^{-3}$). The comparison provides similar information as for other pollutants - while in 2023 February was the most pronounced, in 2024 the highest concentrations were measured in January and especially in the last months of the year.

Fig. 3.7 Comparison of average daily benzene concentrations at a transport station in the Košice agglomeration in 2023 and 2024

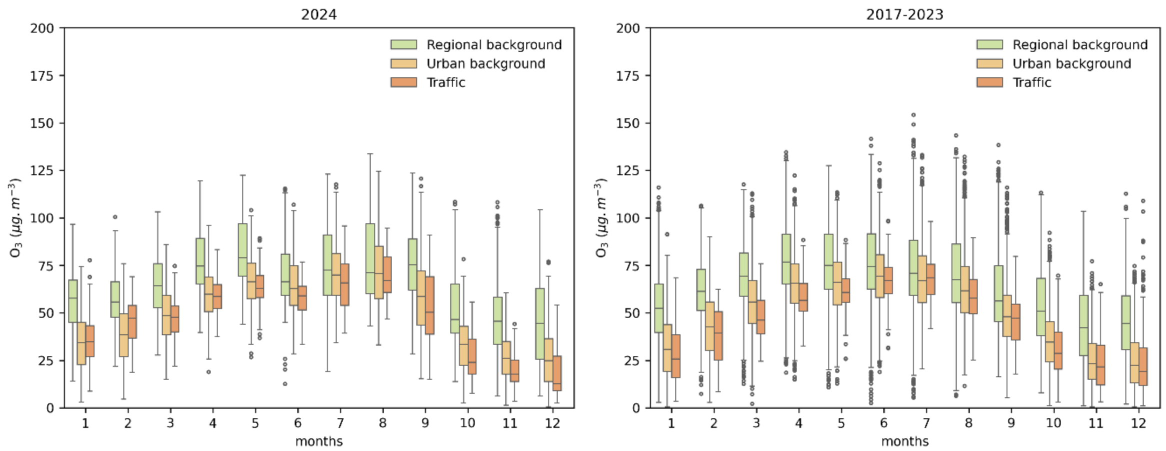


Ozone

Fig. 3.8 shows the seasonality of tropospheric ozone, which is characterized, unlike other pollutants, by a significant maximum in the summer period. Ground-level (tropospheric) ozone is produced by photochemical reactions, for example, from nitric oxide or carbon and volatile organic compounds. The reaction depends on the intensity of solar radiation. In high mountain locations, ozone concentrations are highest, since vertical transfer from higher layers of the atmosphere is manifested here.

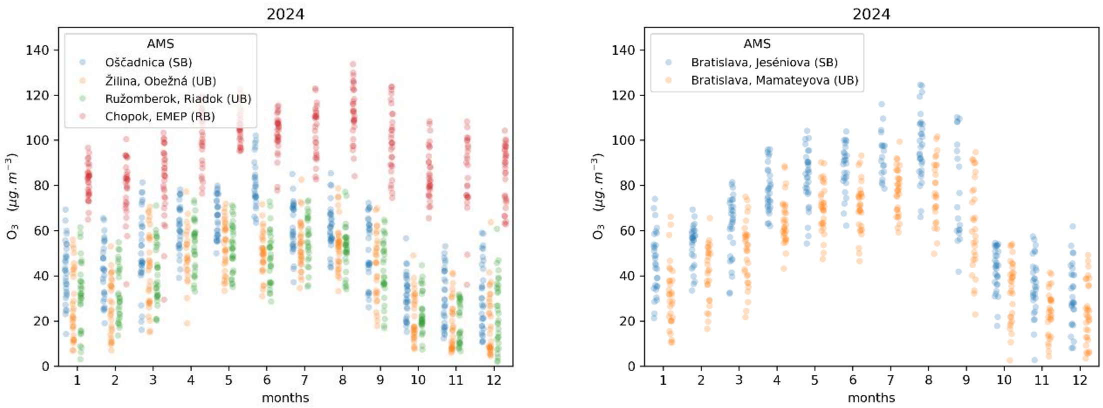
Average ozone concentrations at rural (regional) background locations are noticeably higher than at other types of locations (**Fig. 3.8**) in contrast to other pollutants (**Fig. 3.2, Fig. 3.5**) precisely due to the high values measured at the EMEP station on Chopok (**Fig. 3.3**).

Fig. 3.8 Comparison of O_3 in 2024 (left) and in the period 2017-2023 (right) at individual types of stations



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. 3.9**). We are comparing these locations (Chopok and Bratislava) because the target value for ozone was exceeded in both – in Bratislava this occurred at the (sub)urban background site on Jeséniova Street.

Fig. 3.9 Comparison of average daily concentrations of ground-level ozone in the Žilina Region and in Bratislava.



Pb, As, Ni, Cd

Neither the limit nor the target value was exceeded in 2024.

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

BaP

In 2024, the target value for benzo(a)pyrene (BaP), set at 1.0 ng·m^{-3}, was exceeded at nine monitoring stations. *(Note: In Plášťovce, the required share of valid data of 80 % was not met, and therefore the result is interpreted with limited validity.)*

At most urban and suburban sites in the Bratislava, Trnava, Nitra, and Trenčín Regions, low concentrations below the target value were measured, often well below 0.5 ng·m^{-3}.

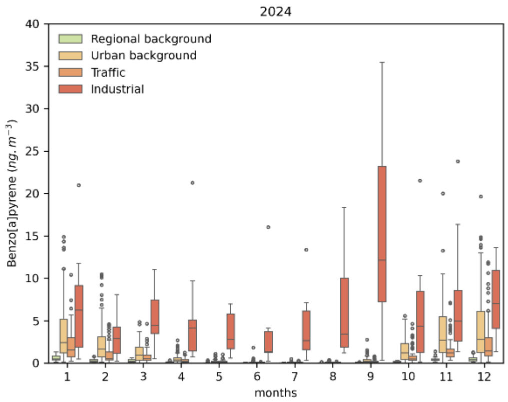
The highest concentrations with repeated exceedances of the limit value were recorded mainly in the Košice and Banská Bystrica regions, where the combined impact of industrial activity (Veľká Ida) and solid fuel combustion in households has been evident for a long time.

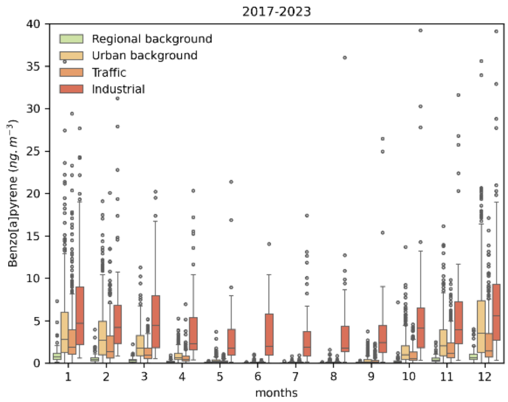
- In **Veľká Ida, the highest** value in Slovakia was recorded in 2024 – **6.2 ng·m^{-3}**, representing a six-fold exceedance of the target value.
- In **Jelšava**, high pollution levels persist – **3.4 ng·m^{-3}**, with no positive trend of reduction observed.

A declining trend in concentrations can be observed in Žilina, Ružomberok, and Žarnovica; however, BaP levels there still exceed the target value, and these sites therefore remain problematic from the perspective of health protection.

At the industrial station in Veľká Ida, no summer minimum occurs – high values were recorded throughout the year. At other AMS, very low values outside the heating season and high values in the winter months are characteristic.

Fig. 3.10 Comparison of BaP in 2024 (left) and in the period 2017-2023 (right) at individual types of stations.





3.3.7 Summary

The year 2024 was relatively more favorable in terms of air quality in Slovakia, even though average pollutant concentrations were higher than in the previous two years. This is mainly due to the fact that 2023 was unusually rich in precipitation, which had a positive impact on air quality. Compared to the long-term average, pollutant concentrations were higher in 2024, particularly in November and December. On the other hand, high precipitation totals in September 2024 were reflected in a decrease in concentrations of mainly PM_{10} and $PM_{2.5}$, but to a lesser extent also of gaseous pollutants in the second and fourth decade of September.

A Saharan dust episode occurred approximately between March 29 and April 2, 2025, during which average daily PM_{10} concentrations exceeded 100 µg/m³ at 48 monitoring stations, and average hourly values surpassed 250 µg/m³ at 3 stations.

A time series of continuous measurements since 2017 shows a significant downward trend in NO_2 levels. PM concentrations fluctuate depending on meteorological conditions, while benzo(a)pyrene remains the most persistent air quality issue.

3.4 REGIONAL MONITORING

Regional air pollution refers to pollution in the boundary layer of the atmosphere above natural areas located at a sufficient distance from local, industrial, and urban emission sources. The boundary layer of the atmosphere is the lowest part of the atmosphere, extending from the Earth's surface to an altitude of approximately 1,000 meters, in which vertical mixing of pollutants occurs.

In remote areas, unlike urbanized or industrial regions, pollutant emissions are generally more evenly distributed throughout the volume of this layer, resulting in lower ground-level concentrations of pollutants.

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

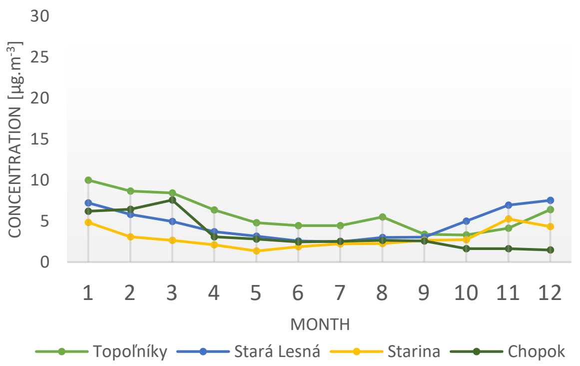
Sulphur dioxide, sulphates

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 2024 the average concentrations per calendar year were at Chopok 0,25 µg $SO_2 \cdot m^{-3}$ and Starina 0,24 µg $SO_2 \cdot m^{-3}$. Even during the winter season, concentrations at Chopok (0,30 µg $SO_2 \cdot m^{-3}$) and Starina (0,35 µg $SO_2 \cdot m^{-3}$) remained low and complied with legislative limits. The limit values are set by Decree No. 250/2023 Coll. of the Ministry of the Environment of the Slovak Republic on air quality in Annex No. 1. The annual average concentrations of sulfur dioxide and sulfates are shown in **Tab. 3.16**. The values are converted to sulfur weight. Sulfates accounted for 3.2% of TSP at Chopok and 5.9% of PM_{10} at Starina.

Nitrogen oxides, 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 (3,4 µg $NO_X \cdot m^{-3}$), Stará Lesná (4,6 µg $NO_X \cdot m^{-3}$), Starina (3,0 µg $NO_X \cdot m^{-3}$) and Topoľníky (5,6 µg $NO_X \cdot m^{-3}$) the limit value has not been exceeded. **Fig. 3.11** shows the monthly average concentrations of nitrogen oxides. Monthly concentrations did not show any significant trend, with the maximum reached in January at 10 µg $NO_X \cdot m^{-3}$ in Topoľníky, which is well below the critical level for vegetation protection for the calendar year. The annual average concentrations of nitrogen dioxide and nitrates are shown in **Tab. 3.16**. The values are converted to nitrogen weight. In 2024, nitrates were again more prevalent in gaseous than in particulate form ($NO_3^-{}_{(s)}/HNO_{3(g)}$) accounting for 4,8% of total TSP at Chopok and 5,1% of PM_{10} in Starina.

Fig. 3.11 *Average monthly NO_X concentrations in air – 2024.*



Tab. 3.16 *Average annual concentrations of pollutants [µg·m^{-3}] in air at EMEP stations – 2024.*

	SO_2	SO_4^{2-}	NO_2	NO_3^-	HNO_3	Cl^-	NH_3	NH_4^+	Na^+	K^+	Mg^{2+}	Ca^{2+}
Chopok	0,13	0,09	0,77	0,02	0,07	0,02	-	-	-	-	-	-
Starina	0,12	0,24	0,93	0,06	0,08	0,03	0,78	0,21	0,10	0,09	0,02	0,15

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 0,25 µg $N \cdot m^{-3}$ and for ammonia 0,78 µg $N \cdot m^{-3}$. Ammonium ions accounted for 2.2% of PM_{10} concentrations in Starina.

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 2024 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 - 2024.

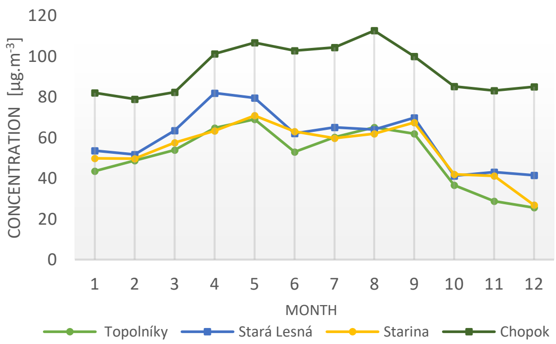
	PM_{10}/TSP[1]	Pb	Cu	Cd	Ni	Cr	Zn	As	Hg[2]	EC/OC	O_3
Chopok[1]	8	0.87	0.32	0.03	0.24	0.37	6.19	0.10	-	-	94
Topoľníky	13	2.98	1.18	0.10	0.95	0.83	14.366	0.14	*1,03	-	51
Starina	12	2.10	0.35	0.08	0.26	0.38	8.267	0.12	1,19	-	60
Stará Lesná	9	2.15	0.89	0.08	0.39	0.44	10.351	0.12	-	1,8/0,29	54

[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 2024, the annual average ozone concentration was 94 $\mu g \cdot m^{-3}$, at Chopok, 51 $\mu g \cdot m^{-3}$ at Topoľníky, 60 $\mu g \cdot m^{-3}$ at Stara Lesná and 54 $\mu g \cdot m^{-3}$ at Starina (**Tab. 3.17**). **Fig. 3.12** 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. 3.12 Average monthly O_3 concentrations in air - 2024.



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 (**Tab. 3.18**). 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 – 2024.

ethane	ethene	ethyne	propane	propene	i-butane	butane	butene
2 .06	0 .80	0.02	0 .90	0 .23	0 .34	0 .52	0 .07
pentane	**pentene**	**hexane**	**isoprene**	**benzene**	**toluene**	**o-xylene**	
0 .17	LOD	0 .18	0 .19	0 .24	0 .14	0.09	

** 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 – 2024.

	Precip. [mm]	pH	conductivity [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	1122	5.15	8.73	0.232	0.186	0.210	0.357	0.154	0.064	0.032	0.235
Topoľníky	580	5.42	12.9	0.331	0.265	0.505	0.286	0.155	0.073	0.082	0.771
Starina	472	5.25	11.52	0.318	0.271	0.374	0.230	0.226	0.201	0.071	0.685
Stará Lesná	403	5.40	8.82	0.280	0.208	0.324	0.269	0.148	0.063	0.044	0.375
Bratislava, Jeséniova	592	5.79	12.23	0.382	0.251	0.484	0.268	0.428	0.105	0.095	0.733

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

- **Main ions, pH, conductivity**

In 2024, regional stations recorded average annual precipitation totals that were within the standard range compared to previous years.

The reaction of rainwater (pH) was slightly acidic at all EMEP stations. The lowest pH (5,15) was recorded at Chopok, a mountain station with limited supply of neutralizing cations in the air. The highest pH (5,42) was measured in Topoľníky. In Bratislava, the pH reached a value of 5,79, which indicates neutralization of acidity by alkaline substances and corresponds to the increased load on urbanized areas (e.g., dust and emissions from anthropogenic sources). (**Tab. 3.19**, **Fig. 3.2**)[9].

The electrical conductivity of atmospheric precipitation, as an indicator of the total content of dissociated ions, was highest in Topoľníky (12,90 µS·cm⁻¹), where agricultural use of the land is more intensive, and outside the EMEP sites, it was highest in Bratislava (12,23 µS·cm⁻¹), which corresponds to a high degree of urbanization. Conversely, the lowest conductivity was measured at Chopok (8,73 µS·cm⁻¹), where we recorded low ion concentrations typical of less polluted mountain environments.

Sulphates (SO_4^{2-}) and nitrates (NO_3^-), as the main inorganic acidic components, had the lowest concentrations at Chopok (0,232 mg·l⁻¹ and 0,186 mg·l⁻¹) (**Tab. 3.19**, **Fig. 3.13**).Their highest values at EMEP stations occurred in Topoľníky in the case of sulphates (0,331 mg·l⁻¹) and in Starina in the case of nitrates (0,271 mg·l⁻¹) and in Bratislava, where there is higher anthropogenic load (transport, fuel combustion, agriculture)

Alkaline cations, especially calcium (Ca^{2+}) and magnesium (Mg^{2+}), which neutralize acidic components, were highest in Topoľníky (0,771 a 0,082 mg·l⁻¹) and Bratislava. Their low content at Chopok (0,235 a 0,032 mg·l⁻¹) is further evidence of the weak neutralization capacity in the mountain atmosphere.

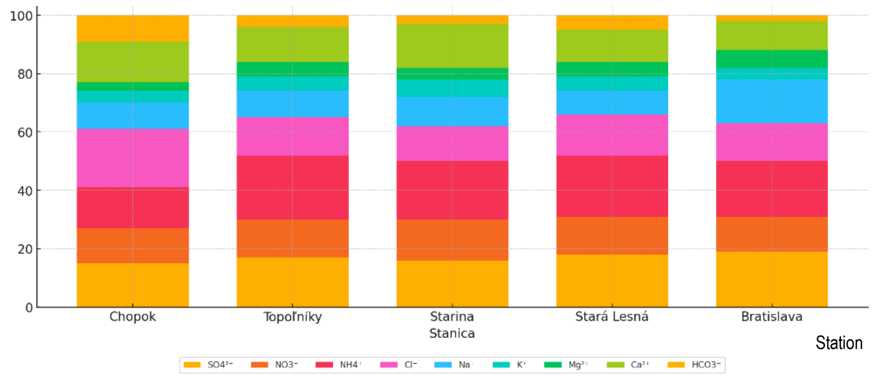
Chlorides (Cl^-) and sodium (Na^+), often associated with marine or road aerosols, were slightly higher in urban and lowland areas (e.g., Bratislava, Topoľníky), but are not dominant components.

Ammonium ions (NH_4^+), which contribute to the neutralization of acidic components, were highest at Topoľníky (0,505 mg·l⁻¹), which correlates with greater agricultural use of the land around the station. At Chopok, their concentration was low (0,210 mg·l⁻¹).

Chlorides (Cl^-) and **sodium (Na^+)**, often associated with marine or road aerosols, were slightly higher in urban and lowland areas (e.g., Bratislava, Topoľníky), but are not dominant components.

[9] *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.*

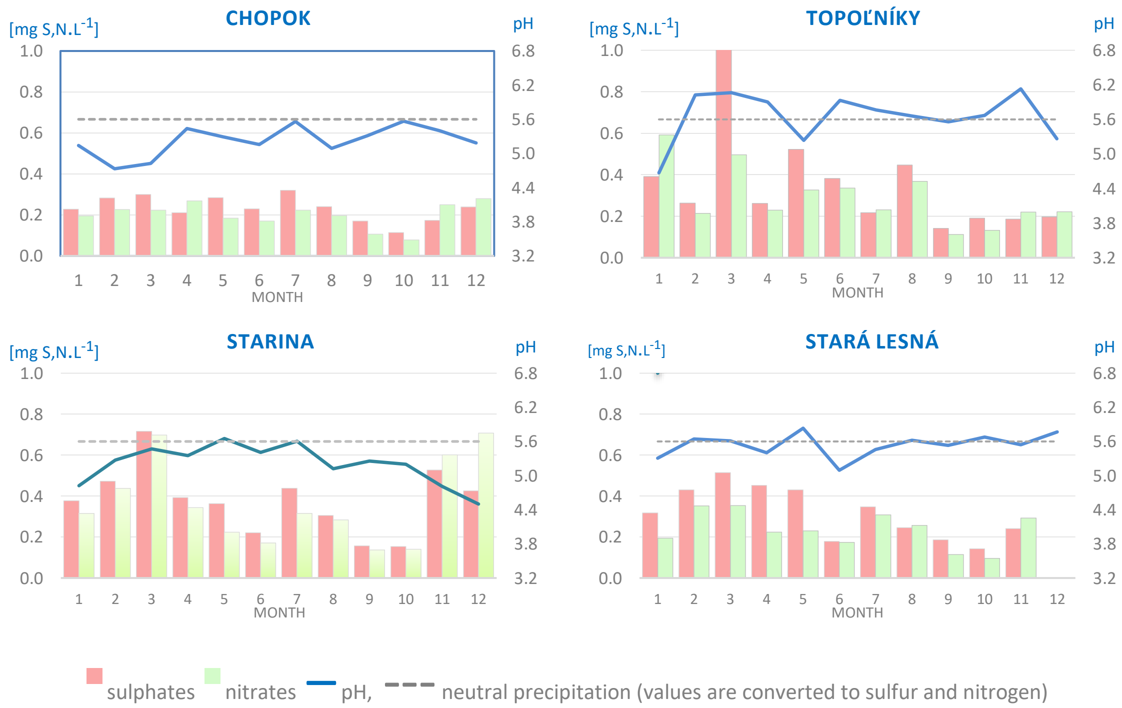
Fig. 3.13 *Relatively equivalent ratios[10] of main ions in precipitation (in %)*



Although the Chopok station shows the lowest representation of major acid anions (sulfates and nitrates), it also has the lowest pH values and the highest proportion of HCO_3^- (calculated from the pH value), which normally has a neutralizing effect. However, at Chopok, this increased proportion is not the result of effective neutralization, but rather the result of low levels of alkaline cations (NH_4^+, Ca^{2+}, Mg^{2+}, Na^+). In an environment with an excess of free H^+, that is not neutralized by cations, more HCO_3^- is partly formed as a product of an equilibrium reaction with CO_2 and elevated dissolved inorganic carbon (DIC). The increased HCO_3^- content thus reflects the acidic conditions and lower buffering potential of the environment (**Fig. 3.13**).

Summary:
***Chopok** represents a mountainous location – low ion concentrations (low conductivity), lowest pH with a low proportion of neutralizing ions (NH_4^+, Ca^{2+}, Mg^{2+}, Na^+, K^+), lower dust levels, therefore there is a relatively higher influence of acidic components (SO_4^{2-}, NO_3^-).*
***Topoľníky and esp. Bratislava** show a higher degree of anthropogenic influence – higher conductivity, higher pH, and relative representation of NH_4^+, Ca^{2+}.*
***Starina and Stará Lesná** are somewhere in between – with a moderate influence of agriculture and the effects of urbanization.*

***Fig. 3.14** Atmospheric precipitation – 2024.*



[10] *represent the proportions between individual ions expressed in equivalent concentrations (they express the ratio to other components and take into account the charge of ions). They are used to evaluate the chemical composition of atmospheric precipitation and identify pollution sources (e.g. industry SO_4^{2-}, Ca^{2+}, Mg^{2+}; agriculture NH_4^+, NO_3^-; transport NO_3^-, K^+ biomass combustion, natural sources Ca^{2+}, Mg^{2+}– soil dust).*

■ 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 (Pb), copper (Cu), cadmium (Cd), nickel (Ni), chromium (Cr), zinc (Zn) and arsenic (As). 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**. Compared to previous years, heavy metal concentrations remained relatively stable, with no significant year-on-year decline. In recent years, there has been a downward trend in lead concentrations in precipitation, despite the fact that in 2024 they were higher than in 2023. In 2024, precipitation totals at most locations were close to long-term averages.

Highest concentrations:

- **Pb (1.08 µg/l)** was recorded at **Stará Lesná**,
- **Zn (22.58 µg/l)** and **Ni (1.20 µg/l)** reached their highest values at the **Starina**,
- **Cu (0.83 µg/l)** was also highest at **Starina**, which may indicate local influences.

In contrast, **the lowest concentrations** of heavy metals occurred mainly at **Chopok** and in **Bratislava**.

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

	Precipitation [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	1169	0.94	0.04	0.15	0.12	0.30	15.33	0.28
Topoľníky	509	0.91	0.04	0.19	0.12	0.45	13.73	0.31
Starina	743	0.99	0.03	0.18	0.16	0.83	22.58	1.20
Stará Lesná	729	1.08	0.02	0.11	0.08	0.20	20.62	0.44
Bratislava, Jeséniova	731	0.66	0.03	0.14	0.10	0.65	11.36	0.27

4 RESULTS OF AIR QUALITY MATHEMATICAL MODELLING

The Air Protection Act No. 146/2023 Coll. defines the procedures and criteria for air quality assessment in full compliance with EU directives. In addition to measurements from monitoring stations, it also allows the use of mathematical modelling for air quality assessment. The primary basis for air quality evaluation in Slovakia is the measurement of pollutant concentrations in the air, conducted by SHMÚ at NMSKO stations.

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.

3.5 BRIEF CHARACTERISTICS OF MODELS USED

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

The Community Multiscale Air Quality Modelling System (CMAQ) is developed and maintained by the U.S. EPA's National Exposure Research Laboratory, located in Research Triangle Park, North Carolina. CMAQ is a third-generation air quality model, meaning it can simulate multiple pollutants simultaneously over large spatial scales, including continental regions. It is a three-dimensional Eulerian chemical transport model used to simulate ozone, atmospheric aerosols (PM), sulfur oxides, nitrogen oxides, and other tropospheric pollutants.

Mathematically, CMAQ calculates changes in pollutant concentrations over time for each grid cell using the continuity equation. These changes are driven by processes such as emissions, advection, diffusion, chemical transformations, and removal mechanisms including dry and wet deposition.

For the purposes of air quality assessment, a simulation was carried out with a horizontal resolution of 2 × 2 km, using meteorological data provided by the ALADIN model. The computational domain of the model encompasses the Central European region.

- **Regression-interpolation model RIO**

The RIO[11] model is an advanced interpolation-regression model. Its inputs include measured pollutant concentrations and various auxiliary spatial fields related to the distribution of a specific pollutant—such as elevation maps, traffic intensity, ventilation index, gridded emissions from residential heating, etc. The set of these so-called drivers is specific to each pollutant. Spatial drivers can also include outputs from other models (e.g., CMAQ) or satellite observations. The RIO model enables the refinement of concentration fields to a higher spatial resolution.

In the first step of the computation, the model determines the spatial correlation between the pollutant concentrations and the available spatial drivers at monitoring station locations. It then optimizes a parameter β, derived as a combination of the selected spatial drivers that show the strongest correlation with the spatial distribution of the pollutant. The model calculates a β parameter that provides the best fit to the observed data.

The differences between the values calculated using the β parameter and the actual measurements at monitoring sites are then interpolated using the ordinary kriging method and added to the β-based

[11] *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*

values for each grid cell. For air quality assessment using the RIO model, a spatial resolution of 1 × 1 km was applied.

IDW-R

The RIO interpolation model belongs to the class of so-called approximating interpolation methods, meaning that it smooths the concentration field and does not necessarily reproduce the exact measured concentrations at monitoring station locations. Therefore, the outputs from the RIO or CMAQ models are further refined using the IDW-R (Inverse Distance Weighting – Regression) technique.

In the first step of the IDW-R method, a linear regression curve is computed between the measured values and the model outputs. In the second step, standard IDW interpolation is applied to the differences between the measured data and the regression-based estimates, resulting in a 2D map of interpolated residuals. This residual map is then multiplied by rescaled input data ranging from 0 to 1 and added to the regression-derived values.

The technique can be applied iteratively, with each iteration typically improving the statistical performance of the model. For evaluating the agreement between modelled and measured values, the root mean square error (RMSE) and bias (BIAS) were used.

3.6 RESULTS AND OUTPUTS

PM_{10}

The dominant source of PM_{10} emissions is household heating, primarily with solid fuels, which accounts for more than 60% of total PM_{10} emissions. PM_{10} emissions from road transport represent less than 10%; however, their impact on air quality near busy roadways is not negligible. Large and medium-sized industrial sources and the energy sector contribute approximately 10% of PM_{10} emissions, with smaller contributions from waste management and agriculture.

Modeling PM using chemical transport or dispersion models is complicated by the relatively significant—though temporally limited—influence of activities whose emissions are difficult to quantify and even approximately localize in space and time. These include construction and demolition work, agricultural activities such as plowing and harvesting, and illegal burning of agricultural residues or waste.

The spatial distribution of PM10 concentrations in Slovakia was calculated using the RIO model. Auxiliary spatial data included outputs from the Gaussian model AtmoStreet (15%), ventilation index (16%), and elevation (69%). The numbers in parentheses represent the weights assigned to each type of spatial data. After subsequent adjustment of the results using the IDW-R method and comparison with measurements, the model achieved an RMSE of 0.2 $\mu g \cdot m^{-3}$ and a BIAS of 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.

Fig. 4.1 Annual mean concentrations of PM_{10} [$\mu g \cdot m^{-3}$] in year 2024.

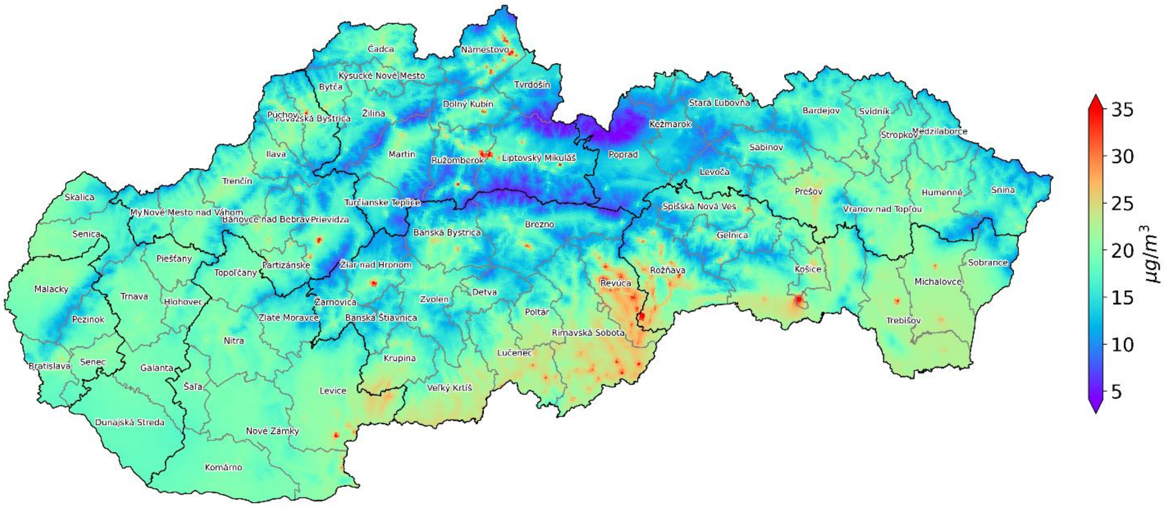
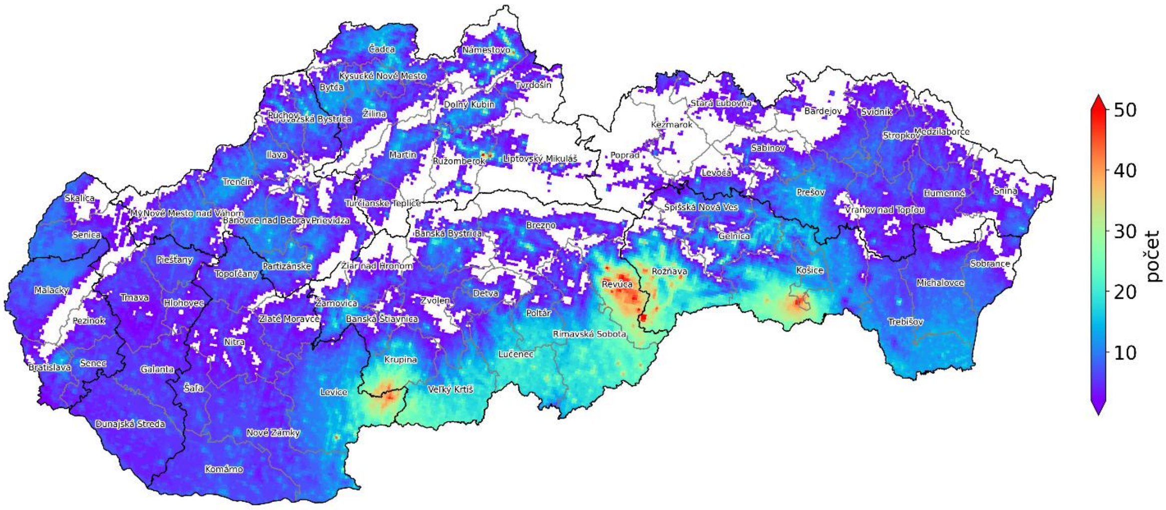


Fig. 4.2 Number of days exceeding the limit value for the 24-hour PM_{10} concentration (50 $\mu g \cdot m^{-3}$) in 2024. Only areas with a non-zero number of exceedances are shown.



■ **$PM_{2,5}$**

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[12].

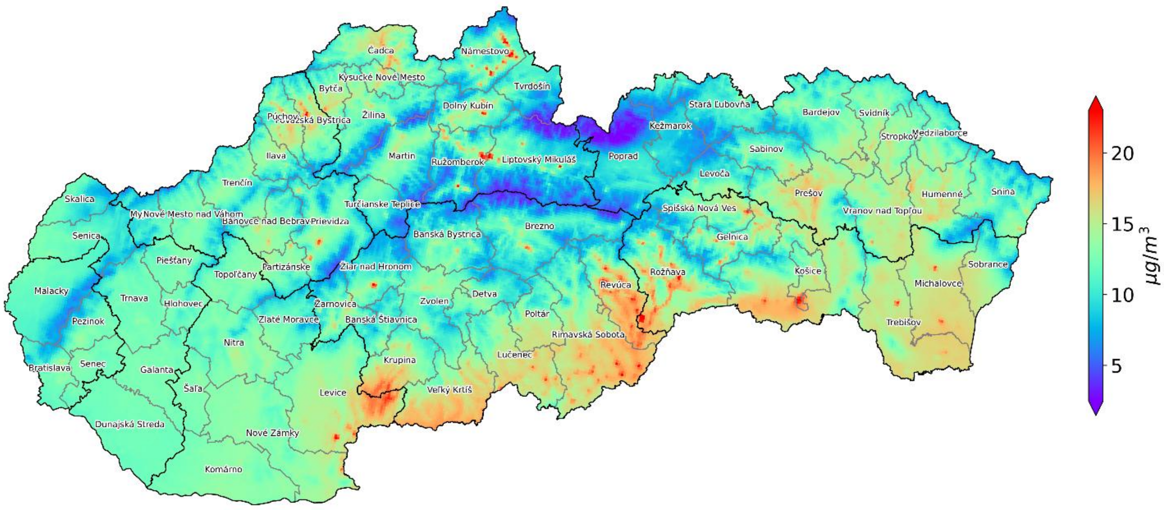
The spatial distribution of $PM_{2.5}$ concentrations in Slovakia was calculated by the RIO model, while the outputs from the AtmoStreet model (11%), ventilation index (24%) and altitude (65%) were used as additional spatial data. After subsequent adjustment of the output of the RIO model using the IDW-R method, we get RMSE = 0.2 $\mu g \cdot m^{-3}$ and BIAS = 0.0 $\mu g \cdot m^{-3}$ when compare with the measurements. The resulting mean concentrations of $PM_{2.5}$ are shown in **Fig. 4.3.**

The annual average limit value of 20 $\mu g \cdot m^{-3}$ in 2024 was exceeded only in a few places at this spatial resolution, namely in Orava, Dolný Liptov, Gemer (around Jelšava), the vicinity of Košice, the area around Martin, Čierny Balog, and Plášťovce.

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

This corresponds with the measured data, which showed that the limit value was exceeded in Plášťovce, and relatively high concentrations of $PM_{2.5}$ = 20 µg·m^{-3} were also recorded in Veľká Ida, Žarnovica, and Jelšava. The highest concentrations, similar to PM_{10}, occur in locations with a large number of local solid-fuel heating sources situated in enclosed mountain valleys.

Fig. 4.3 *Annual mean concentrations of $PM_{2,5}$ [µg·m^{-3}] in year 2024.*

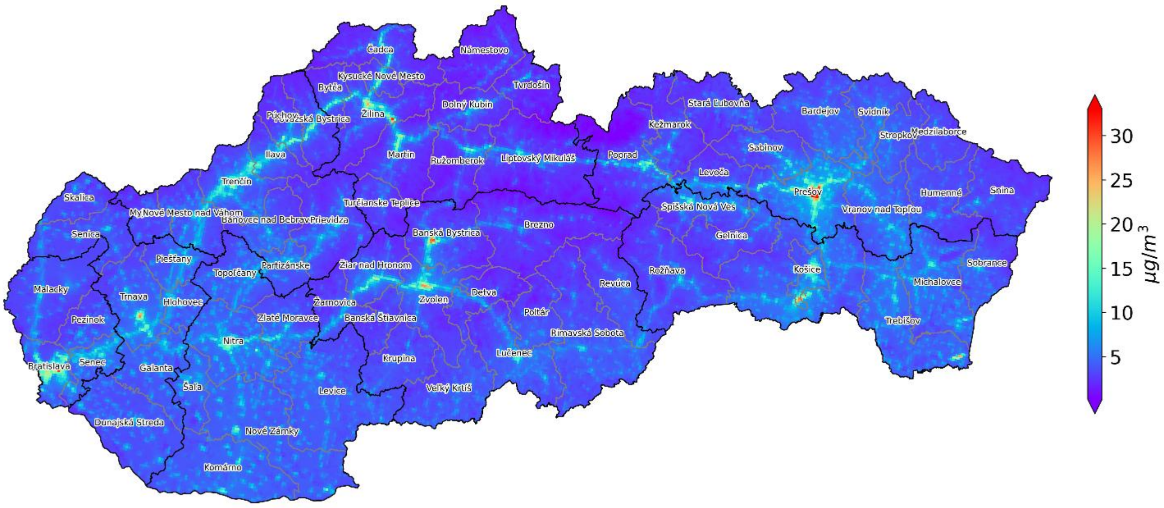


NO₂

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 (42%), altitude (18%) and land use (40%). After subsequent modification of the model by the IDW-R method and comparison with measurements, we get RMSE = 1 µg·m^{-3} and BIAS = 0.0 µg·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 spatial resolution the limit value for the average annual concentration (40 µg·m^{-3}) was not exceeded in 2024. Also, the limit value of the average hourly concentration (200 µg·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 concentrations of NO_2 [µg·m⁻³] in year 2024.



Ozone

The spatial distribution of ozone concentrations in Slovakia was calculated by the RIO model, with AtmoStreet model output considering only road traffics (36%), altitude (64%) 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 = 0.6 µg·m⁻³ and BIAS = 0 µg·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 µg·m⁻³ (i.e., the target value for the protection of human health), showing the average number of days for the period 2022 – 2024 (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 2022 – 2024 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 2020 – 2024 (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 [µg·m⁻³] in year 2024.

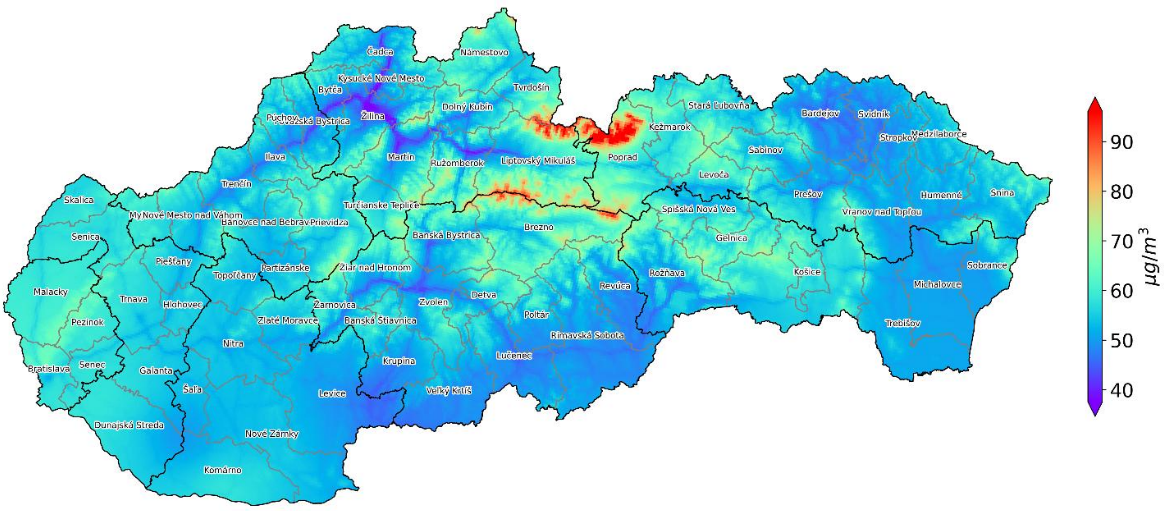


Fig. 4.6 *Number of days, in which eight-hour mean concentration of surface ozone exceeded value120 µg·m^{-3} (mean during years 2022 – 2024).*

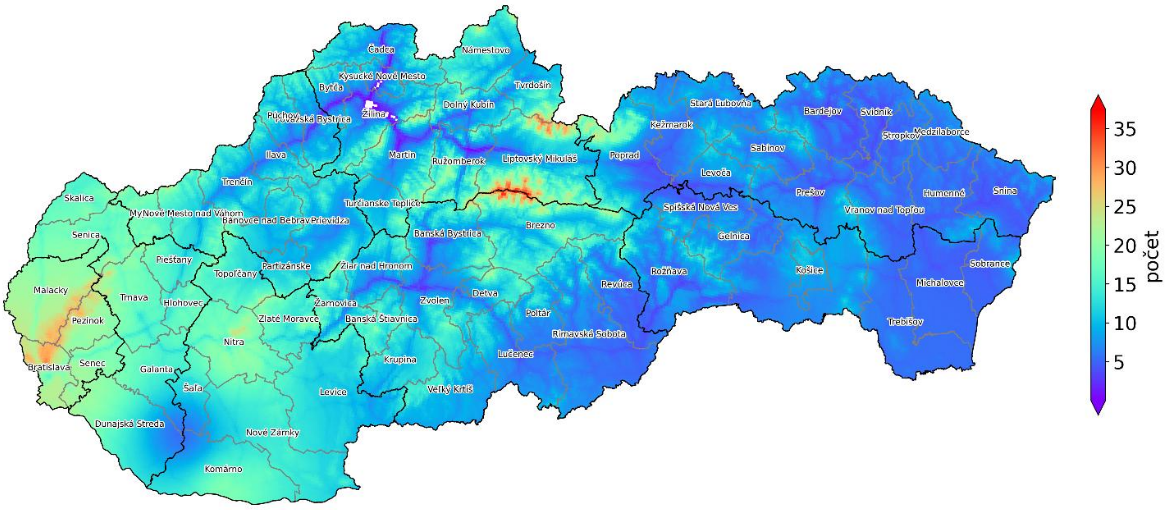
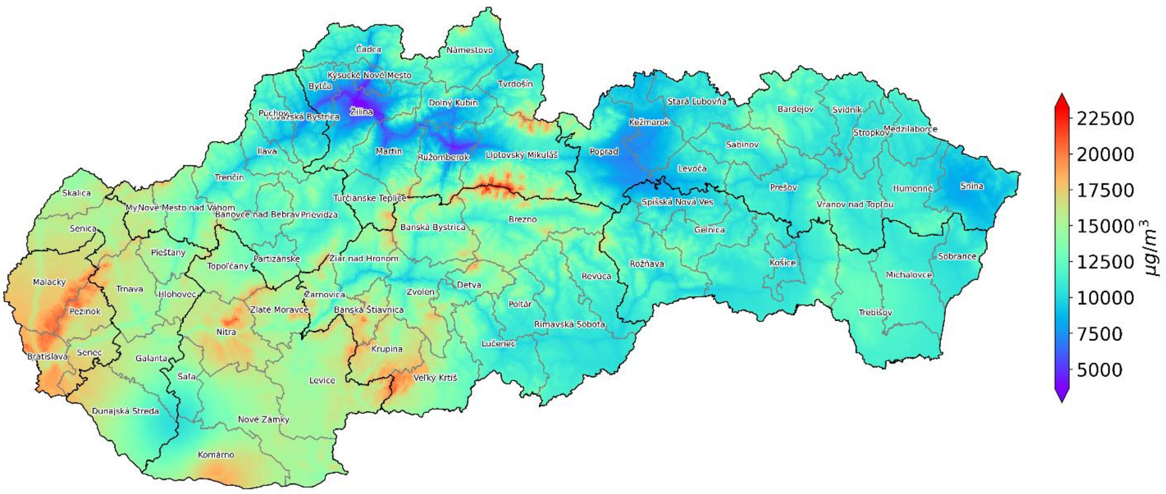


Fig. 4.7 *Mean values of AOT40 during the period of five years (2020 – 2024).*



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.

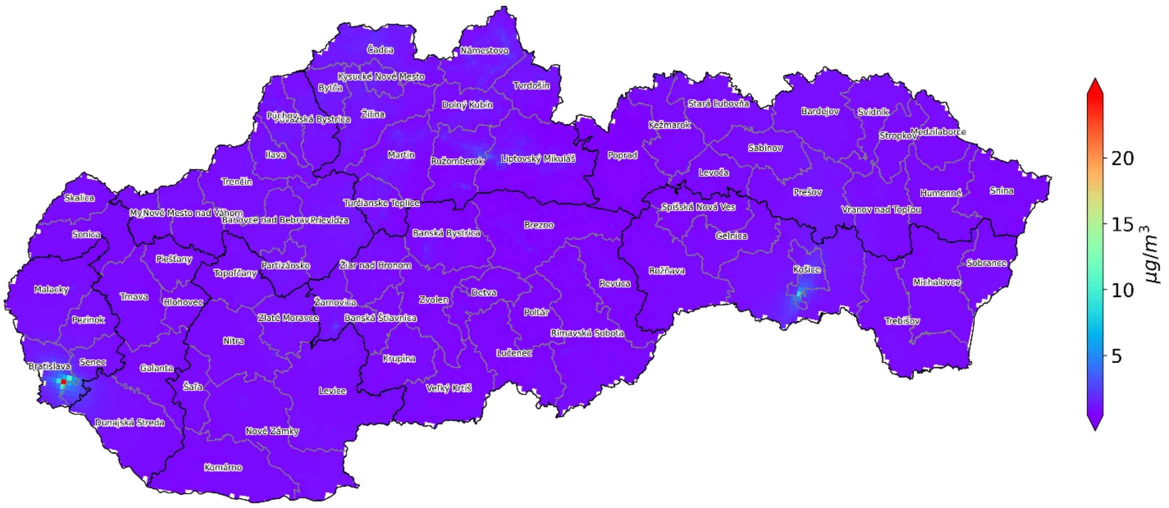
The spatial distribution of SO_2 concentrations in Slovakia was calculated by the CMAQ model, while meteorological data from the ALADIN model were used.

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). 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. The Nováky power plant also ceased operations in December 2023.

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[13] 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 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 [µg·m^{-3}] in year 2024.

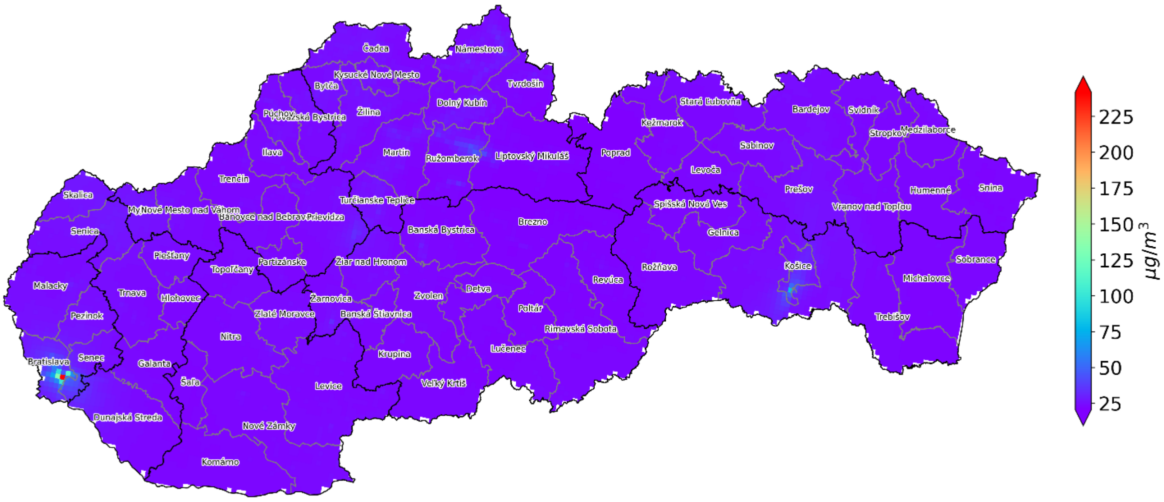


Hourly mean SO_2 concentrations should not exceed 350 µg·m^{-3} more than 24 times in a calendar year. Therefore, the 99.7 percentile of the hourly values is calculated (this percentile corresponds roughly to the 25th highest hourly concentration). Interestingly, in the case of the 99.7 hourly percentile, our measurement results correlate reasonably well with the CMAQ mode (r = 0,65). It can be assumed that the measurements capture the peak concentrations reasonably well. The concentrations calculated by

[13] *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*

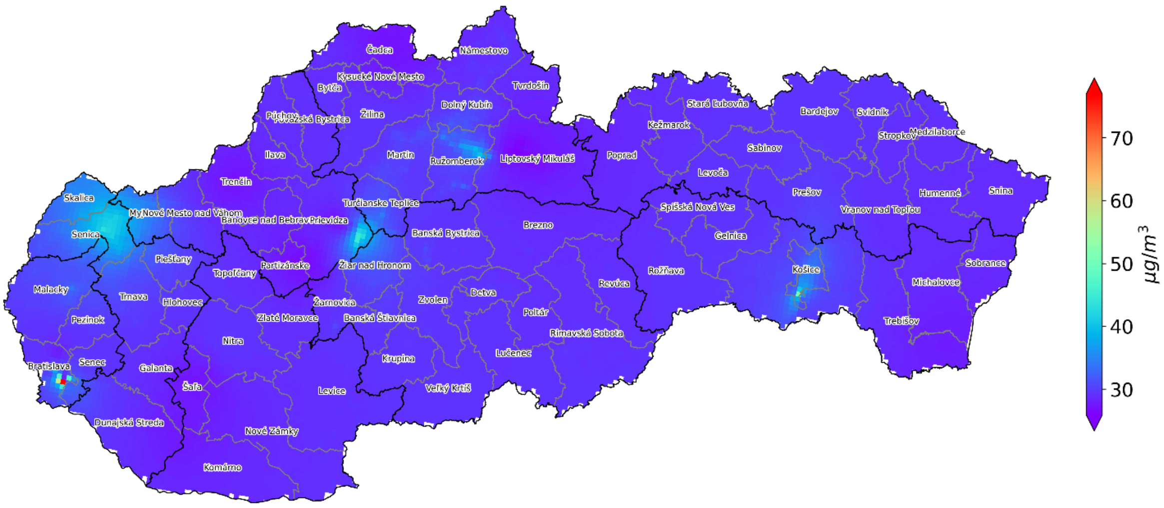
the CMAQ model were then processed by the IDW-R method to obtain the best agreement with the measurements (RMSE = 8.1 µg·m^{-3} and BIAS = –1.8 µg·m^{-3}). The resulting 99.7 hourly percentile of SO_2 concentrations is at **Fig. 4.9**, from which it can be seen that the 25th highest hourly concentration was well below the limit value of 350 µg·m^{-3}.

Fig. 4.9 *99.7 percentile [µg·m^{-3}] from hourly mean values of SO_2 concentrations in year 2024.*



The daily mean SO_2 concentration should not exceed 125 µg·m^{-3} more than 3 times in a calendar year. This is represented by the 99.2 percentile of the average daily values, which corresponds to roughly the 4th highest daily concentration. As in the previous case, the CMAQ model results were further processed by the IDW-R method (RMSE = 4.2 µg·m^{-3} and BIAS = -0.8 µg·m^{-3}). The resulting 99.2 percentile of the average daily SO_2 concentrations is shown in **Fig. 4.10**, from which it can be seen that the 4th highest average daily concentration was well below the limit value of 125 µg·m^{-3}.

Fig. 4.10 *99.2 percentile [µg·m^{-3}] from daily mean values of SO_2 concentrations in year 2024.*



CO

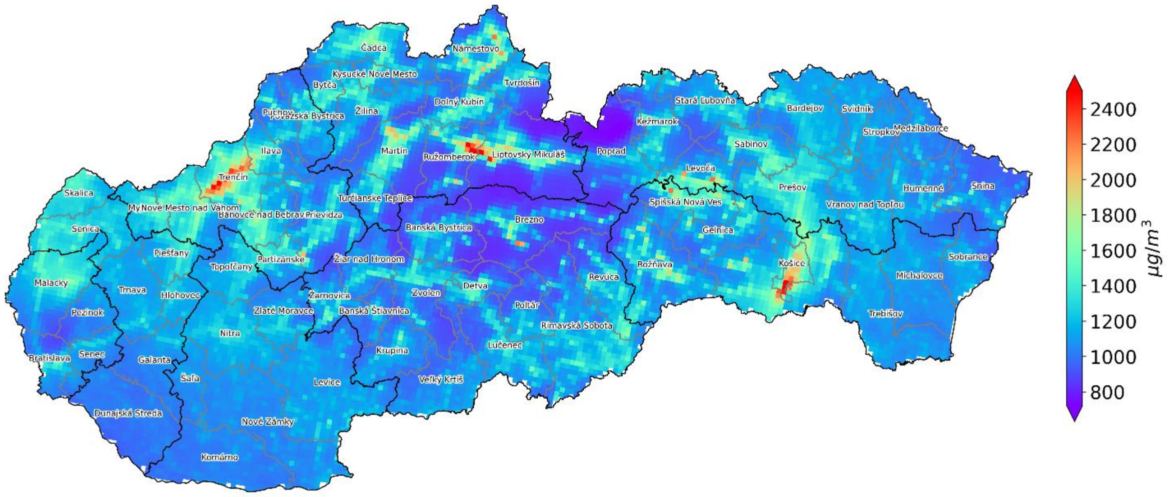
The spatial distribution of CO concentrations in Slovakia was calculated by the CMAQ model, using meteorological data from the ALADIN model.

The most important sources of CO emissions are local heating (almost 55% of total emissions), followed by industrial point sources. More than 1200 significant chimneys (vents) registered in NEIS database were included in the calculation. Also, emissions from road transport (approximately 20% from total emission inputs) and agriculture (approximately 5% from total emission inputs) were included in the simulation.

Outside the territory of SR emissions from TNO-MAC III database were used. Maximum daily 8-hour moving average CO concentrations in year 2024 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 = 28.3 μg·m^{-3} a BIAS = 2.7 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 2024.*

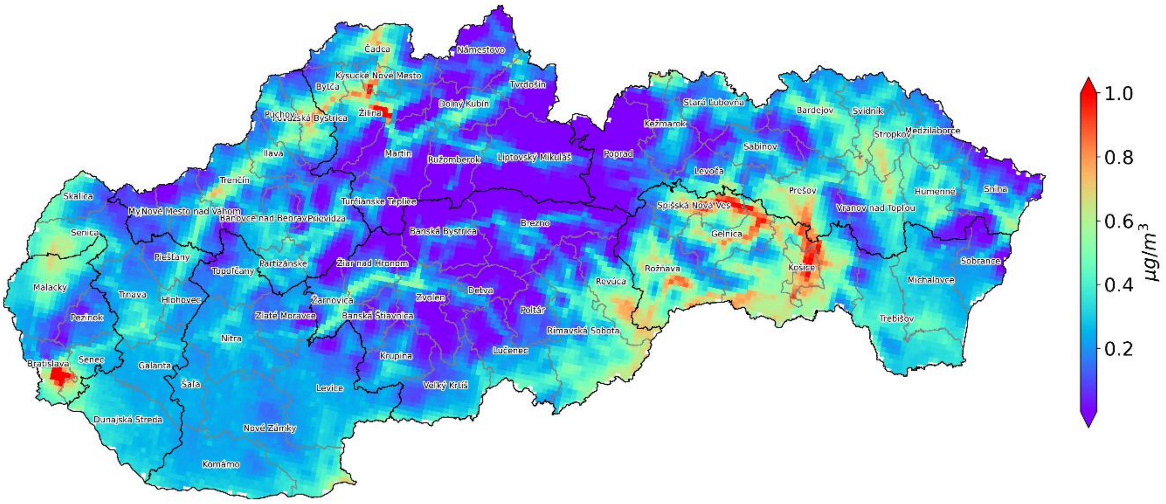


Benzene

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[14] database were used. Annual mean concentrations of benzene in year 2024 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.

[14] 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

Fig. 4.12 Annual mean concentrations of benzene [µg·m^{-3}] in year 2024.



■ 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[15]), for example, the share was more than 80%[16]. 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 2024, the highest annual mean concentration of benzo(a)pyrene among monitoring stations in Slovakia was recorded here again, namely 6.2 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 2024 at this station was 3.5 ng·m^{-3} , with a target value of 1 ng·m^{-3} .

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[17]. 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 = 0.8), 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 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. The lowest concentrations are at rural background stations and in cities in the Danube Lowland.

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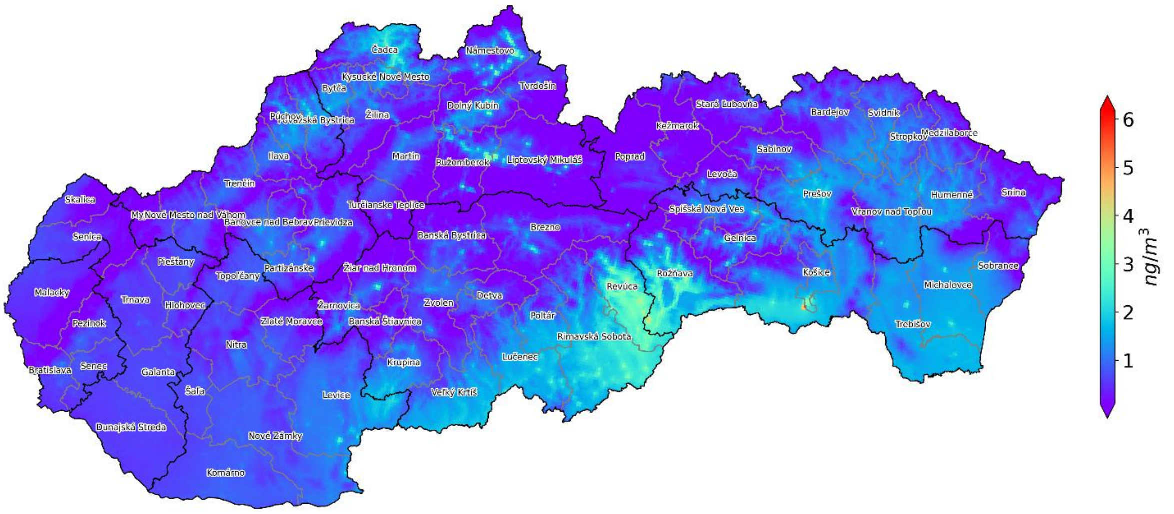
[15] *http://www.shmu.sk/sk/?page=1613&id=*

[16] *https://www.ceip.at/status-of-reporting-and-review-results/2019-submissions, - údaje predkladané v roku 2019 sa vzťahujú na rok 2017 http://www.shmu.sk/File/oko/rocenky/SHMU_Sprava_o_kvalite_ovzdusia_SR_2018_v3.pdf*

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

This fact is also reflected in the modelling results, with the highest concentrations in the east of the country. The model may overestimate benzo(a)pyrene concentrations, especially in the vicinity of Košice, the East Slovak Lowland and the eastern part of the South Slovak Basin, as it is strongly influenced by the high average annual concentration measured in Veľká Ida, which, together with Krompachy, is only one of 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 2024.*



3.7 CONCLUSION

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

In 2024, the highest PM concentrations were recorded in November, which was related to the frequent occurrence of strong temperature inversions. Household heating with solid fuels has a substantial impact on these elevated concentrations. The situation is most problematic in mountain valleys, in areas with good access to firewood and frequent adverse dispersion conditions, especially during the heating season. Financial constraints often prevent local residents from using natural gas for heating or purchasing modern low-emission heating systems. This also contributes to poor air quality in the aforementioned 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 2024, especially during the colder part of the year (October – March). In 2024, the highest PM concentrations were recorded in November, which was related to the frequent occurrence of temperature inversions. Household heating with solid fuels has a substantial impact on these elevated concentrations. The situation is most problematic in mountain valleys, in areas with good access to firewood and frequent adverse dispersion conditions. Financial constraints often prevent local residents from using natural gas for heating or purchasing modern low-emission heating systems. This also contributes to poor air quality in the aforementioned areas.

5 AIR QUALITY ASSESSMENT - CONCLUSION

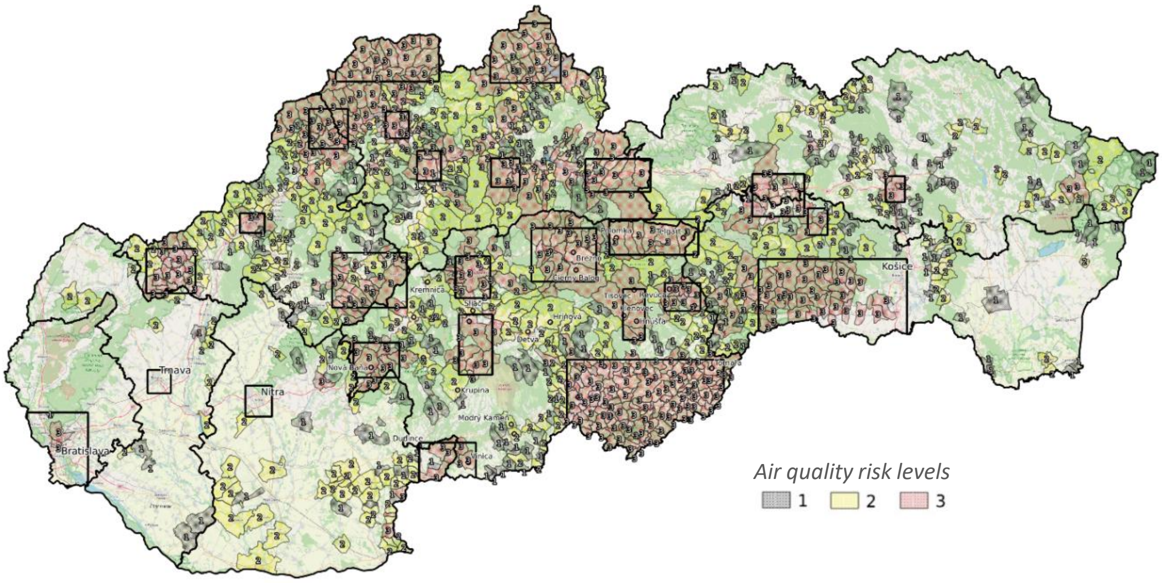
5.1 PROPOSAL FOR THE DEFINITION OF AIR QUALITY MANAGEMENT AREAS IN 2025

Based on the assessment of air quality in zones and agglomerations in 2022 – 2024, the SHMÚ's task is to, according to § 8 par. 3 of Act No. 137/2010 Coll. on Air, as amended, to propose an update of the definition of the air quality management areas of the Slovak Republic for 2025.

Monitoring results play a crucial role in assessing air quality. Since 2021, the results of mathematical modelling are also taken into account in the design of Air Quality Management Areas (ORKO), as the orography reduces the areas represented by individual monitoring station and therefore it is not possible to cover the whole country with measurements. Methodology for identifying municipalities at risk of poor air quality from household heating, based on the article *Determination of air quality risk areas for PM_{10} particles from local heating in Slovakia*[18], was proposed in 2021 and updated in 2022[19].

In 2023, the current integrated municipal assessment method with regard to the risk of adverse air quality[20] was proposed, which incorporates the rate of household heating with solid fuels, the impact of impaired dispersion conditions in the short and long term, the results of the CMAQ chemical-transport model, the RIO interpolation model, and the results of high-resolution CALPUFF modelling of selected domains with the assumption of impaired air quality (**Fig. 5.1**).

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



Risk levels from 0 to 3 are assigned to municipalities based on the described methodology with risk level 3 indicating the greatest risk of deteriorating air quality. Municipalities in which the limit value for

[18] *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.*

[19] *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*

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

a pollutant has been exceeded either according to high-resolution modelling or according to measurement are automatically assigned risk level 3.

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

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

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

There were no changes in the list of currently proposed Air Quality Management Areas compared to 2024.

5.2 SUMMARY

In 2024, the monitored values of air pollutants slightly increased compared to the previous year. A contributing factor in several months and locations was the lack of precipitation, which would otherwise have helped improve air quality. On the other hand, very high rainfall totals were recorded in September, which did result in reduced pollutant concentrations but also led to flooding events.

High PM concentrations were observed in January, November, and December due to prolonged and repeated episodes of adverse dispersion conditions. The highest PM_{10} values occurred on April 1st as a result of an extreme Saharan dust transport episode.

As in previous years, problems with exceeding the limit value for PM_{10} persisted in Slovakia. In 2024, the daily limit value for PM_{10} was exceeded at three monitoring stations (Jelšava, Plášťovce, Veľká Ida). At one station (Plášťovce), the annual limit value for $PM_{2.5}$ was also exceeded.

NO_2 values declined compared to the average for the years 2017–2023.

The most significant ongoing issue remains high concentrations of benzo(a)pyrene. The target value for benzo(a)pyrene was exceeded at the following monitoring stations: Veľká Ida, Letná; Jelšava, Jesenského; Oščadnica; Žarnovica; Krompachy, SNP; Ružomberok, Riadok; Púchov, 1. mája; and Žilina, Obežná.

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

List of tables

LIST OF ANNEXES