2021

AIR POLLUTION
IN THE SLOVAK REPUBLIC

Air quality monitoring department
SLOVAK HYDROMETEOROLOGICAL INSTITUTE

Bratislava, December 2022
Verzia 1

Material was elaborated by:

Slovak Hydrometeorological Institute
Air Quality Division
Jeséniova 17, 833 15 Bratislava

Responsible: M. Kremler

Coordination: M. Mladý, J. Jagnešáková

Editor: M. Mladý

Graphical design and processing K. Pukančíková

Authors:

Chapter 1 - J. Matejovičová, D. Štefánik, J. Krajčovičová, M. Mladý

Chapter 2 - B. Paveleková, M. Mitošinková, M. Mladý

Chapter 3 - B. Paveleková, M. Mitošinková, J. Matejovičová, V. Mináriková

Chapter 4 - D. Štefánik. J. Beňo, J. Krajčovičová, J. Matejovičová, G. Szabo

Chapter 5 - J. Krajčovičová, J. Matejovičová, D. Štefánik, J. Beňo

Annexes - L. Čaracký, M. Mladý, J. Matejovičová, V. Mináriková, J. Krajčovičová, V. Nemček

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

CONTENT

FOREWORD

The Slovak Hydrometeorological Institute (hereinafter referred to as SHMÚ) annually publishes the Air Quality Report as one of the results of the systematic and professional work of our Air Quality Division.

Air quality issues are not easy to understand, on the contrary. That is why we have tried to prepare the publication in such a way covering important information not only to experts, but also to the general public.

The report includes results combining monitoring and modelling of air quality, which we, as an authorized organization, carry out for the whole territory of the Slovak Republic. The resulting assessment is the outcome of all departments' work of the Air Quality Division as well as inputs from other divisions of our Institute, without whose help it would not have been possible to prepare this report. We are the only organization in Slovakia that carries out long-term monitoring of outdoor air quality 24 hours a day, 365 days a year. Expansion, renewal and improvement of monitoring are directly dependent on funding from the state budget, and above all also on funding from the European Union. Continuous operation of monitoring has been a major challenge for us in the last two years, to which we have been able to adapt despite the constraints resulting from the global pandemic. In addition, as part of the project Improving the National Air Quality Monitoring Network, we have managed to extend the monitoring network to new locations where monitoring had not been carried out before. Information on pollutant concentrations is obtained by continuous air monitoring at 52 stationary air quality stations. Measurements are performed with high precision using reference methods. The results of continuously monitored pollutants are available with hourly frequency directly on the SHMÚ website. Pollutants that require manual sampling and subsequent laboratory analysis are available in this report. The outputs from the monitoring, together with data on emission sources and weather, are used in air quality modelling, which provides spatial information on air quality throughout the Slovak Republic. Modelling is a useful indicator of pollution in locations not covered by a network of monitoring stations. The main task of the Report is to identify areas of deteriorated air quality, based on the air quality assessment for the past year, which are used by the competent authorities to ensure the goal of improving air quality in Slovakia.

We strive to continuously progress and provide comprehensive and reliable results in our daily work. That is why we are taking steps to improve air quality information throughout the Slovak Republic. All important and up-to-date information can be found on the SHMÚ website (*www.shmu.sk*) in the Air Quality Services and SHMÚ products/Air Quality.

Ministry of environment of the Slovak Republic upon the Act No. 137/2010 Coll. of Acts on air in wording of later prescriptions, with aim to secure information on air quality to the public, authorized the Slovak Hydrometeorological Institute by elaboration of:

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

Slovak Hydrometeorological Institute as authorized organization fulfils by this Report commitments resulting from §13 section (1) letters c) and d) cited Act and submits to the laic and expert public the Report, containing all belongings in such a way as requested in the Act No. 137/2010 Coll. of Acts on air in wording of later prescriptions.

1 DESCRIPTION OF THE TERRITORY OF SLOVAKIA IN TERM OF AIR QUALITY

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

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

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

Wind conditions

Direction of air circulation is mostly influenced by the general air circulation in central Europe and country relief. In Slovakia, prevails west and northwest air circulation (being modified in some locations, mainly in passes, valleys and basins as a consequence of relief). In Záhorie, southeast wind prevails over the northwest, in Danube lowlands it is opposite case. Northern air convection dominates in middle Považie, Ponitrie and east Slovakia.

In the lowlands of western Slovakia, the annual average wind speed in height of 10 meters above the surface varies between 3 – 4 $m \cdot s^{-1}$, on the eastern of Slovakia between 2 – 3 $m \cdot s^{-1}$.

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

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

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

- **Atmospheric precipitation**

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

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

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

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

1.1 COUNTRY BREAKDOWN INTO AGGLOMERATIONS AND ZONES IN 2021

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

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

1.1.1 Country breakdown into zones and agglomerations in 2021, for SO_2, NO_2, NO_X, PM_{10}, $PM_{2.5}$, benzene, polycyclic aromatic hydrocarbons and CO

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

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

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

		Area [km^2]	Population*
Bratislava region	(Bratislavský kraj)	2 053	723 714
Trnava region	(Trnavský kraj)	4 146	565 296
Trenčín region	(Trenčiansky kraj)	4 502	573 699
Nitra region	(Nitriansky kraj)	6 344	673 547
Žilina region	(Žilinský kraj)	6 809	689 525
Banská Bystrica region	(Banskobystrický kraj)	9 454	620 986
Prešov region	(Prešovský kraj)	8 973	807 657
Košice region	(Košický kraj)	6 754	780 288

** Status to 31. 12. 2021* *Source: Statistical Office of the SR*

1.1.2 Country breakdown into zones and agglomerations in 2021 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 at the territory of SR. In Slovakia, it is possible to observe a return to the combustion of solid fuels. Unlike in neighbouring Poland, where coal combustion is increasing, in our country it is mainly wood combustion. Wood combustion does not have a significant impact on arsenic concentrations in the air.

The issue of tropospheric ozone has a regional character; share of transport from stratosphere is significant and transboundary transport is also not negligible[1]. Road transport in bigger cities is the source of ozone precursors, but nitrogen oxides also cause ozone titration (chemical reaction of ozone with oxides of nitrogen causes ozone decay) near the busiest routes. Target value for human health protection is exceeded in several places in the territory of SR, especially in photochemical more active years and possible improvements by local measures are limited.

1.2 THE LIST OF AIR QUALITY MANAGEMENT AREAS FOR YEAR 2021

Zones and agglomerations create large territories and cover overall the whole territory of SR. In each zone is relatively variable spatial distribution of pollutant concentrations – it usually contains areas with significant emission sources and deteriorated air quality, but also relatively clean areas without this kind of sources. In order to facilitate the management of air quality, the so-called areas of air quality management were defined. These areas are the subset of individual zones and each zone can contain several of them.

In case, the measured concentrations of some air pollutant on respective monitoring station exceed limit or target value in monitored year, the respective area representing by measurement of its station, is (in coincidence with Act No. 137/2010 Coll. of Acts on air, as amended) announced as Area of air quality management (AQMA). The district office in the region will draw up a Programme for improving air quality for the given zone or agglomeration. In case, the limit or target values are exceeded for more pollutants, district office in the region will develop an integrated programme for AQMA.

Air quality monitoring and assessment is carried out by the Slovak Hydrometeorological Institute (SHMÚ), as accredited organization in all agglomerations and zones for air pollutants, for which are stated limit values or target values and for ozone precursors, in the manner established by the implementing regulation, according to § 33 letter d).

SHMÚ proposes annually the list of AQMA, upon the base of air pollution monitoring (for the period longer than one year). Pollutant is removed from AQMA list, if pollutant concentration on the station did not exceed the limit value within the three consecutive years.

In 2021, based on mathematical modelling and data on the type of fuels used for heating households, a list of at-risk municipalities was assigned[2], which were defined as "AQMA assigned on the basis of mathematical modelling". When defining the municipalities at risk, emphasis was placed on air pollution by heating households with solid fuel in areas with unfavourable air dispersion conditions. Therefore,

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

[2] *D. Štefánik: Určenie rizikových obcí s kvalitou ovzdušia ohrozenou lokálnym vykurovaním a zhoršenými rozptylovými podmienkami. SHMÚ, Bratislava, august 2021 dostupné na* https://www.shmu.sk/File/oko/studie_analyzy/ *Popis%20met%C3%B3dy%20na%20ur%C4%8Denie%20rizikov%C3%BDch%20oblast%C3%AD.pdf*

the inputs to this consideration were the share of solid fuels for household heating, the average wind speed and the outputs of mathematical modelling and other auxiliary data.

Areas of air quality management in SR, proposed by SHMÚ, upon the base of air quality assessment in zones and agglomerations in years 2018 – 2020 for year 2021, are presented in **Tab. 1.2** (*https://www.shmu.sk/sk/?page=2186*).

Tab. 1.2 *Air quality management areas for year 2021 defined according to the measurement of basic pollutants in the years 2018 – 2020 and mathematical modelling.*

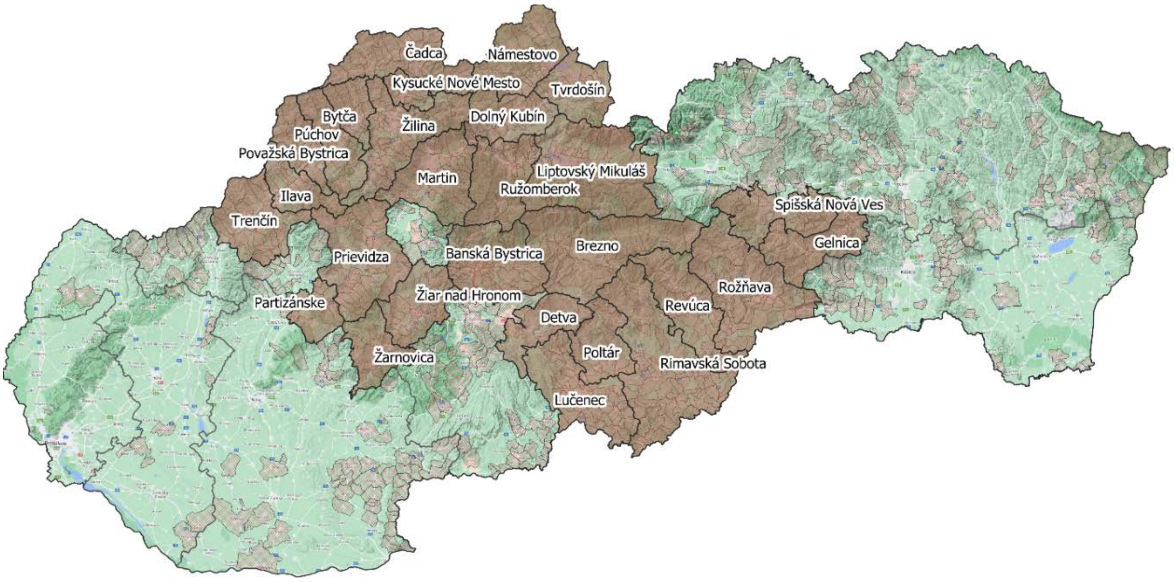
AGGLOMERATION Zone	Air quality management area	Pollutant	AMS and year of exceedance of limit/target value
BRATISLAVA	Territory of capital of SR, Bratislava	NO_2	Bratislava, Trnavské mýto (2018)
	Risk areas have been identified in the agglomeration on the basis of modelling*	PM_{10}, $PM_{2.5}$	
KOŠICE [3]	Territory of Košice city and municipalities Veľká Ida, Sokoľany, Bočiar and Haniska	PM_{10}, $PM_{2.5}$, BaP	PM_{10}: Košice, Štefánikova (2018 – 2019); Veľká Ida (2018 – 2019) $PM_{2.5}$: Veľká, Ida 2018 (24.4 µg·m^{-3}), 2019 (20.7 µg·m^{-3}) BaP: Veľká Ida (2009 – 2020)
	Risk areas have been identified in the agglomeration on the basis of modelling*	PM_{10}, $PM_{2.5}$	
Banská Bystrica region	Territory of Banská Bystrica city	PM_{10}, BaP	PM_{10}: Banská Bystrica, Štefánikovo nábr, (2018) BaP: BB Štefánikovo nábr. (2018 – 2020), Zelená (2019 – 2020)
	Territory of Jelšava city and municipalities Lubeník, Chyžné, Magnezitovce, Mokrá Lúka, Revúcka Lehota	PM_{10}, $PM_{2.5}$, BaP	PM_{10}: Jelšava (2018 – 2020) $PM_{2.5}$: Jelšava 2018 (23.7 µg·m^{-3}), 2019 (20.9 µg·m^{-3})
	Risk areas have been identified in the zone on the basis of modelling*	PM_{10}, $PM_{2.5}$	
Bratislava region	Risk areas have been identified in the zone on the basis of modelling*	PM_{10}, $PM_{2.5}$	
Košice region [4]	Territory of Krompachy city	BaP	Krompachy, SNP (2019 – 2020)
	Risk areas have been identified in the zone on the basis of modelling*	PM_{10}, $PM_{2.5}$	
Nitra region	Risk areas have been identified in the zone on the basis of modelling*	PM_{10}, $PM_{2.5}$	
Prešov region	Territory of Prešov city and municipality Ľubotice	NO_2	Prešov, Arm. gen. L. Svobodu (2018)
	Risk areas have been identified in the zone on the basis of modelling*	PM_{10}, $PM_{2.5}$	
Trenčín region	Territory of Trenčín city	PM_{10}	Trenčín, Hasičská (2018)
	Prievidza district	BaP	Prievidza, Malonecpalská (2020)
	Risk areas have been identified in the zone on the basis of modelling*	PM_{10}, $PM_{2.5}$	
Trnava region	Risk areas have been identified in the zone on the basis of modelling*	PM_{10}, $PM_{2.5}$	
Žilina region	Territory of Ružomberok city and municipality Likavka	$PM_{2.5}$	Ružomberok, Riadok 2018 (20.7 µg·m^{-3})
	Territory of Žilina city	$PM_{2.5}$, BaP	$PM_{2.5}$: Žiliina, Obežná 2018 (21.7 µg·m^{-3}) BaP: Žiliina, Obežná (2019 – 2020)
	Risk areas have been identified in the zone on the basis of modelling*	PM_{10}, $PM_{2.5}$	

** These areas are shown on the map of at-risk municipalities and districts* ***Fig. 5.1***

[3] *Agglomeration Košice - territory of the Košice city and municipalities Bočiar, Haniska, Sokoľany and Veľká Ida http://www.shmu.sk/sk/?page=1&id=oko_info_az*
[4] *Zone Košice region - territory of Košice region without Košice agglomeration http://www.shmu.sk/sk/?page=1&id=oko_info_az*

The map in **Fig. 1.1** shows the risk areas that have been defined as AQMA on the basis of modelling. These are areas at risk of poor air quality due to emissions from household heating, due to a higher proportion of solid fuel consumption for heating and worse dispersion conditions. The results of the CMAQ chemical-transport modelling and the shape of the terrain also enter into the calculation. In order to simplify the design of further measures to improve air quality, as well as for conservative reasons, districts containing at least 40% of at-risk municipalities have been defined as at-risk whole. Note: When interpreting the modelling results, it is important to bear in mind that modelling is burdened with more bias than air quality monitoring. The identification of the risk areas will be updated whenever more detailed data are available.

Fig. 1.1 *Map of risk municipalities and districts based on mathematical modelling for the year 2021.*



2 AIR QUALITY MONITORING NETWORK

Despite of the fact, the first air pollutant measurements in Slovakia were carried out in the second half of the fifties in 20th century, systematic monitoring in our territory begun in 1967, when the first Act on air protection (Act No. 35/1967 Coll. of Acts about measures against air pollution) entered into force. Measurements, which included at the beginning only SO_2 and dust fallout in Bratislava, Košice and surrounding, were gradually supplemented for other air pollutants and locations. Legislation has changed over time – adding more pollutants to be monitored and tightening the limit values. An example of the latest modification is the reduction of the limit value for the $PM_{2.5}$ annual average concentration, which has been changed to 20 $\mu g \cdot m^{-3}$ from 2020 (the previous limit value was 25 $\mu g \cdot m^{-3}$). The current form of Slovak legislation is an implementation of EU legislation (directions of European parliament and Council 2008/50/EC on ambient air quality and cleaner air in Europe). We can expect a tightening of legislative frameworks in the near future, especially following the new WHO recommendations in the area of air quality, which were presented in September 2021.As the aim of monitoring is to characterize air quality as best as possible, taking into account human health protection, the structure of monitoring network was proposed in such a way, as the individual stations characterize the extent of pollution in major pollution areas – in past those were mainly locations in vicinity of large industrial air pollution sources. These stations are also now a part of monitoring network, similarly as locations exposed to emissions from road transport. The monitoring plan is further enlarging extended to locations where household heating is the dominant source of air pollution, 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 the regional background stations. Pollutants depending on their properties (e.g. deposition, chemical reactivity) can persist in air even several days and according to air masses convection, can be transported on large distances. High concentrations of air pollutants can be therefore find also in relatively clean mountainous areas. Monitoring of air quality in regional background stations plays essential role also at the assessment of long-term air quality trends, because in case of other stations these trends are influenced predominantly by local sources.

Network of measurement stations under the name National monitoring air quality network (NMSKO) started to be build up already in ČSFR in 1991 (Závodský, 2010). Currently, it comprises continual measurements using automatic instruments and manual measurements based on the sampling and chemical analyses in the SHMÚ Testing laboratory as well as other external laboratories. Manual monitoring covers the air measurements of heavy metal concentrations, volatile organic compounds VOC and polycyclic aromatic hydrocarbons PAH in air and also air quality monitoring and analyses of precipitation quality on regional background stations, with monitoring programme EMEP (Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe). Location of NMSKO network monitoring stations and their measurements programme in year 2021 is presented in **Fig. 2.1**.

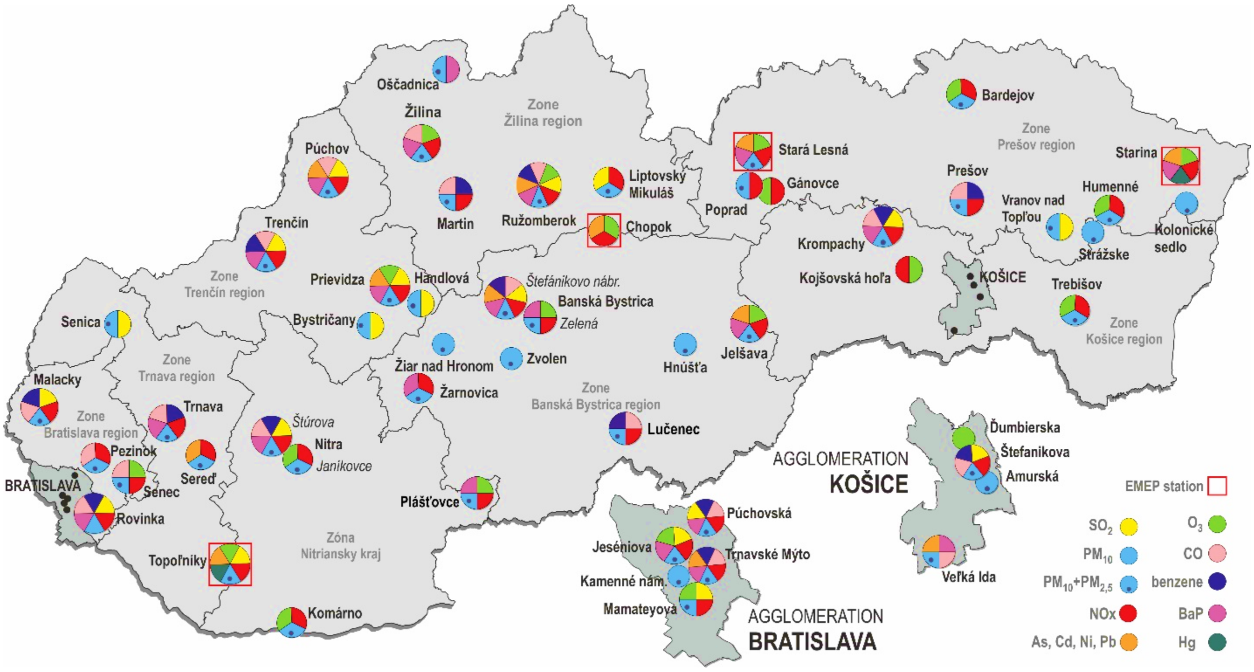
Detailed list of monitoring instruments of individual stations and methods which instruments used is described in "Annex A – Measurement stations of monitoring air quality networks – 2021".

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

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

Monitoring programme in EMEP network was gradually extended. Measurements of sulphur compounds and analyses of precipitation were enhanced for oxides of nitrogen, nitrates, ammonium ions in ambient air, particulate matter and ozone. In 1994, the measurements of volatile organic compounds (VOCs) began to be carried out under the auspices of Chemical Coordinating Centre – NILU (Norwegian Institute for Air Research in Kjeller). Later on, also heavy metals (HMs) and, from autumn 2020, organic and elemental carbon EC/OC in the air have been included into the measurement programme.

Fig. 2.1 National air quality monitoring network in year 2021.



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

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

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

AGLOMERATION Zone	Station name	Type of		Continuously								Manually	
		area	station	PM_{10}	$PM_{2.5}$	Oxides of nitrogen NO, NO_2, NO_X	Sulphur dioxide SO_2	Ozone O_3	Carbon monoxide CO	Benzene	Mercury Hg	Heavy metals As, Cd, Ni, Pb	Polyaromatic hydrocarbons BaP
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
	Together 5 stations			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
	Together 4 stations			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			
	Žiar nad Hronom, Jilemnického	U	B	x	x								
	Žarnovica, Dolná	S	B	x	x	x							x
	Zvolen, J. Alexyho	U	B	x	x								
	Together 8 stations			8	8	5	1	2	2	2		2	4
Bratislava region	Malacky, Mierové nám.	U	T	x	x	x	x		x	x			
	Pezinok, Obrancov mieru	U	B	x	x	x			x				
	Rovinka	S	B	x		x	x		x	x			x
	Senec, Boldocká	U	T	x	x	x		x	x				
	Together 4 stations			4	3	4	2	1	4	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
	Together 4 stations			3	3	3	1	2	1	1			1
Nitra region	Nitra, Štúrova	U	T	x	x	x	x		x	x			x
	Nitra, Janíkovce	U	B	x	x	x		x					
	Komárno, Vnútorná Okružná	U	B	x	x	x		x					
	Plášťovce	S	B	x	x	x		x					x
	Together 4 stations			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					
	Together 9 stations			7	7	7	1	5	1	1	1	2	2

AGLOMERATION Zone	Station name	Type of area	Type of station	Continuously PM$_{10}$	PM$_{2.5}$	Oxides of nitrogen NO, NO$_2$, NO$_X$	Sulphur dioxide SO$_2$	Ozone O$_3$	Carbon monoxide CO	Benzene	Mercury Hg	Manually Heavy metals As, Cd, Ni, Pb	Polyaromatic hydrocarbons BaP
Trenčín region	Prievidza, Malonecpalská	U	B	x	x	x	x	x				x	x
	Bystričany, Rozvodňa SSE	S	B	x	x		x						
	Handlová, Morovianska cesta	U	B	x	x		x						
	Trenčín, Hasičská	U	T	x	x	x	x		x	x			x
	Púchov, 1. mája	S	B	x	x	x	x		x			x	x
	Together 5 stations			5	5	3	5	1	2	1		2	3
Trnava region	Topoľníky, Aszód, EMEP	R	B	x	x	x	x	x			x	x	
	Senica, Hviezdoslavova	U	T	x	x		x						
	Trnava, Kollárova	U	T	x	x	x			x	x			x
	Sereď, Vinárska	U	B	x	x	x						x	
	Together 4 stations			4	4	3	2	1	1	1	1	2	1
Žilina region	Chopok, EMEP	R	B			x		x				x	
	Martin, Jesenského	U	T	x	x	x			x	x			
	Ružomberok, Riadok	U	B	x	x	x	x	x	x	x		x	x
	Žilina, Obežná	U	B	x	x	x		x	x				x
	Oščadnica	S	B	x	x								x
	Liptovský Mikuláš, Školská	U	B	x	x	x	x						
	Together 6 stations			5	5	5	2	3	3	2		2	3
NMSKO altogether 53 monitoring stations [5]				48	47	39	19	21	19	14	2	12	21

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

Air quality monitoring programme on EMEP stations in year 2021 is listed in **Tab. 2.2**. Ozone is measured continuously. Sampling interval for heavy metals is one week, for VOC once weekly 10 minutes and the other pollutants are analysed from 24-hour sampling.

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

	Ozone (O$_3$)	Sulphur dioxide (SO$_2$)	Nitrogen dioxide (NO$_2$)	Sulphates (SO$_4^{2-}$)	Nitrates (NO$_3^-$)	Nitric acid (HNO$_3$)	Chlorides (Cl)	Ammonia, Ammonium ions (NH$_3$, NH$_4^+$)	Alkali ions (K$^+$, Na$^+$, Ca^{2+}, Mg^{2+})	VOC	PM$_{10}$ / TSP*	EC/OC	Lead (Pb)	Arsenic (As)	Cadmium (Cd)	Nickel (Ni)	Chromium (Cr)	Cooper (Cu)	Zinc (Zn)	Mercury (Hg)**
Chopok	x	x	x	x	x	x	x				x*		x	x	x	x	x	x	x	
Topoľníky	x										x		x	x	x	x	x	x	x	x
Starina	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
Stará Lesná	x										x	x	x	x	x	x	x	x	x	

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

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

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

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

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

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

2.1 ASSESSMENT OF MONITORING EXTENT FOR INDIVIDUAL POLLUTANTS

Sulphur dioxide SO_2

This pollutant was monitored at 19 stations. Minimum required extent of monitoring[6] was fulfilled. Monitoring of sulphur dioxide was carried out continuously, using reference method, at all 19 stations. The required number of valid measured data (90%) was achieved at 16 monitoring stations, 3 monitoring stations started measuring during 2021 (Bratislava, Púchovská; Púchov, 1. mája and Liptovský Mikuláš, Školská), as also can be seen in the proportion of valid data.

Oxides of nitrogen NO_2 and NO_X

This pollutant was monitored at 39 stations. The minimum required monitoring coverage[6] was fulfilled. Nitrogen oxides were monitored continuously by the reference method at all 39 stations. The required number of valid measured data (90%) was achieved at 29 monitoring stations (only the new monitoring stations [Bratislava, Púchovská; Lučenec, Gemerská cesta; Žarnovica, Dolná; Senec, Boldocká; Trebišov, T. G. Masaryka; Komárno, Vnútorná Okružná; Plášťovce, Poprad, Železničná; Púchov, 1. mája and Liptovský Mikuláš, Školská], which were put into operation only in 2021, had a lower proportion of valid measurements).

Particulate matter PM_{10}

This pollutant was monitored at 48 stations. The minimum required monitoring coverage[6] was met. PM_{10} monitoring was provided by the equivalent, continuous oscillation microbalance method (TEOM devieces) and the beta radiation absorption method (BAM devices). The required number of valid measured data (90%) was reached at 38 monitoring stations (only the new monitoring stations [Bratislava, Púchovská; Lučenec, Gemerská cesta; Žarnovica, Dolná; Senec, Boldocká; Trebišov, T. G. Masaryka; Komárno, Vnútorná Okružná; Plášťovce, Poprad, Železničná; Púchov, 1. mája and Liptovský Mikuláš, Školská], which were put into operation only during 2021, had a lower proportion of valid measurements).

[6] *Number and location according to Appendix No. 6 to regulation of MoE SR No. 244/2016 Coll. A on air quality in reading of later directives*

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

- This pollutant was monitored at 47 stations. The minimum required monitoring coverage[6] was fulfilled. $PM_{2.5}$ monitoring was provided by the same method as PM_{10} measurements, by TEOM and BAM devices. The required number of valid measured data (90%) was reached at 36 monitoring stations (only the new monitoring stations [Bratislava, Púchovská; Lučenec, Gemerská cesta; Žarnovica, Dolná; Senec, Boldocká; Komárno, Vnútorná Okružná; Plášťovce; Poprad, Železničná; Púchov, 1. mája; Liptovský Mikuláš, Školská and Oščadnica], which were put into operation only in 2021, had a lower proportion of valid measurements).

- **Carbon monoxide CO**

This pollutant was monitored at 19 monitoring stations. The minimum required monitoring coverage[6] was fulfilled. Carbon monoxide was monitored continuously, by reference method, at 15 stations. The required number of valid measured data (90%) was reached at 15 monitoring stations (only the new monitoring stations [Bratislava, Púchovská; Lučenec, Gemerská cesta; Senec, Boldocká and Púchov, 1. mája], which were commissioned during 2021, had a lower proportion of valid measurements). CO concentrations were below the lower assessment threshold (LAT), the number of monitoring sites is therefore sufficient.

- **Ozone O_3**

Ozone was monitored at 21 monitoring stations. The minimum required monitoring coverage[6] was fulfilled. Ozone was monitored continuously, using reference method, at all 21 stations. The required number of valid measured data (90%) was achieved at 17 monitoring stations (only the new monitoring stations [Senec, Boldocká; Trebišov, T. G. Masaryka; Komárno, Vnútorná Okružná and Plášťovce], which were put into operation in 2021, had a lower proportion of valid measurements).

- **Benzene**

Benzene was monitored at 14 monitoring stations. The minimum required monitoring coverage[6] was met. Monitoring of benzene was provided continuously, by the reference method, at 12 stations, continuously by reference method. Required number of valid measured data (90%) was reached at all 12 stations (only the new monitoring stations [Bratislava, Púchovská and Lučenec, Gemerská cesta], which were put into operation in 2021, had a lower proportion of valid measurements).

- **Mercury**

Overall gas mercury was monitored at two EMEP stations (Topoľníky and Starina). Mercury monitoring was secured continuously, by differential Zeeman atomic absorption spectrometry. The proportion of valid measured data exceeded 90% at both monitoring stations.

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

Heavy metals were monitored at 12 monitoring stations. Samples for heavy metal analysis are collected at the urban stations every other day during 24 hours on nitrocellulose filter, then analysed at the SHMÚ Testing laboratory by gas chromatography. In 2021, heavy metals (Pb, As, Cd, Ni) were sampled at one suburban, seven urban and four EMEP monitoring stations (Pb, As, Cd, Ni, Cr, Zn, Cu – weekly sampling).

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

In 2021, benzo(a)pyrene monitoring was provided at 21 monitoring stations. Sampling was realized every third day for 24 hours on a quartz filter. After extraction, the samples are analysed at the SHMÚ Testing laboratory by gas chromatography with mass detection (GC-MS). The minimum required number of monitoring stations[6] was fulfilled.

VOC

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

EC/OC

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

Air quality monitoring on EMEP stations

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

Atmospheric precipitation monitoring on EMEP stations

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

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

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

	District	Station name*	Type of		Geographical		Altitude [m]
			area	station	longitude	latitude	
BRATISLAVA	Bratislava II	Bratislava, Vlčie Hrdlo (Slovnaft, a.s.)	S	I	17°10'10"	48°08'00"	134
	Bratislava II	Bratislava, Pod. Biskupice (Slovnaft, a.s.)	U	B	17°12'20"	48°08'05"	132
KOŠICE	Košice II	Košice, Haniska (U.S. Steel, s.r.o.)	S	I	21°15'07"	48°36'54"	212
	Košice II	Košice, Poľov (U.S. Steel, s.r.o.)	R	B	21°11'54"	48°39'40"	271
Bratislava region	Senec	Rovinka (Slovnaft, a.s.)	S	B	17°13'40"	48°06'15"	133
Košice region	Košice - surrounding	Veľká Ida (U.S. Steel, s.r.o.)	S	I	21°10´12"	48°33´35"	208
	Trebišov	Leles (Slovenské elektrárne, a.s.)	R	B	22°01´23"	48°27´46"	100
Nitra region	Šaľa	Trnovec nad Váhom (Duslo, a.s.)	S	B	17°55'43"	48°08'60"	114
Trenčín region	Prievidza	Oslany (Slovenské elektrárne, a.s.)	S	B	18°28´12"	48°37´60"	228
Žilina region	Ružomberok	Ružomberok (Mondi a.s. - Supra)	U	I	19°19'12"	49°04'43"	478

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

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

3 AIR QUALITY ASSESSMENT IN AGGLOMERATIONS AND ZONES OF SLOVAKIA

3.1 INTRODUCTION

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

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

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

3.2 AIR QUALITY ASSESSMENT CRITERIA

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

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

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

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

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

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

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

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

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

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

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

* *Permitted number of exceedances is listed in brackets*

** *Limit value for $PM_{2.5}$ until 1.1.2020: 25 $\mu g \cdot m^{-3}$*
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.*

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

3.3 AIR QUALITY MONITORING RESULTS - LOCAL AIR POLLUTION

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

Tab. 3.3 *Proportion of valid data* in % in year 2021.*

AGGLOMERATION Zone	Pollutant	SO_2	NO_2	PM_{10}	$PM_{2.5}$	CO	Benzene	O_3
BRATISLAVA	Bratislava, Kamenné nám.			99	99			
	Bratislava, Trnavské mýto		96	99	99	96	98	
	Bratislava, Jeséniova	96	96	99	98			98
	Bratislava, Mamateyova	95	95	99	99			97
	Bratislava, Púchovská*	55	56	58	58	55	10	
KOŠICE	Košice, Štefánikova	94	96	99	99	96	99	
	Košice, Amurská			99	99			
	Košice, Ďumbierska							96
	Veľká Ida, Letná			99	99	96		
Banská Bystrica region	Banská Bystrica, Štefánik. nábr.	95	95	99	99	95	97	
	Banská Bystrica, Zelená		95	98	98			94
	Jelšava, Jesenského		96	99	99			95
	Hnúšťa, Hlavná			98	99			
	Lučenec, Gemerská cesta*		4	8	8	4	0.5	
	Zvolen, J. Alexyho			95	95			
	Žarnovica, Dolná*		43	42	42			
	Žiar n/H, Jilemnického			99	99			
Bratislava region	Malacky, Mierové nám.	96	96	99	99	96	99	
	Pezinok, Obrancov mieru*		97	98	97	94		4
	Rovinka	97	97	99		97	98	
	Senec, Boldocká*		32	27	27	32		32
Košice region	Kojšovská hola		95					95
	Trebišov, T. G. Masaryka*		88	91	91			90
	Strážske, Mierová			99	99			
	Krompachy, SNP	94	96	99	99	96	98	
Nitra region	Nitra, Janíkovce		96	99	99			95
	Nitra, Štúrova	94	96	99	99	96	99	
	Komárno, Vnútorná Okružná*		59	59	59			61
	Plášťovce*		50	53	53			55
Prešov region	Gánovce, Meteo. st.		96					96
	Humenné, Nám. Slobody		96	99	99			96
	Prešov, Arm. gen. L. Svobodu		96	99	99	96	99	
	Vranov n/T, M. R. Štefánika	96		99	99			
	Stará Lesná, AÚ SAV, EMEP		94	99	98			96
	Starina, Vodná nádrž, EMEP		95					93
	Kolonické sedlo, Hvezdáreň			96	96			
	Poprad, Železničná*		43	42	44			
	Bardejov, Pod Vinbargom		96	99	98			98
Trenčín region	Prievidza, Malonecpalská	95	95	99	99			95
	Bystričany, Rozvodňa SSE	95		99	99			
	Handlová, Morovianska cesta	95		98	98			
	Púchov, 1. mája*	33	33	28	28	33		
	Trenčín, Hasičská	96	96	99	99	96	97	
Trnava region	Senica, Hviezdoslavova	94		99	98			
	Trnava, Kollárova		96	99	99	95	99	
	Topoľníky, Aszód, EMEP	97	97	97	96			96
	Sereď, Vinárska		95	99	99			

AGGLOMERATION Zone	Pollutant	SO_2	NO_2	PM_{10}	$PM_{2.5}$	CO	Benzene	O_3
Žilina region	Chopok, EMEP		95					91
	Liptovský Mikuláš, Školská*	13	5	15	15			
	Martin, Jesenského		96	99	99	94	99	
	Oščadnica*			7	7			
	Ružomberok, Riadok	96	96	99	99	96	98	**85
	Žilina, Obežná		96	99	99	95		95

*(green) ≥ 90% of valid measurements   * AMS started measuring during 2021   ** will be added to the database

Air quality assessment according to limit values (LV) for the protection of human health for SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and benzene for individual monitoring stations and pollutants in 2021 is presented in **Tab. 3.4**. The number of alert threshold exceedances is also presented in the table.

Tab. 3.4 *Air quality assessment according to limit values for human health protection and numbers of warning threshold exceedances – 2021.*

AGGLOMERATION Zone		Health protection									AT2)	
	Pollutant	SO_2		NO_2		PM_{10}		$PM_{2.5}$	CO	Benzene	SO_2	NO_2
	Averaging period	1 h	24 h	1 h	1 year	24 h	1 year	1 year	8 h 1)	1 year	3 h consecutively	3 h consecutively
	Parameter	number of exceedances	number of exceedances	average	number of exceedances	average	average	average	average	number of exceedances	number of exceedances	number of exceedances
	Limit value [μg·m⁻³]	350	125	200	40	50	40	20	10 000	5	500	400
	Maximum number of exceedances	24	3	18		35						
BRATISLAVA	Bratislava, Kamenné nám.					5	18	13				
	Bratislava, Trnavské mýto			0	33	16	24	15	928	0.74		0
	Bratislava, Jeséniova	0	0	0	9	2	16	13			0	0
	Bratislava, Mamateyova	0	0	0	17	5	19	14			0	0
	Bratislava, Púchovská*	0	0	0	13	0	18	12	781	0.80	0	0
KOŠICE	Košice, Štefánikova	0	0	0	22	28	28	18	1500	0.66	0	0
	Košice, Amurská					21	25	18				
	Veľká Ida, Letná					56	35	21	2186			
Banská Bystrica region	Banská Bystrica, Štefánik.nábr.	0	0	2	25	38	30	19	1828	0.85	0	0
	Banská Bystrica, Zelená			0	10	8	20	14				0
	Jelšava, Jesenského			0	9	68	34	24				0
	Hnúšťa, Hlavná					13	25	16				
	Lučenec, Gemerská cesta*			0	20	3	31	**27	1059	3.12		0
	Zvolen, J. Alexyho					7	20	15				
	Žarnovica, Dolná*			0	12	19	28	**23				0
	Žiar n/H, Jilemnického					3	17	13				
Bratislava region	Malacky, Mierové nám.	0	0	0	16	4	21	15	1248	0.59	0	0
	Pezinok, Obrancov mieru*			0	16	11	22	12	1113			0
	Rovinka	1	0	0	12	7	22		665	0.93	0	0
	Senec, Boldocká*			0	23	4	25	20	1070			0
Košice region	Kojšovská hola			0	5							0
	Trebišov, T. G. Masaryka*			0	12	20	23	17				0
	Strážske, Mierová					12	22	18				
	Krompachy, SNP	0	0	0	14	26	25	20	1574	0.90	0	0
Nitra region	Nitra, Janíkovce			0	9	5	20	14				0
	Nitra, Štúrova	0	0	0	27	9	25	16	1611	0.63	0	0
	Komárno, Vnútorná Okružná*			0	13	12	30	14				0
	Pláštovce*			0	6	23	28	**24				0

AGGLOMERATION Zone	Pollutant	SO_2		NO_2		PM_{10}		$PM_{2.5}$	CO	Benzene	AT[2)] SO_2	AT[2)] NO_2
		Health protection									AT[2)]	
	Averaging period	1 h	24 h	1 h	1 year	24 h	1 year	1 year	8 h [1)]	1 year	3 h consecutively	3 h consecutively
	Parameter	number of exceedances	number of exceedances	average	number of exceedances	average	average	average	average	number of exceedances	number of exceedances	number of exceedances
	Limit value [µg·m⁻³]	350	125	200	40	50	40	20	10 000	5	500	400
	Maximum number of exceedances	24	3	18		35						
Prešov region	Gánovce, Meteo. st.			0	8							0
	Humenné, Nám. slobody			0	10	23	25	18				0
	Prešov, Arm. gen. L. Svobodu			0	33	22	27	18	1472	1.01		0
	Vranov n/T, M. R. Štefánika	0	0			16	22	16			0	
	Stará Lesná, AÚ SAV, EMEP			0	5	1	12	8				0
	Starina, Vodná nádrž, EMEP			0	3							0
	Kolonické sedlo, Hvezdáreň					1	16	11				
	Poprad, Železničná*			0	17	1	16	10				0
	Bardejov, Pod Vinbargom			0	10	7	20	15				0
Trenčín region	Prievidza, Malonecpalská	0	0	0	15	5	20	16			0	0
	Bystričany, Rozvodňa SSE	0	0			5	20	17			0	
	Handlová, Morovianska cesta	0	0			4	19	18			0	
	Púchov, 1. mája*	0	0	0	13	2	26	**22	1201		0	0
	Trenčín, Hasičská	0	0	0	23	18	27	15	1236	0.90	0	0
Trnava region	Senica, Hviezdoslavova	0	0			9	22	15			0	
	Trnava, Kollárova			0	28	7	22	16	1140	0.74		0
	Topoľníky, Aszód, EMEP	0	0	0	6	3	17	13			0	0
	Sereď, Vinárska			0	14	6	20	15				0
Žilina region	Chopok, EMEP			0	2							0
	Liptovský Mikuláš, Školská*	0	0	0	26	5	26	**23			0	0
	Martin, Jesenského			0	21	28	29	21	1232	0.95		0
	Oščadnica*					6	39	**35				
	Ružomberok, Riadok	0	0	0	16	15	24	19	2113	1.20	0	0
	Žilina, Obežná			0	19	24	25	19	2050			0

≥90% of valid measurements

1) maximum 8-hour concentration

** AMS started to measure in 2021*

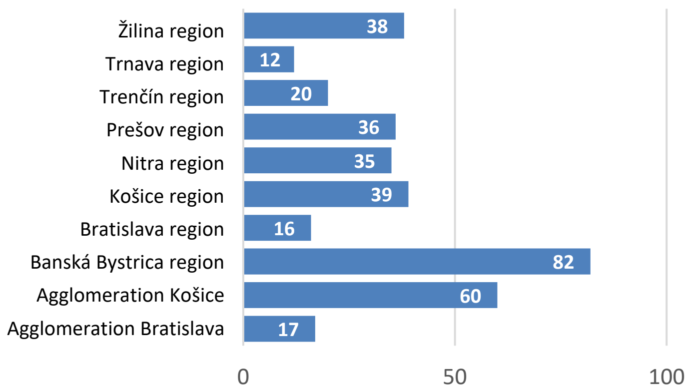
Exceedances of limit value are marked in red.

2) Limit values for alert thresholds (AT)

*** There were not enough measurements for a full year assessment in 2021*

The limit value for the average daily PM_{10} concentration (the average daily PM_{10} concentration must not exceed 50 µg·m⁻³ more than 35 times per calendar year) was exceeded in 2021 only at three monitoring stations – Veľká Ida, Letná; Banská Bystrica, Štefánikovo nábr. and Jelšava, Jesenského.

Fig. 3.1 *Number of days with the average daily PM_{10} concentration > 50 µg·m⁻³ at a minimum of one station in agglomeration/zone.*



Counting all the days, in which at least on one station in given zone (agglomeration) exceeded the average daily concentration of 50 µg·m^{-3}, we get 82 exceedances for Banská Bystrica region. In 2020, this parameter had a value of 53. It is the highest value of this parameter among all zones and agglomerations in year 2020 (**Fig. 3.1**). The station Jelšava, Jeséniova (68 exceedances) contributed the most to the total of 82 exceedances, followed by Banská Bystrica, Štefánikovo nábrežie (38 exceedances). The station Veľká Ida (56 exceedances) contributed the most to the high number of exceedances in the Košice agglomeration.

Fig. 3.2 and **Fig. 3.3** compare the dependence of measured $PM_{2.5}$ and NO_2 values and meteorological parameters for different types of stations (urban background station in Jelšava, traffic station in Banská Bystrica and Bratislava, suburban industrial station in Veľká Ida).

Fig. 3.2 *Comparison of the dependence of average monthly $PM_{2.5}$ concentrations with average wind speed and temperature in 2017 – 2021.*

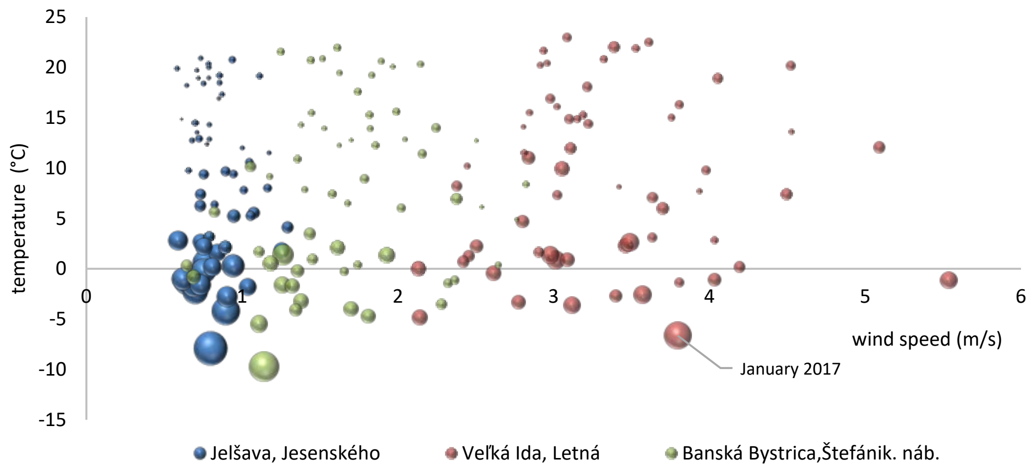
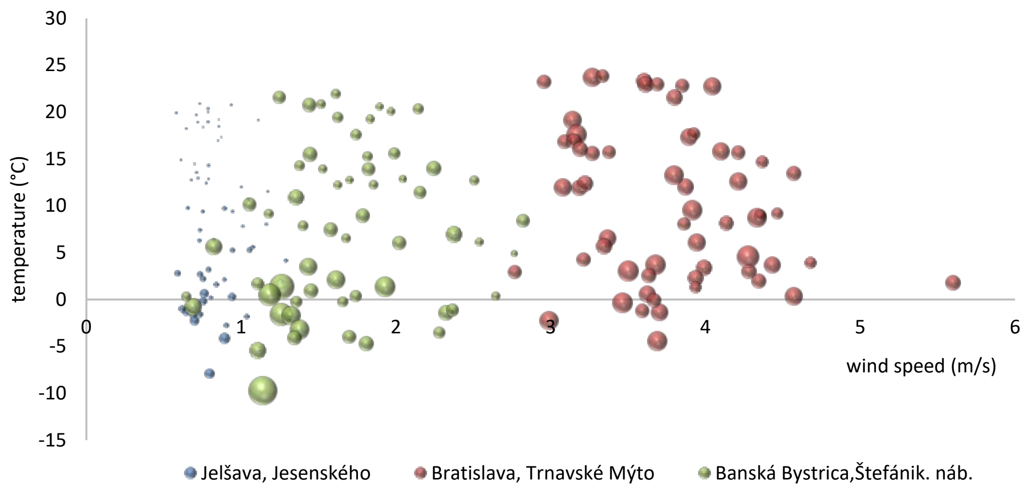


Fig. 3.3 *Comparison of the dependence of average monthly NO_2 concentrations with average wind speed and temperature in 2017 – 2021.*



Comparing the dependence of $PM_{2.5}$ concentrations on the average monthly temperature and wind speed (**Fig. 3.2**), we can see that while higher $PM_{2.5}$ values in Jelšava and in Banská Bystrica, Štefánikovo nábr. are measured in the cold season, in Veľká Ida they can occur at any time of the year, which is characteristic of the year-round influence of the metallurgical complex. The highest concentrations were recorded at all stations in the extremely cold month of January 2017. It is likely that in Veľká Ida, in addition to the impact of the industrial source of air pollution, household heating from a people of marginalised group living nearby is also a factor. At the same time, low wind speeds are strongly discernible in Jelšava, which are related to worse dispersion conditions.

In the case of NO_2, the increase in concentrations in the cold season in Jelšava and Banská Bystrica is expected to be smaller than for $PM_{2.5}$, and in the case of the traffic station in Bratislava, Trnavské mýto, the increase in the cold months does not manifest itself at all.

Tab. 3.5 *Air pollution assessment by heavy metals (As, Cd, Ni a Pb) – 2021.*

AGGLOMERATION Zone	Pollutant		As	Cd	Ni	Pb
	Pollutant	[ng·m⁻³]	As	Cd	Ni	Pb
	Target value	[ng·m⁻³]	6.0	5	20	-
	Limit value	[ng·m⁻³]	-	-	-	500
	Upper assessment threshold	[ng·m⁻³]	3.6	3	14	350
	Lower assessment threshold	[ng·m⁻³]	2.4	2	10	250
BRATISLAVA	Bratislava, Trnavské mýto		0.3	0.1	0.9	5.3
Slovakia	Banská Bystrica, Štefánik. náb.		0.4	0.3	2.6	9.4
	Jelšava, Jesenského		0.3	0.2	0.7	3.7
	Ružomberok, Riadok		0.4	0.2	0.9	5.1
	Velká Ida, Letná		0.5	0.5	1.3	19.4
	Prievidza, Malonecpalská		0.6	0.1	1.2	4.2
	Sereď, Vinárska		0.3	0.2	1.6	44.9
	Púchov, 1. mája*		1.0	0.3	0.7	5.5

** Measurements at the station Púchov, 1. mája started on 16. 10. 2021, the average value is therefore not representative for a year-long assessment.*

In **Tab. 3.6** are presented annual mean concentrations of benzo(a)pyrene (BaP) in air according to measurements in years 2017 – 2021.

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

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

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

** PAH measurements started during the year - on 14. 11. 2021 at AMS Bratislava, Púchovská (however, there was no measurement here in December due to a technical failure), on 19. 6. 2021 in Plášťovce, on 16. 10. 2021 in Púchov and on 7.12. in Oščadnica – therefore there are not enough valid measurements for a full year assessment. PAH monitoring at Trenčín was not carried out due to a technical failure during June and December.*

According to the annual assessment, the target value for benzo(a)pyrene was exceeded again in 2021 at majority of stations (Veľká Ida, Letná; Banská Bystrica, Štefánikovo nábrežie; Banská Bystrica, Zelená; Jelšava, Jesenského; Krompachy, SNP; Prievidza, Malonecpalská; Žilina, Obežná; Ružomberok, Riadok and Žarnovica, Dolná). Measurements in Žarnovica were carried out until the end of August at the mobile station, then at the AMS.

The highest values were measured at the monitoring station in Veľká Ida (the maximum concentration of 41.5 ng·m^{-3} was recorded on 7 October 2021, the other three average daily concentrations were higher than 30 ng·m^{-3}). At the AMS in Veľká Ida, the annual average concentration also increased the most compared to the previous year.

The most significant source of benzo(a)pyrene at most of the monitored sites is household heating with solid fuel, the exception is Veľká Ida, where the dominant source is a metallurgical complex with coke production, household heating is less significant here. The extremely high average value in Oščadnica is the average of 9 samples taken only during the heating season – measurements started here in December 2021 (two average daily concentrations were higher than 20 ng·m^{-3}).

Occurrence and period of pollution duration at the level of alert thresholds for SO_2 during the last 8 years is presented in **Tab. 3.7**. Alert threshold for SO_2 in NMSKO was exceeded last time in 2013 on AMS Bystričany, Rozvodňa SSE. Alert threshold for NO_2 was not exceeded during 2014 – 2021.

Tab. 3.7 *Assessment of SO_2 air pollution according to the occurrence and duration of exceedance alert threshold in 2014 – 2021 on station Bystričany, Rozvodňa SSE.*

Year	2014	2015	2016	2017	2018	2019	2020	2021
Number of alert threshold exceedances	0	0	0	0	0	0	0	0
Duration in hours	0	0	0	0	0	0	0	0

Legislation sets out the conditions for the announcement of a smog situation also for PM_{10} to protect human health, also at the shorter-term deterioration in air quality. According to Regulation of MoE SR No. 244/2016 Coll. of Acts on air quality, as amended, the announcement of a smog situation also for particulate matter PM_{10} is issued in case if the 12-hour moving average of PM_{10} concentration exceeds the information threshold 100 μg·m^{-3}, and at the same time, according to the air pollution development and upon the base of meteorological forecast, it is not reasonable to expect a decrease in the concentration of this pollutant in the course of the next 24 hours below the value of information threshold.

Serious smog warning for particles PM_{10} is issued, if the 12-hour moving average of PM_{10} concentrations exceeds alert threshold of 150 μg·m^{-3}, and at the same time, according to the air pollution development and the meteorological forecast, is not reasonable to expect a decrease in the concentration of this pollutant below the alert threshold within the next 24 hours.

Conditions for issuing the announcement of termination of a smog situation or announcement of cancellation of the serious smog warning occur, if PM_{10} concentration does not exceed the respective threshold value and these conditions persists:

- Conditions for issuing a notice of termination of a smog situation or a notice of lifting of a severe smog warning if the concentration of PM_{10} does not exceed the relevant threshold value and the condition persist: continuously 24 hours, and according to the air pollution development and the meteorological forecast is not reasonably to expect the respective threshold value to be exceeded again within the following 24 hours, or
- for at least 3 hours and, according to the air pollution development and meteorological forecast, it is almost impossible that the respective threshold value will be exceeded again within the next 24 hours.

The duration of exceedances of the information and warning threshold[7] for PM_{10} in 2021 compared to 2020 is shown in **Tab. 3.8**. In 2021, we observed an almost threefold increase in the number of hours

[7] *Announcement about the initiation of smog situation, or warning before serious smog situation were delivered in case of achievement the above-mentioned conditions.*

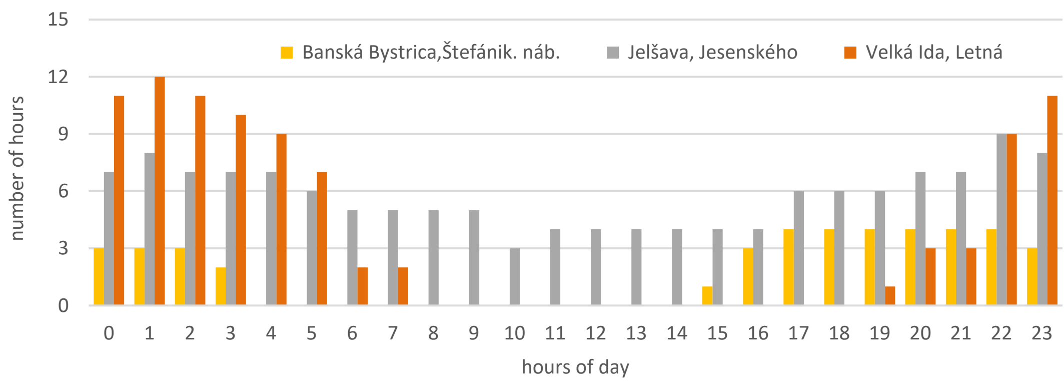
with an exceedance of the information threshold compared to 2020. The alert threshold was not exceeded in 2021.

Tab. 3.8 Duration of information and warning thresholds for PM_{10} in 2021 compared to 2020.

	Type		2020		2021	
			Duration of exceedance [h]		Duration of exceedance [h]	
Station	area	station	information threshold	alert threshold	information threshold	alert threshold
Bratislava, Trnavské Mýto	U	T	11		13	
Bratislava, Mamateyova	U	B			1	
Košice, Amurská	U	B	1		6	
Košice, Štefánikova	U	T			55	
Veľká Ida, Letná	S	I	12		91	
Banská Bystrica, Štefánik. náb.	U	T	4		42	
Jelšava, Jesenského	U	B	33		138	
Hnúšťa, Hlavná	U	B			8	
Žarnovica, Dolná	S	B			11	
Pezinok	U	B			29	
Rovinka, mobil AMS	S	B	10			
Senec, Boldocká	U	T			9	
Krompachy, SNP	U	T	21		9	
Nitra, Štúrova	U	T			5	
Plášťovce	S	B			8	
Humenné, Nám. Slobody	U	B			14	
Prešov, Arm. gen. L. Svobodu	U	T			22	
Vranov nad Top., M. R. Štefánika	U	B				
Prievidza, Malonecpalská	U	B				
Handlová, Morovianska cesta	U	B			1	
Trenčín, Hasičská	U	T			18	
Senica, Hviezdoslavova	U	T				
Trnava, Kollárova	U	T			6	
Liptovský Mikuláš, Školská	U	B			8	
Oščadnica	S	B			11	
Ružomberok, Riadok	U	B	80	3	10	
Martin, Jesenského	U	T	8		9	
Žilina, Obežná	U	B			1	

The highest number of hours with an exceedance of the information threshold was recorded in 2021 at the monitoring station Jelšava, Jesenského (138), with exceedances at this station measured during January, February and December. In Jelšava, in addition to low temperatures, the influence of temperature inversions is also evident. Fig. 3.4 illustrates the exceedances of the information threshold during day. Most of the exceedances were recorded in the evening and night hours, which, with the prevailing influence of household heating, may indicate different heating intensities during the day, but evening and night temperature inversions also play a role. The peculiarity is that in Jelšava the exceedances of the information threshold in 2021 occurred at any hour of the day.

Fig. 3.4 Number of hours with exceedance of information threshold for PM_{10} – comparison of AMS Jelšava, Jesenského, Ružomberok Riadok and Veľká Ida, Letná – according to hours of day.



Air quality assessment is carried out by continuous measurements in agglomerations and zones in such places, where the air pollution level is higher than the upper threshold for air pollution level assessment. Where sufficient data are available, the upper and lower threshold exceedances for air pollution level assessment have to 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 from the last five years.

In case, the less than five years data are available, the exceedances of the upper and lower thresholds for air pollution level assessment can be identified by combining results from measurement campaigns of shorter duration, carried out over a one-year period – namely in locations, with probably the highest air pollution levels and results obtained from emission inventories and modelling (Regulation of MoE SR No. 244/2016 Coll. on air quality, as amended). The classification of monitoring stations according to the upper and lower assessment thresholds is presented in **Tab. 3.9** and **Tab. 3.10**.

Tab. 3.9 *Classification of AMS according to upper assessment thresholds (UAT) resp. lower assessment thresholds (LAT) to determine the air quality assessment method in 2017–2021.*

AGLOMERATION Zone	Station	UAT and LAT with regard to human health protection																							
		SO_2			SO_2						SO_2						SO_2			SO_2			SO_2		
		24h average			24h average			24h average			24h average			24h average			24h average			24h average			24h 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	> ULA	≤ ULA; >LLA	≤ LLA
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
KOŠICE	Košice, Štefánikova			x		x			x		x			x			x					x			x
	Košice, Amurská										x				x		x								
	Veľká Ida, Letná										x			x			x					x			
Banská Bystrica region	Banská Bystrica, Štefánikovo nábr.			x			x		X		x			x			x					x			x
	Banská Bystrica, Zelená						x			x		x				x		x							
	Zvolen, J. Alexyho										x					x		x							
	Jelšava, Jesenského						x			x	x			x			x								
	Hnúšťa, Hlavná										x				x			x							
	Žarnovica, Dolná**																								
	Lučenec, Gemerská cesta**																						x		
	Žiar nad Hronom, Jilemnického											x				x		x							
Bratislava region	Malacky, Mierové nám.			x			x			x	x				x			x				x			x
	Pezinok						x			x	x					x			x			x			
	Rovinka			x			x			x	x				x							x			x
	Senec, Boldocká**																								
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**																								
Nitra region	Nitra, Janíkovce						x			x	x					x		x							
	Nitra, J. Štúrova			x			x		x		x				x			x				x			x
	Komárno, Vnútorná Okružná**																								
	Pláštovce**																								

AGLOMERATION Zone	Station	UAT and LAT with regard to human health protection																							
		SO_2			SO_2						SO_2						SO_2			SO_2			SO_2		
		24h average			24h average			24h average			24h average			24h average			24h average			24h average			24h 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	> ULA	≤ ULA; >LLA	≤ LLA
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**																								
	Bardejov, Pod Vinbargom						x			x		x				x		x							
Trenčín region	Prievidza, Malonecpalská			x			x			x	x					x		x							
	Bystričany, Rozvodňa SSE			x							x					x		x							
	Handlová, Morovianska cesta			x							x					x		x							
	Púchov, 1. mája**																								
	Trenčín, Hasičská			x			x		x		x				x			x				x			x
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**																								
	Oščadnica**																								
	Chopok, EMEP*						x			x															
	Ružomberok, Riadok			x			x			x	x				x		x					x			x
	Žilina, Obežná						x			x	x				x		x					x			

* *stations indicate regional background level.*   *** AMS started to measure in the course of year 2021*

***Tab. 3.10** AMS stations monitoring heavy metals and benzo(a)pyrene according to upper assessment threshold (UAT) and lower assessment threshold (LAT) to determine the air quality assessment method in 2017 – 2021.*

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*															
Veľká Ida, Letná			x			x			x			x	x		
Banská Bystrica, Štefánikovo nábr.			x			x			x			x	x		
Banská Bystrica, Zelená													x		
Jelšava, Jesenského			x			x			x			x	x		
Žarnovica, Dolná*															
Rovinka														x	
Krompachy, SNP						x			x			x	x		
Nitra, Štúrova													x		
Plášťovce*															
Starina, Vodná nádrž, EMEP															x
Stará Lesná, EMEP															x
Prievidza, Malonecpalská						x			x			x	x		

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
Trenčín, Hasičská**															
Púchov, 1. mája*															
Trnava, Kollárova														x	
Žilina, Obežná													x		
Ružomberok, Riadok			x			x			x			x			
Oščadnica*															
Sereď, Vinárska*			x			x			x			x			

** AMS started to measure during 2021* *** data outage due to technical failure*

Tab. 3.11 shows the annual average concentrations of tropospheric ozone in 2009 – 2021 compared to the photochemical extremely active year 2003.

Tab. 3.11 *Annual average concentrations of ground-level ozone [$\mu g \cdot m^{-3}$] in years 2003 and 2009 – 2021.*

Station	2003	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Bratislava, Jeséniova	71	60	61	63	65	62	60	71	56	64	68	66	61	62
Bratislava, Mamateyova	53	48	46	51	53	48	46	54	36	51	54	54	49	50
Košice, Ďumbierska	68	81	63	73	62	61	55	57	55	55	63	56	46	49
Banská Bystrica, Zelená		53	56	60	66	66	58	48	45	57	56	47	48	54
Jelšava, Jesenského	55	49	44	-	-	41	36	45	48	49	49	45	39	41
Kojšovská hoľa	91	85	90	87	83	78	75	61	81	80	82	78	72	74
Nitra, Janíkovce		74	53	-	62	58	52	63	43	60	60	54	56	58
Humenné, Nám. slobody	66	59	53	53	55	60	40	41	50	52	51	54	49	49
Stará Lesná, AÚ SAV, EMEP	67	61	67	65	63	71	56	66	58	63	67	59	57	47
Gánovce, Meteo. st.	68	62	63	64	66	67	58	66	38	53	56	57	51	53
Starina, Vodná nádrž, EMEP	73	58	51	59	60	64	55	64	58	60	64	62	54	57
Prievidza, Malonecpalská		50	49	51	52	50	53	54	39	51	52	49	46	47
Topoľníky, Aszód, EMEP	67	59	55	-	59	64	51	51	49	47	54	55	24	49
Chopok, EMEP	109	90	87	96	93	96	52	88	91	98	95	90	91	89
Žilina, Obežná	48	48	47	48	49	53	42	36	43	38	44	44	36	38
Ružomberok, Riadok									37	37	36	36	35	40
Bardejov, Pod Vinbargom														44
Trebišov, T. G. Masaryka														49
Plášťovce														49
Komárno, Vnútorná Okružná														47
Senec, Boldocká														35
Average	65	62	59	61	63	63	53	58	52	57	59	57	51	50

≥ 90% requested valid data

Regulation of MoE SR No. 244/2016 Coll. of Acts on air quality, as amended, determines a ozone target value for the protection of human health as follows: *The highest daily 8-hour mean concentration shall not exceed 120 $\mu g \cdot m^{-3}$ for more than 25 days per calendar year in an average of three year**. The number of days with exceedances of the ground-level ozone target value is shown in **Tab. 3.12**.

**<u>Methodical note</u>: 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 it ends, i.e., the first calculation period for any one day is the period from 17.00 hour on the previous day to 1.00 on that day; the last calculation period for any one day is the period from 16.00 to the end of that day).*

***Tab. 3.12** Number of days with exceedances of the ground-level ozone target value for the protection of human health.*

Station	2019	2020	2021	Average 2019 – 2021
Bratislava, Jeséniova	40	17	23	27
Bratislava, Mamateyova	32	12	15	20
Košice, Ďumbierska	6	0	0	2
Banská Bystrica, Zelená	2	0	3	2
Jelšava, Jesenského	4	2	2	3
Kojšovská hoľa	11	2	4	6
Nitra, Janíkovce	10	9	15	11
Humenné, Nám. Slobody	3	3	1	2
Stará Lesná, AÚ SAV, EMEP	3	5	0	3
Gánovce, Meteo. st.	0	0	0	0
Starina, Vodná nádrž, EMEP	3	4	0	2
Prievidza, Malonecpalská	1	2	3	2
Topoľníky, Aszód, EMEP	19	0	3	7
Chopok, EMEP	36	33	22	30
Žilina, Obežná	6	0	0	2
Ružomberok, Riadok	1	0	0	0
Bardejov, Pod Vinbargom			0	0
Trebišov, T. G. Masaryka			2	2
Plášťovce			19	19
Komárno, Vnútorná Okružná			7	7
Senec, Boldocká			2	2

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

***Tab. 3.13** Number of exceedances (in hours) of the information threshold (IT) and alert threshold (AT) for ground-level ozone for alerting and warning of inhabitants.*

Station	IT1h = 180 μg·m^{-3}			AT1h = 240 μg·m^{-3}		
	2019	2020	2021	2019	2020	2021
Bratislava, Jeséniova	0	0	0	0	0	0
Bratislava, Mamateyova	0	0	0	0	0	0
Košice, Ďumbierska	0	0	0	0	0	0
Banská Bystrica, Zelená	0	0	0	0	0	0
Jelšava, Jesenského	0	0	0	0	0	0
Kojšovská hoľa	0	0	0	0	0	0
Nitra, Janíkovce	0	0	0	0	0	0
Humenné, Nám. slobody	0	0	0	0	0	0
Stará Lesná, AÚ SAV, EMEP	0	0	0	0	0	0
Gánovce, Meteo. st.	0	0	0	0	0	0
Starina, Vodná nádrž, EMEP	0	0	0	0	0	0
Prievidza, Malonecpalská	0	0	0	0	0	0
Topoľníky, Aszód, EMEP	0	0	0	0	0	0
Chopok, EMEP	0	0	0	0	0	0
Žilina, Obežná	0	0	0	0	0	0
Ružomberok, Riadok	0	0	0	0	0	0
Bardejov, Pod Vinbargom			0			0
Trebišov, T. G. Masaryka			0			0
Plášťovce			0			0
Komárno, Vnútorná Okružná			0			0
Senec, Boldocká			0			0

≥ 90% valid data requirement

The ground-level ozone AOT40 values for vegetation protection are presented in **Tab. 3.14**. 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 four stations (i.e. at these stations the average of the AOT40 values for years 2017 – 2021 exceeded value 18 000 μg·m^{-3}).

Tab. 3.14 *Ground-level ozone AOT40 values for vegetation protection (May – July). The AOT40 target value is 18 000 μg·m^{-3}.*

Station	2017	2018	2019	2020	2021	Average 2017 – 2021
Bratislava, Jeséniova	25 042	25 103	20 609	12 501	19 274	20 506
Bratislava, Mamateyova	21 525	22 658	19 340	10 655	17 655	18 367
Košice, Ďumbierska	11 557	14 384	11 752	3 269	7 368	9 666
Banská Bystrica, Zelená	17 198	16 982	8 298	7 723	15 869	13 214
Jelšava, Jesenského	12 756	6 660	12 361	5 191	10 186	9 431
Kojšovská hoľa	13 056	18 706	12 202	4 995	13 260	12 444
Nitra, Janíkovce	25 925	25 036	13 313	12 741	18 931	19 189
Humenné, Nám. slobody	14 209	10 833	13 326	5 981	12 578	11 385
Stará Lesná, AÚ SAV, EMEP	13 197	22 437	8 666	7 890	2 491	10 936
Gánovce, Meteo. st.	7 020	6 646	8 954	3 251	6 707	6 483
Starina, Vodná nádrž, EMEP	12 154	13 116	11 601	5 072	11 737	10 736
Prievidza, Malonecpalská	16 167	15 889	8 301	6 198	11 799	11 671
Topoľníky, Aszód, EMEP	9 334	15 886	17 690	-	13 176	11 217
Chopok, EMEP	29 820	32 667	23 711	15 957	23 654	23 997
Žilina, Obežná	10 956	13 364	11 800	559	4 794	8 295
Ružomberok, Riadok	2 801	3 789	5 307	1 999	8 041	3 369
Bardejov, Pod Vinbargom					10 607	10 607
Trebišov, T. G. Masaryka					12 369	12 369
Plášťovce*					24 211	-
Komárno, Vnútorná Okružná*					17 818	-
Senec, Boldocká*					-	-

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

According to the assessment of monitoring stations' measurements of the other operators (industrial stations outside NMSKO), the limit value for PM_{10} was not exceeded at any site (**Tab. 3.15**).

Tab. 3.15 *Air pollution assessment according to limit values for the protection of human health in 2021 from industrial stations of other operators – VZZO.*

AGLOMERATION Zone	Pollutant / Averaging period / Limit value [μg·m^{-3}] / (number of exceedances)	Health protection						
		SO_2		NO_2		PM_{10}		CO
		1 h 350 (24)	24 h 125 (3)	1 h 200 (18)	1 year 40	24 h 50 (35)	1 year 40	8 h [1)] 10 000
BRATISLAVA	Bratislava, Pod. Biskupice (Slovnaft, a.s.)	0	0	0	18	6	20	1 167
	Bratislava, Vlčie Hrdlo (Slovnaft, a.s.)	0	0	0	18	6	20	703
KOŠICE	Košice, Poľov (U.S. Steel, s.r.o.)					6	17	
	Košice, Haniska (U.S. Steel, s.r.o.)	0	0			12	19	
Bratislava region	Rovinka (Slovnaft, a.s.)	1	0	0	14	3	21	584
Košice region	Veľká Ida (U.S. Steel, s.r.o.)					22	27	
	Leles (Slovenské elektrárne, a.s.)	1	0	0	6	8	34	
Nitra region	Trnovec nad Váhom (Duslo, a.s.)	0	0	0	10	4	19	
Trenčín region	Oslany (Slovenské elektrárne, a.s.)	1	0	0	8	11	39	
Žilina region	Ružomberok (Mondi a.s. - Supra)					13	22	

[1)] *maximum 8-hour concentration*

3.3.1 Air quality assessment according to limit and target values for human health protection concerning SO_2, NO_2, PM_{10}, $PM_{2.5}$, benzene, CO and benzo(a)pyrene by agglomeration and zone in 2021

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

3.3.2 Air quality assessment according to limit and target values for human health protection concerning Pb, As, Cd, Ni and O_3, by agglomerations and zones in 2021

- **Agglomeration Bratislava**

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

The target value for ozone (the highest daily 8-hour mean concentration does not exceed 120 $\mu g \cdot m^{-3}$ for more than 25 days per calendar year on a three-year average) was exceeded at the monitoring station Bratislava, Jeséniova. This could be due to several factors – good availability of ozone precursors, higher NO_2/NO ratio in favour of NO_2 at these sites, so that ozone is not degraded by nitric oxide from road traffic as much as at busy roads. Episodes of long-range transport may also have occurred here. There were no exceedances of the information threshold or the alert threshold in Bratislava in 2021.

- **Zone Slovakia**

The zone defines the territory of the Slovak Republic apart from the territory of the Slovak capital Bratislava.

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

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

3.4 REGIONAL MONITORING

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

3.4.1 Air

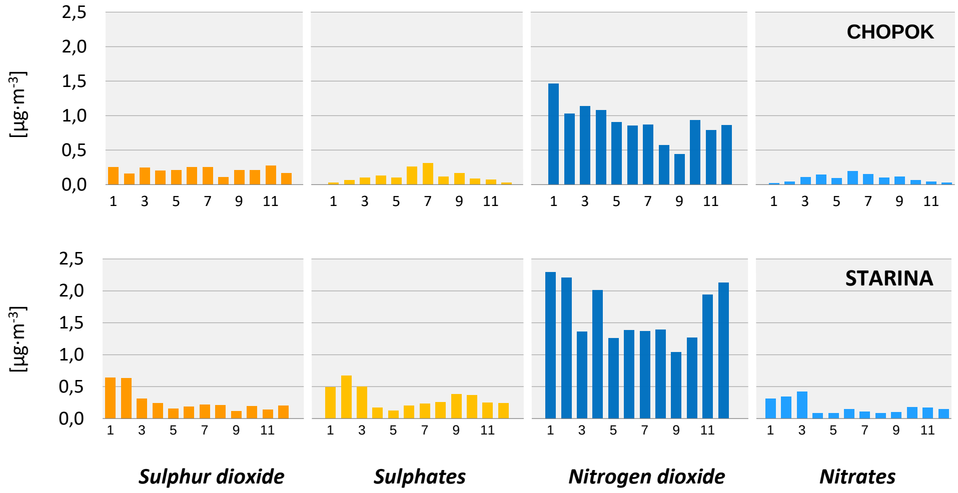
- **Sulphur dioxide, sulphates**

Sulphur dioxide and sulphates are among the substances with acidifying potential. Concentrations of these substances have been kept at a low levels over the long term and meet the legislative limits of the critical level of air pollution for protection of vegetation (20 μg $SO_2 \cdot m^{-3}$) for both calendar year and winter period with a large margin. In 2021, the average annual concentrations at Chopok and Starina were 0.43 μg $SO_2 \cdot m^{-3}$ and 0.54 μg $SO_2 \cdot m^{-3}$, respectively. Also, for the winter period, the concentrations at both Chopok 0.37 μg $SO_2 \cdot m^{-3}$ and Starina 0.71 μg $SO_2 \cdot m^{-3}$ were at a low level and met the legislative limits. Limit values, critical levels of air pollution and target values are set by Decree of the Ministry of Environment of the Slovak Republic No. 244/2016 Coll. on air quality, as amended, and can be found in Annexes 1 to 3. **Tab. 3.16** shows the concentrations of sulphur dioxide and sulphates converted to Sulphur mass. **Fig. 3.5** illustrates the monthly course of the monitored compounds.

- **Nitrogen dioxide, nitrates**

Nitrogen compounds can also contribute to environmental acidification. Therefore, the critical level of air pollution for the protection of vegetation has been set by legislation at 30 μg $NO_x \cdot m^{-3}$ per calendar year, which is listed in Annex 2 to Decree No. 244/2016 Coll. of the Ministry of the Environment of the SR on air quality, as amended. At the regional stations Topoľníky 8.88 μg $NO_x \cdot m^{-3}$ and Stará Lesná 9.05 μg $NO_x \cdot m^{-3}$ the limit value has not been exceeded. Monthly average concentrations did not exceed 20 μg $NO_x \cdot m^{-3}$. **Tab. 3.16** shows the nitrogen dioxide concentrations converted to nitrogen at the Chopok and Starina regional stations in 2021 and **Fig. 3.5** shows the monthly nitrate and nitrogen dioxide concentrations.

Fig. 3.5 *Monthly average concentrations of air pollutants – 2021 (converted to sulphur resp. nitrogen).*



Ammonia, ammonium ions and ions of alkali metals

Detailed air quality composition in accordance with the EMEP monitoring strategy has been carried out since 2007 at the Starina regional monitoring station Concentrations of ammonia, ammonium, sodium, potassium, calcium and magnesium cations are monitored in the air on a daily basis. The annual average concentrations of the above components (NH_3 a NH_4^+ converted to nitrogen) in 2021 are presented in **Tab. 3.16**. For ammonium ions the annual concentration was 0.77 µg N·m^{-3} and for ammonia 1.20 µg N·m^{-3}.

Tab. 3.16 *Annual average concentrations of pollutants [µg·m^{-3}] in air on EMEP stations – 2021.*

	SO_2	SO_4^{2-}	NO_2	NO_3^-	HNO_3	Cl^-	NH_3	NH_4^+	Na^+	K^+	Mg^{2+}	Ca^{2+}
Chopok	0.21	0.12	0.98	0.09	0.04	0.07	-	-	-	-	-	-
Starina	0.27	0.32	1.64	0.18	0.06	0.12	1.20	0.77	0.20	0.17	0.03	0.15

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

Atmospheric aerosol, heavy metals

The annual heavy metal concentrations (lead, copper, cadmium, nickel, chromium, zinc and arsenic) for the year 2021 are presented in **Tab. 3.17**. High values of lead and zinc were recorded at Topoľníky station, particularly in the last three months of the year, when concentrations above 10 ng·m^{-3} were recorded at this station on several weeks. At the end of 2020, the qualitative composition of the PM_{10} fraction started to be monitored for elemental and organic carbon at the EMEP station Stará Lesná, and this year we have the results for the whole year presented in **Tab. 3.17**.

Tab. 3.17 *Annual average concentrations of PM_{10}/TSP, EC/OC [µg·m^{-3}] and heavy metals [ng·m^{-3}] in ambient air at EMEP stations – 2021.*

	PM_{10}/TSP[1]	Pb	Cu	Cd	Ni	Cr	Zn	As	Hg[2]	EC/OC
Chopok[1]	5.4	0.81	0.36	0.03	0.36	0.52	3.53	0.11	-	
Topoľníky	13.5	4.55	1.50	0.09	0.28	0.56	15.81	0.28	1.2	
Starina	10.7	1.99	0.63	0.07	0.32	0.37	9.50	0.23	1.4	
Stará Lesná	9.1	2.61	0.93	0.07	0.23	0.39	11.25	0.28	-	3.02/0.37

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

Ozone

Stará Lesná station has the longest time series of ozone measurements, since 1992. Ozone measurements in Topoľníky, Starina and Chopok started during 1994. In 2021, the annual average ozone concentration was 89 µg·m^{-3} at Chopok, 49 µg·m^{-3} at Topoľníky, 47 µg·m^{-3} at Stará Lesná and 57 µg·m^{-3} at Starina.

Volatile Organic Compounds

VOCs (Volatile Organic Compounds) C2 – C8, (so-called light hydrocarbons) started to be sampled at the Starina station in autumn 1994. Starina is one of the few European stations included into the EMEP network with regular monitoring of VOCs. Laboratory analyses of VOCs were carried out in 2021 at the Central Laboratory of Immissions (CLI) of the Czech Hydrometeorological Institute (ČHMÚ) in Prague.

Tab. 3.18 *Annual average concentrations of volatile organic compounds [µg·m^{-3}] at EMEP station Starina – 2021.*

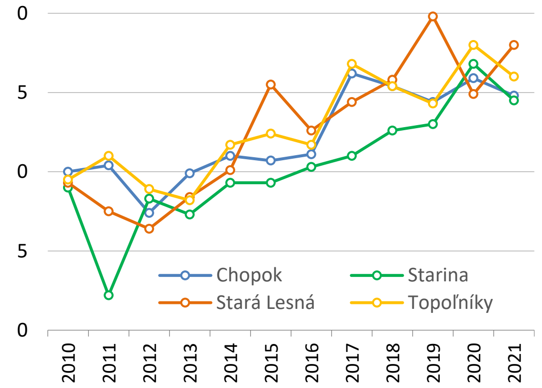
ethane	ethene	propane	propene	i-butane	butene	2-metylbutane	pentane	hexane	isoprene
2.74	0.89	1.45	0.34	0.72	0.90	0.71	2.31	0.15	0.52
Σ butenes	**Σ pentenes**	benzene	i-octane	heptene	toluene	ethylbenzene	octane	m+p-xylene	o-xylene
0.19	0.07	0.80	0.09	0.12	0.78	0.40	0.09	0.81	0.40

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.

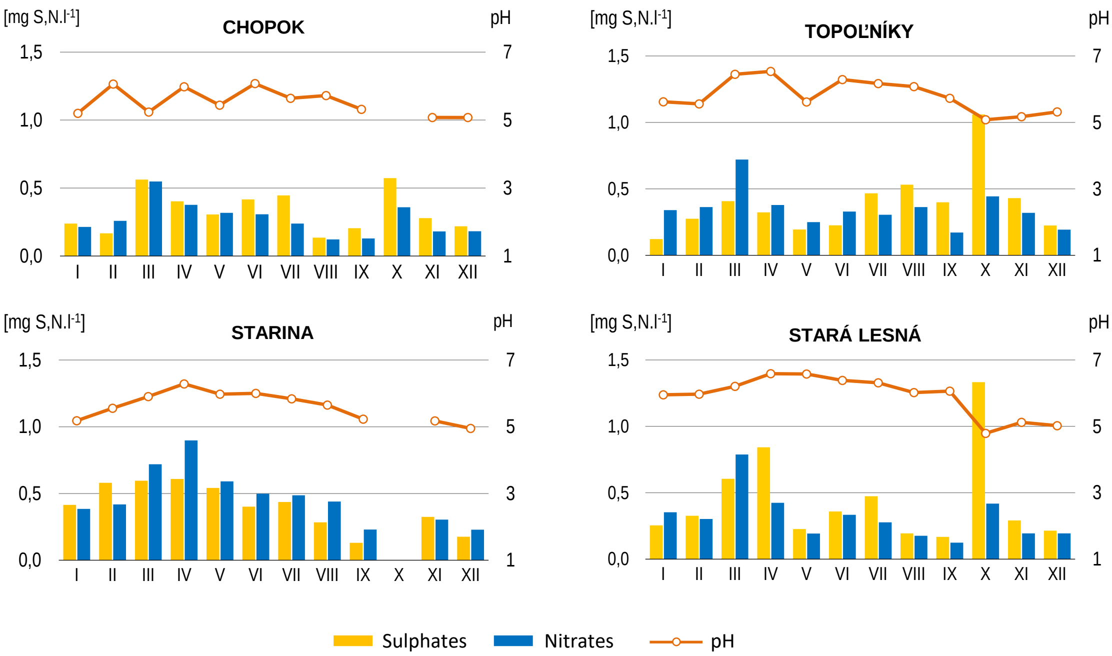
- **Major ions, pH, conductivity**

Fig. 3.6 *pH in atmospheric precipitation.*



In 2021, precipitation totals at regional stations ranged from 448 to 1364 mm, with the lowest amount of precipitation at Stará Lesná and the upper limit of the range at Chopok. Annual average pH values ranged from 5.45 at Starina to 5.80 at Stará Lesná (where we also recorded the lowest monthly mean pH value of 4.79 in October, but this was not a value that could damage vegetation) (**Tab. 3.19**, **Fig. 3.6**). The conductivity of atmospheric precipitation is a reflection of the dissociated ions in the precipitation. Sulphate concentrations in precipitation (**Tab. 3.19**, **Fig. 3.7**), converted to sulphur were in the range 0.29 to 0.40 mg·l^{-1} at the EMEP stations. The lowest values occurred at Chopok and at all stations the values were slightly higher compared to year 2020. Due to the significant decrease of sulphate concentrations in the air over the last decades, nitrates, which in the past contributed to the acidity of precipitation to a lesser extent than sulphates, have started to play a greater role nowadays, also due to less significant decreases in their concentrations. Nitrates converted to nitrogen showed a concentration range 0.25 to 0.45 mg·l^{-1} at the EMEP stations. (**Tab. 3.19**, **Fig. 3.7**). The lower end of the range is represented by Chopok and the upper by Starina. Ammonium ions are also among the main ions and their concentration range at the EMEP stations were 0.36 – 0.61 mg·l^{-1}(**Tab. 3.19**). The evolution of the annual average pH values of atmospheric precipitation at the EMEP stations over the last eleven years is presented in the graph in **Fig. 3.6**. It shows that up to 2016 annual average pH values below 5 have occurred, and these had an adverse effect mainly on materials (increased corrosion and other degradation of materials of various kinds).

Fig. 3.7 *Atmospheric precipitation – 2021.*



Tab. 3.19 Annual weighted averages of pollutants concentrations in atmospheric precipitation – 2021.

	Precip. [mm]	pH	Cond. [µS·cm⁻¹]	SO_4^{2-} [mg·l⁻¹]	NO_3^- [mg·l⁻¹]	NH_4^+ [mg·l⁻¹]	Cl^- [mg·l⁻¹]	Na^+ [mg·l⁻¹]	K^+ [mg·l⁻¹]	Mg^{2+} [mg·l⁻¹]	Ca^{2+} [mg·l⁻¹]
Chopok	1364	5.48	9.40	0.287	0.246	0.364	0.172	0.205	0.087	0.032	0.196
Topoľníky	560	5.60	12.20	0.397	0.297	0.564	0.184	0.137	0.116	0.045	0.395
Starina	700	5.45	12.55	0.375	0.447	0.393	0.233	0.383	0.259	0.066	0.385
Stará Lesná	448	5.80	14.13	0.343	0.260	0.610	0.240	0.427	0.173	0.084	0.518
Bratislava, Jeséniova	466	5.96	19.68	0.58	0.56	1.11	0.38	0.63	0.56	0.16	1.12

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

Heavy metals in atmospheric precipitation

Monitoring of heavy metals in precipitation is carried out on the basis of the monitoring strategy of the CCC EMEP (Chemical Coordinating Centre of EMEP). Heavy metals – lead, copper, cadmium, nickel, chromium, zinc and arsenic ions – are monitored at stations Level 1. At the monitoring station Bratislava, Jeséniova the same range of heavy metals has been measured. This station is not a regional monitoring station, so we do not include it in the assessment. The results of the annual weighted averages of heavy metal concentrations in atmospheric precipitation for the year 2021 are presented in **Tab. 3.20**. Zinc, lead and copper have a higher abundance than other metals among the metals monitored, similar to the metals in air (**Tab. 3.17**). The long-term trend of heavy metals in precipitation is decreasing, but the concentrations in particular of lead and cadmium in air and in precipitation are high in Slovakia compared to most of the countries participating in the EMEP monitoring. At most of the monitoring sites participating in the EMEP monitoring, the annual average air concentrations of lead are below 0.6 µg·l^{-1}. Annual average concentrations of cadmium in precipitation are below 0.02 µg·l^{-1} and in air below 0.06 µg·m^{-3}.

Tab. 3.20 Annual weighted averages of heavy metal concentrations in atmospheric precipitation at EMEP stations – 2021.

	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	1442.9	1.19	0.07	0.41	0.52	0.75	33.20	0.45
Topoľníky	440.0	1.35	0.09	0.23	0.60	0.82	253.94	0.59
Starina	702.1	1.13	0.17	0.37	0.65	1.35	31.42	0.62
Stará Lesná	623.2	0.98	0.09	0.20	0.36	0.54	18.57	0.31
Bratislava, Jeséniova	555.4	2.07	0.13	0.55	0.59	1.32	37.04	0.83

3.5 SUMMARY

PM$_{10}$

The aim of the monitoring is to sufficiently cover the territory of Slovakia, taking into account the possible impact of various sources of air pollution sources, therefore in 2021 monitoring stations were successively added to reflect the impact of household heating. The assumption that high concentrations of PM$_{10}$, PM$_{2.5}$ and benzo(a)pyrene would occur at such sites was confirmed, with high values measured at stations in Plášťovce, Oščadnica and Žarnovica, for example.

In 2021, no monitoring stations exceeded the limit value for the annual mean concentration of PM$_{10}$ (40 µg·m^{-3}). The highest values of this indicator were recorded at Veľká Ida, Letná (35 µg·m^{-3}) and Jelšava, Jesenského (34 µg·m^{-3}). Exceedances of the limit value for the protection of human health for 24-hour concentrations occurred at three AMS: Jelšava, Jesenského, Veľká Ida, Letná and Banská Bystrica, Štefánikovo nábrežie.

At the transport station in Banská Bystrica, Štefánikovo nábrežie, road transport is the dominant source, but the influence of heating is also visible. In 2021, PM values here were also affected by construction work near the station. In Jelšava, the dominant source of PM$_{10}$ is household heating with solid fuels, while this location is also affected slightly less by industrial sources. The problem here is usually also the very unfavourable dispersion conditions in winter. Fig. 3.8 shows the long-term trend of PM$_{10}$ in Jelšava compared to Veľká Ida. In the summer months, due to better dispersion conditions, the values measured in Veľká Ida are also lower. The long-term slightly decreasing trend may reflect a decrease in regional background pollution combined with a decrease in emissions from the industrial source.

Fig. 3.8 PM$_{10}$ in Jelšava, Jesenského and Veľká Ida, Letná between 2003 and 2021.

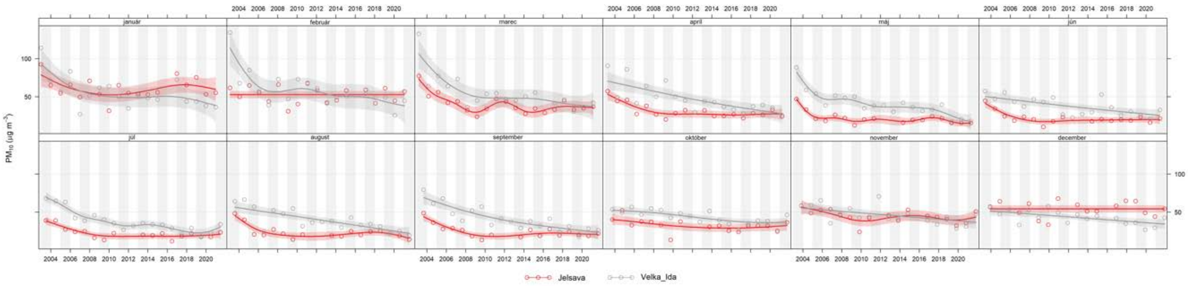


Fig. 3.9 Average daily PM$_{10}$ concentrations at AMS Jelšava, Jesenského and Veľká Ida, Letná.

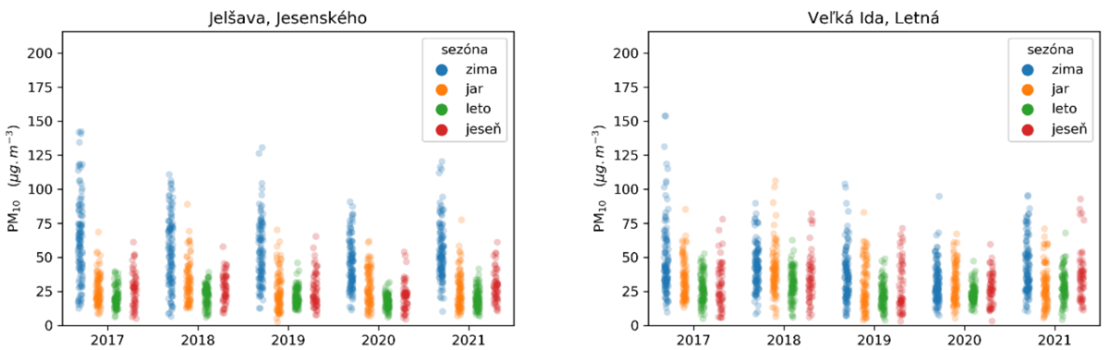


Fig. 3.9 also illustrates the increase in average daily PM$_{10}$ concentrations in Jelšava compared to the situation in Veľká Ida in the winter of 2021 compared to 2020.

The minimum in the summer months is much more noticeable in Jelšava compared to Veľká Ida, reflecting the different seasonality of the dominant sources at the two sites. Concentrations measured at the site mainly influenced by household heating (Jelšava) are comparably high to those measured at the industrial station Veľká Ida, Letná, sometimes even higher. Both stations show the highest PM concentrations for a long time (as mentioned above, Veľká Ida is also affected to a lesser extent by household heating, but this is mainly due to the influence of the metallurgical complex).

In 2021, we have seen a significant increase in the number of hours with information thresholds exceeded compared to 2020. The alert threshold was not exceeded in 2021. The number of PM_{10} smog warnings increased in 2021 compared to 2020. No serious smog warnings were issued and several smog warnings were issued (4 for Jelšava, 3 for Veľká Ida and 1 each for Hnúšťa, Banská Bystrica, Prešov, Martin, Trenčín, Košice and Oščadnica). In the case where an improvement of the dispersion situation could be expected on the basis of the meteorological forecast, no announcement or warning was issued (the conditions are described in Chapter 3.3). Tab. 3.8 shows the list of monitoring stations and the duration of the exceedance of the information or alert threshold for PM_{10}.

$PM_{2.5}$

For $PM_{2.5}$, a limit value of 20 µg·m^{-3} (for the annual average concentration) is set, which entered into force on 1 January 2020 (Commission Implementing Decision 2011/850/EU, Annex 1, point 5). In 2021, the limit value was exceeded at 3 automatic air quality monitoring stations: Veľká Ida, Letná; Jelšava, Jesenského and Martin, Jesenského. The monitoring station in Martin records the impact of road traffic, to a lesser extent household heating. Episodically also at this station the long-range transport of dust from dry areas occurred.

The health effects resulting from PM air pollution depend on both the size and composition of the particulate matter (PM). The smaller the particles are, the more the serious health consequences appear. European and Slovakian legislation therefore shifts the focus of attention to $PM_{2.5}$. An indicator that reflects the trend in the population burden of $PM_{2.5}$ concentrations is the $PM_{2.5}$ Average Exposure Indicator (AEI). It is defined as a three year moving average of annual averages of $PM_{2.5}$ from selected urban and suburban background stations. For example, the AEI 2021 is calculated as the average of the three annual average concentrations from these stations in 2019, 2020 and 2021. Tab. 3.21 shows the values of this indicator since 2010, which is the reference year for the AEI. According to Annex 4 of Regulation No. 244/2016 Coll. of Acts, as amended, the national reduction target for $PM_{2.5}$ Average Exposure Indicator has been set at 18 µg·m^{3} to be achieved by 2020. This goal has been achieved. The national reduction target for $PM_{2.5}$ Average Exposure Indicator in 2021 has also been met by the Slovak Republic.

National target of exposition decrease for particles $PM_{2.5}$

Target of exposition decrease concerning average exposition indicator in year 2010 Reduction target concerning $PM_{2.5}$ Average Exposure Indicator in 2010		Year, in which the exposition reduction target to be achieved
Beginning concentration in µg·m^{-3}	Aim of decrease	
≤ 8.5	0%	2020
> 8.5 – < 13	10%	
= 13 – < 18	15%	
= 18 – < 22	20%	
≥ 22	All convenient measures to reach 18 µg·m^{-3}	

Commitment of decreasing $PM_{2.5}$ Average Exposure Indicator

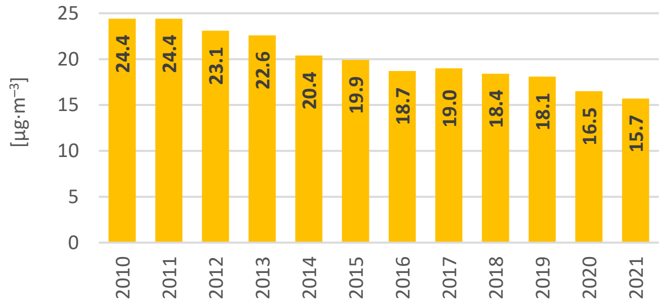
Commitment of decreasing concentration exposition valid from year 2015	20 µg·m^{-3}

Tab. 3.21 $PM_{2.5}$ Average Exposure Indicator (AEI) in 2010 – 2021.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
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

Fig. 3.10 shows the development of the $PM_{2.5}$ Average Exposure Indicator (AEI) of over the last eleven years. Its decrease in year 2021 can be probably explained by the emission decrease in Slovakia and neighbouring countries. More detailed information will be available after the processing of emission inventories for 2021 and after subsequent analysis using mathematical modelling.

Fig. 3.10 *$PM_{2.5}$ Average Exposure Indicator in 2010 – 2021.*



SO_2

In contrast to PM, NO_2, CO and benzo(a)pyrene, SO_2 is mainly emitted by large industrial sources and power engineering industry (heat power plants).

In Rovinka, the average hourly SO_2 concentration exceeded the value of 350 $\mu g \cdot m^{-3}$ once (the limit value is 24 exceedances at the most). This year, there have been no cases of exceedances of the alert threshold at monitoring stations in the Slovak Republic. Measured concentrations have been below the limit value over a long period.

The critical value for the protection of vegetation is 20 $\mu g \cdot m^{-3}$ per calendar year and winter season. This limit value has not been exceeded during 2021 at any of the EMEP stations, neither for the calendar year nor for the winter season. All values were below the lower threshold for vegetation protection assessment.

NO_2

NO_2 is formed in atmosphere by oxidation of NO, emitted from road traffic and various industrial sources. The share of NO/NO_2 therefore changes significantly with distance from the source – e.g. from the road – in favour of NO_2. Annual limit value for NO_2 was not exceeded in year 2020, on any monitoring stations. Exceeding of limit value for human health protection for hourly concentrations was also not recorded on any monitoring station. In year 2020 was not recorded even the case of NO_2 alert threshold exceedance.

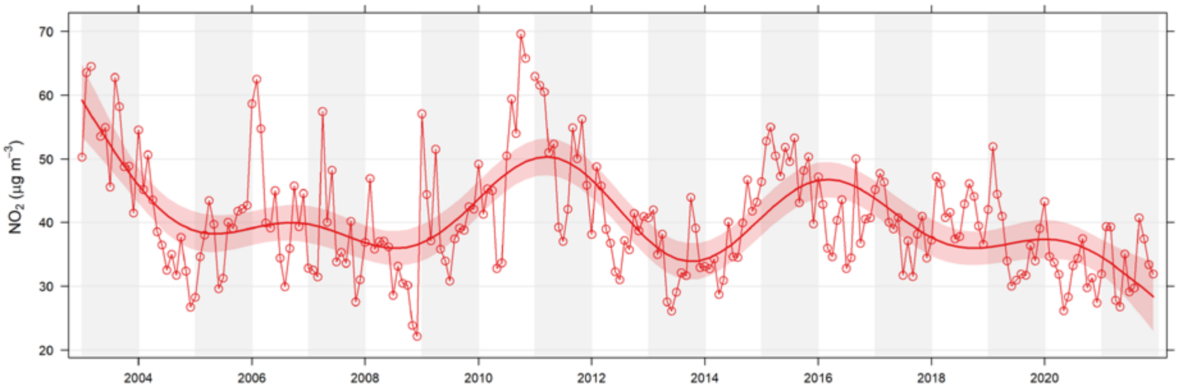
In 2021, the annual limit value for NO_2 (40 $\mu g \cdot m^{-3}$) was not exceeded at any monitoring station. The limit value for the protection of human health for hourly concentrations of this pollutant was also not exceeded. In 2021, there was also no exceedance of the alert threshold for NO_2.

Critical value for vegetation protection (30 $\mu g \cdot m^{-3}$ in calendar year, expressed as NO_X) was not exceeded on any of EMEP stations in year 2020. Values were deeply below the low limit for vegetation protection and nature ecosystems.

The highest annual average (33 $\mu g \cdot m^{-3}$) was recorded at two traffic stations – Bratislava, Trnavské Mýto and Prešov, Arm. gen. L. Svobodu. At the monitoring station Banská Bystrica, Štefánikovo nábrežie an average hourly concentration above 200 $\mu g \cdot m^{-3}$ was measured twice.

The last exceedance of the limit value for the annual average concentration of NO_2 was measured in 2018 at Bratislava, Trnavské mýto and Prešov, Arm. gen. L. Svobodu. In the long-term development, NO_2 concentrations at traffic station Bratislava, Trnavské Mýto have a slightly decreasing trend (**Fig. 3.11**). Local maxima are probably influenced by meteorological conditions.

Fig. 3.11 *NO_2 in Bratislava, Trnavské Mýto between 2003 and 2021.*

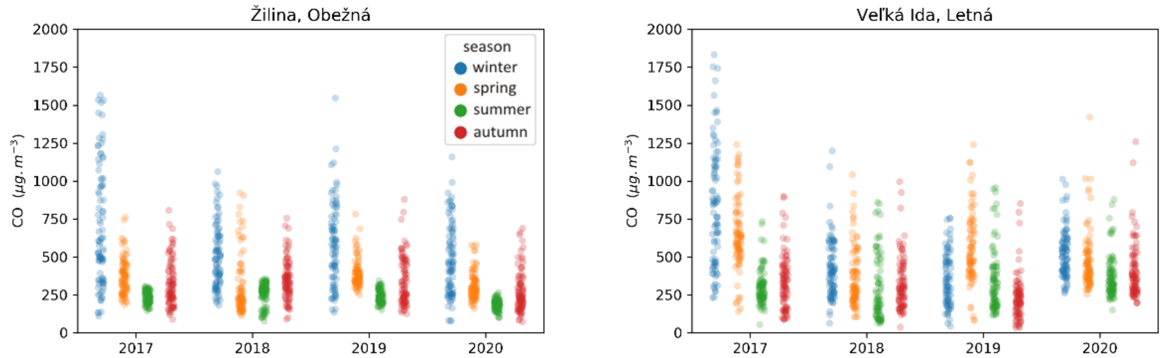


The critical air pollution level for vegetation protection (30 µg·m^{-3} per calendar year expressed as NO_x) was not exceeded at any of the EMEP stations in 2021. The values were well below the lower threshold for assessing air pollution level that is designed to protect vegetation and natural ecosystems.

CO

Source of CO emission are combustion processes in industry, power engineering, household heating and road transport. None of the monitoring stations in Slovakia exceeded the limit value for CO in 2021. The level of air pollution for the previous period 2012-2021 is below the lower threshold for assessing the level of ambient air pollution. In **Fig. 3.12** we can compare the course of average daily concentrations at two different locations – at AMS Veľká Ida, Letná the concentrations are distributed approximately evenly throughout the year, at AMS Žilina, Obežná the maximum occurs in the winter months, which may be due to the effect of household heating.

Fig. 3.12 *Average daily CO concentrations at AMS Veľká Ida, Letná and Žilina, Obežná.*



Benzene

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

The highest level of benzene in yearly monitoring was measured at the station Ružomberok, Riadok in 2021 (1.2 µg·m^{-3}). However, the values of annual average concentrations were significantly well below the limit value of 5 µg·m^{-3}.

Ozone

The tropospheric ozone issue is regional in nature, as both ozone and its precursors are subject to long-range transport in both horizontal and vertical directions. The tropospheric ozone issue is regional in nature, as both ozone and its precursors are subject to long-range transmission in both horizontal and vertical direction. The situation is complicated also by chemism and its formation and chemical degradation in the atmosphere – ozone is formed in the presence of solar radiation, e.g. from nitrogen monoxide (from road traffic) and volatile organic hydrocarbons (from various combustion processes, paints and dissolvents, but also from biogenic sources); in the presence of nitrogen monoxide, however, ozone decomposes, which is why there is usually low ozone concentrations in the vicinity of busy roads. Higher concentration can be measured in the suburbs, as nitrogen monoxide oxidizes is rapidly oxidised to nitrogen dioxide and is therefore less abundant at greater distances from roads.

Fig. 3.13 shows the seasonality of tropospheric ozone concentrations, which, unlike other pollutants (see Annex B of this Report), has a pronounced peak in summer. Ground-level ozone is formed from photochemical reactions of, for example, from nitrogen monoxide or carbon monoxide and volatile organic substances. The reaction depends on the intensity of solar radiation (UV-B part of spectrum). At high mountain altitudes (e.g. on Chopok), ozone concentrations are highest.

The target value of ground-level ozone was exceeded by measurements at two stations: Bratislava, Jeséniova and Chopok, EMEP. In 2021, neither the warning nor the information threshold was exceeded at any station.

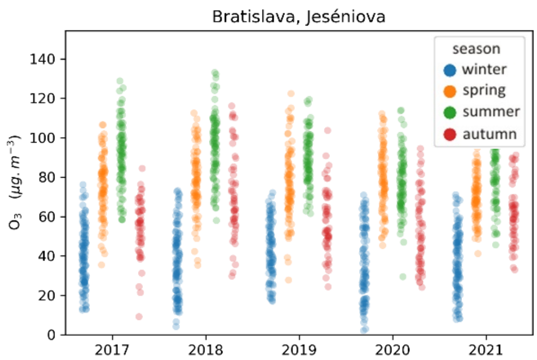
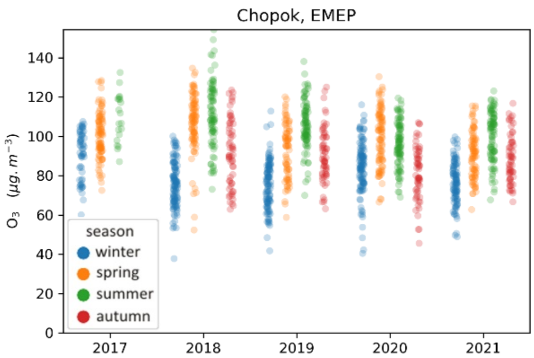
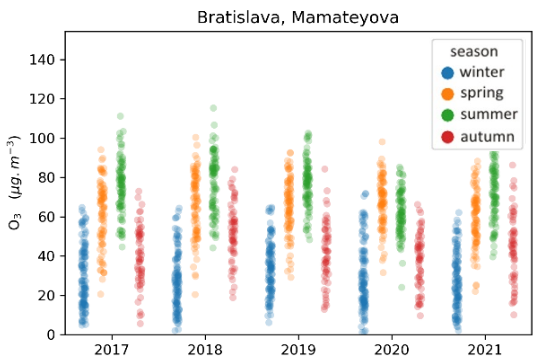


Fig. 3.13 *Daily average concentrations of ground-level ozone at the monitoring stations Bratislava, Jeséniova; Bratislava, Mamateyova and Chopok, EMEP.*





Pb, As, Ni, Cd

Neither the limit value nor the target value was exceeded in 2021. The annual average concentrations of heavy metals measured at NMSKO stations are mostly only fraction of their target or limit value.

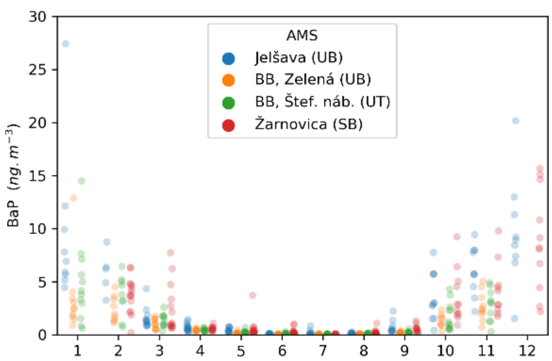
BaP

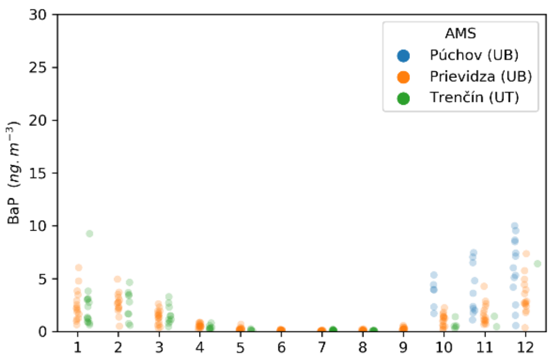
The target value for BaP was exceeded again in 2021 at most stations (Veľká Ida, Letná; Banská Bystrica, Štefánikovo nábrežie; Banská Bystrica, Zelená; Jelšava, Jesenského; Krompachy, SNP; Prievidza, Malonecpalská; Žilina, Obežná; Ružomberok, Riadok).

The highest values were measured at the monitoring station in Veľká Ida; the annual average value at this station also increased the most compared to previous year. The most significant source of benzo(a)pyrene at most of the monitored sites is household heating with solid fuel, most often insufficiently dried wood or various types of waste. In the municipality of Jelšava, the situation is complicated by extremely unfavourable dispersion conditions, with low wind speeds and frequent temperature inversions in winter. In contrast, in Veľká Ida, where the metallurgical complex with coke production is the dominant source, household heating is less of an issue.

The annual course of benzo(a)pyrene concentrations has significant peaks in the winter months at all stations except AMS Veľká Ida, Letná, which is influenced, apart from household heating, mainly by a industrial source – mainly coke production. Relatively high concentrations of benzo(a)pyrene were also measured at the new monitoring stations – in Žarnovica, Púchov, Plášťovce and Oščadnica (**Fig. 3.14**).

Fig. 3.14 *Daily average concentrations of benzo(a)pyrene in 2021 in two NUTS 3 regions – Banská Bystrica region and Trenčín region.*





4 RESULTS OF AIR QUALITY MATHEMATICAL MODELLING

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

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

4.1 BRIEF CHARACTERISTICS OF MODELS USED

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

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

- **Regression-interpolation model RIO**

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

---

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

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

- **IDW-R**

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

4.2 RESULTS AND OUTPUTS

- **PM_{10}**

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

The spatial distribution of PM_{10} concentrations in Slovakia was calculated by the RIO model, while the outputs from the AtmoStreet Gaussian model for the year 2019[11] (60.2%), emissions from local heating plants (8.8%), the ventilation index[12] (6.1%), altitude (8.5%), land use[13] (16.5%)[14] (%) were used as proxy spatial fields. After subsequent adjustment of the results using the IDW-R method and comparison with measurements, we get RMSE = 0.2 $\mu g \cdot m^{-3}$ and BIAS = –0.04 $\mu g \cdot m^{-3}$.

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. Compared to 2020, we generally observe an increase in concentrations, which is probably caused by the colder winter months in 2021 compared to 2020.

In **Fig. 4.2** shows the number of days with daily mean concentration of PM_{10} > 50 $\mu g \cdot m^{-3}$. The number of such days per year must not exceed 35. We can see from the picture that this condition is not met for Gemer valleys close to Jelšava, the vicinity of Veľká Ida and part of Banská Bystrica. 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.

---

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

[11] *This model includes a significant background from the RIO model, based on the emissions from local heating, altitude and the CMAQ model.*

[12] *The height of mixing multiplied by average wind speed in layer under this height.*

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

[14] *Percents in brackets express the contribution of individual spatial fields.*

Fig. 4.1 *Annual mean concentrations of PM_{10} [$\mu g \cdot m^{-3}$] in year 2021. Only values above 15 $\mu g \cdot m^{-3}$ are displayed.*

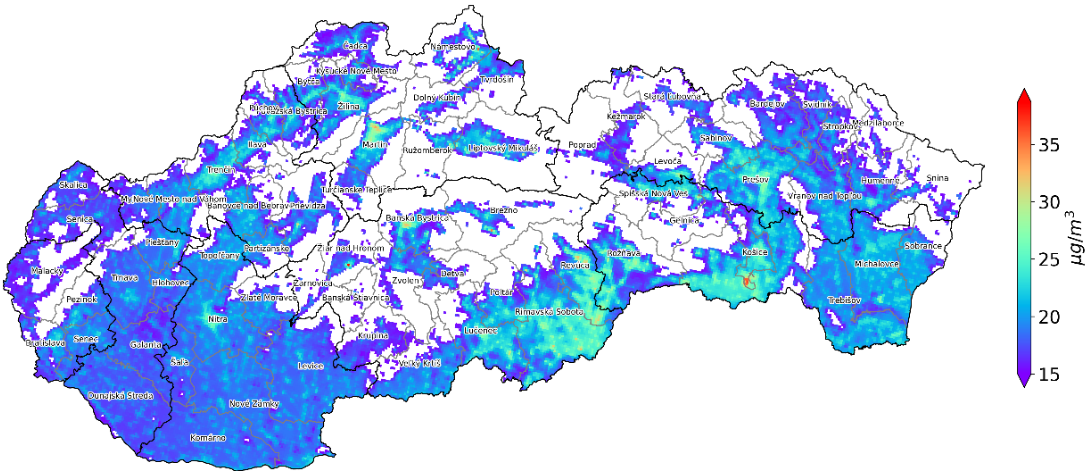
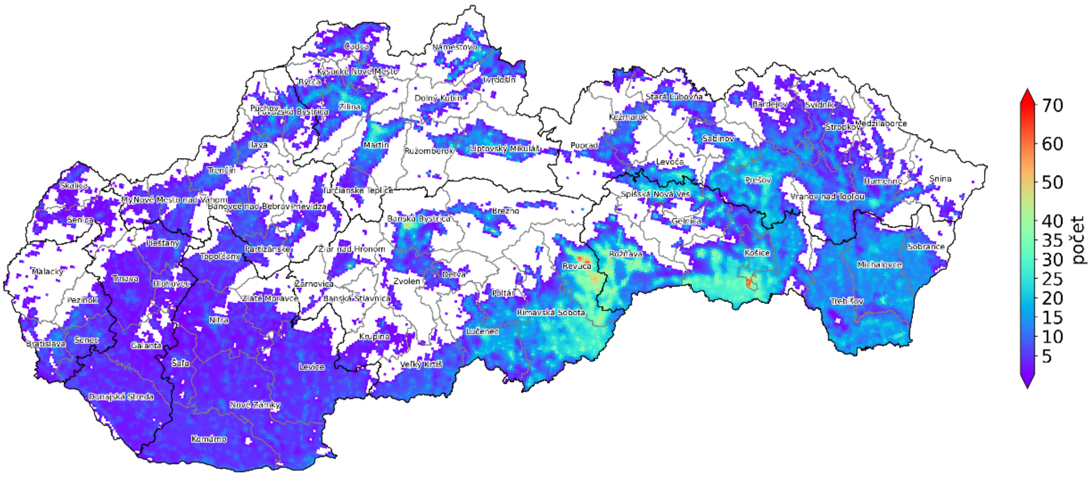


Fig. 4.2 *Number of days exceeding the limit value for the 24-hour PM_{10} concentration (50 $\mu g \cdot m^{-3}$) in 2021. Only areas with a non-zero number of exceedances are shown.*



■ $PM_{2.5}$

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

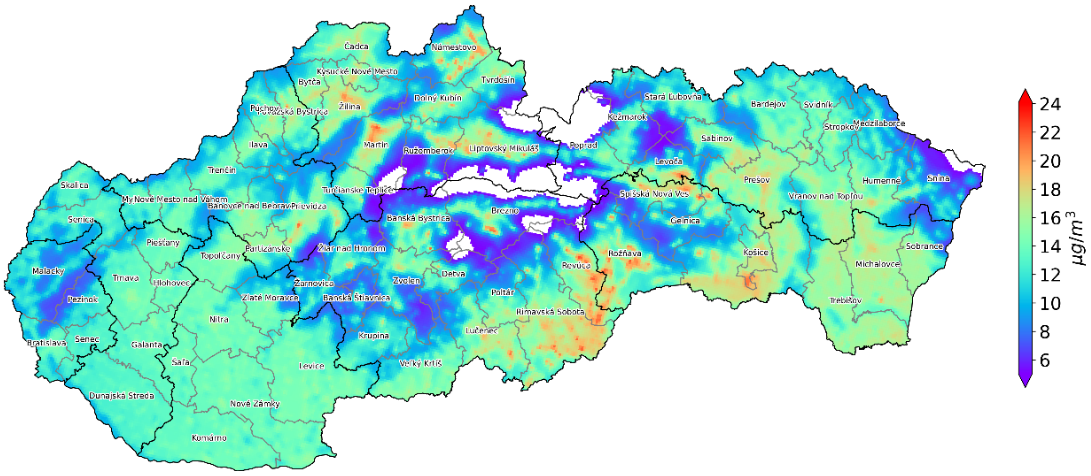
The spatial distribution of $PM_{2.5}$ concentrations in Slovakia was calculated by the RIO model, while the outputs from the AtmoStreet model (100%) were used as additional spatial data, in which the RIO model was used as a background, containing the following auxiliary spatial data: emissions from local heating systems, ventilation index, altitude, land use[16], CMAQ model results and temperature at 2 m. After subsequent adjustment of the output of the RIO model using the IDW-R method, we get RMSE = 0.1 $\mu g \cdot m^{-3}$ and BIAS = –0.05 $\mu g \cdot m^{-3}$ when compared with the measurements. The resulting annual mean concentrations of $PM_{2.5}$ are shown in **Fig. 4.3**.

In 2021, the limit value of the average annual concentration of $PM_{2.5}$ (20 $\mu g \cdot m^{-3}$) was exceeded only in a few places, namely in Gemer in the vicinity of Jelšava, in the vicinity of Košice, in the Hornádská basin, in the vicinity of Martin and Čierny Balog, based on modelling with this spatial resolution. The highest concentrations are similarly to PM_{10} concentrations, in locations with a high share of solid fuels used for local heating, in closed mountain valleys.

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

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

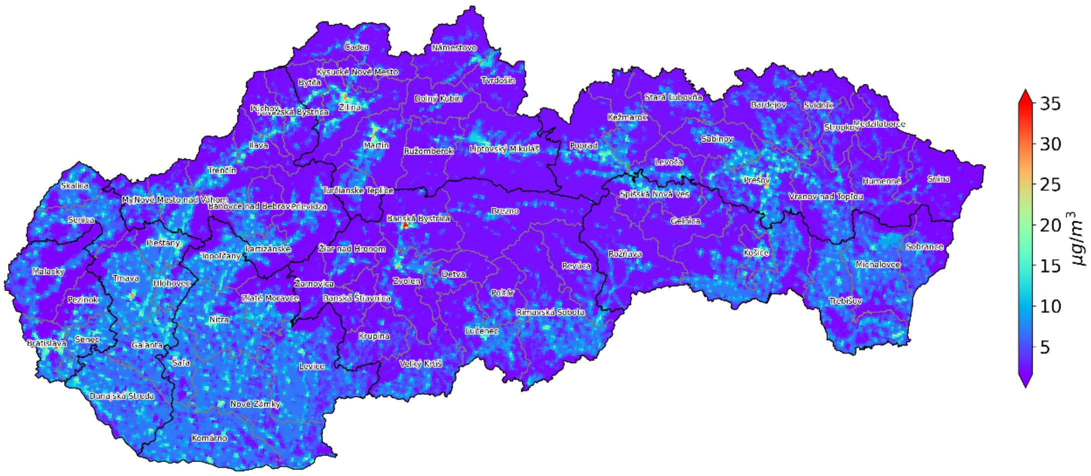
Fig. 4.3 *Annual mean concentration $PM_{2.5}$ [$\mu g \cdot m^{-3}$] in the year 2021. Only values higher than 5 $\mu g \cdot m^{-3}$ are shown, which is the limit value recommended by the WHO.*



NO₂

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

Fig. 4.4 *Annual mean concentration of NO_2 [$\mu g \cdot m^{-3}$] in the year 2021.*



The spatial distribution of NO_2 concentrations in Slovakia was calculated by the RIO model, while the following spatial proxy data were used: road traffic intensity (30%) and land use[17] (70%). After subsequent modification of the model by the IDW-R method and comparison with measurements, we get RMSE = 1.3 $\mu g \cdot m^{-3}$ and BIAS = –0.8 $\mu g \cdot m^{-3}$. The resulting average annual concentrations of NO_2 are shown in **Fig. 4.4**. The highest concentrations occur in the vicinity of large cities, i.e. in places with increased intensity of road traffic. As can be seen, the model does not capture the increase in concentrations near roads outside municipalities. This can be caused either by the fact that the concentrations here are really low (emissions are in the form of NO and have not yet had time to transform into NO_2 in the vicinity of the narrow road) or that the RIO methodology with the given inputs and resolution is not sufficient. The answer to this question can be provided by high-resolution modelling in the near future. It can be seen from the figure that in the given resolution the limit value

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

for the average annual concentration (40 µg·m^{-3}) was not exceeded in 2021. 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.

Ozone

The spatial distribution of ozone concentrations in Slovakia was calculated by the RIO model, with altitude (57.1%), ventilation index (30%), traffic intensity (10.9%), CMAQ model (1.7%) 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 = 0.7 µg·m^{-3} and BIAS = 0 µg·m^{-3}. Data from monitoring stations in 2021 were included in the analysis. The resulting annual mean ozone concentrations are shown in **Fig. 4.5**. **Fig. 4.6** illustrates the number of days in which the eight-hour average ground-level ozone concentration exceeded 120 µg·m^{-3} (i.e., the target value for the protection of human health), showing the average number of days for the period 2019 – 2021. (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 2019 – 2021 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 2017 – 2021 (according to Decree of the Ministry of the Interior of the Slovak Republic No. 244/2016 Coll. on air quality, as amended). The target value of 18,000 is also exceeded in high mountain locations and in western Slovakia.

Fig. 4.5 *Annual mean concentration of ozone [µg·m^{-3}] in the year 2021.*

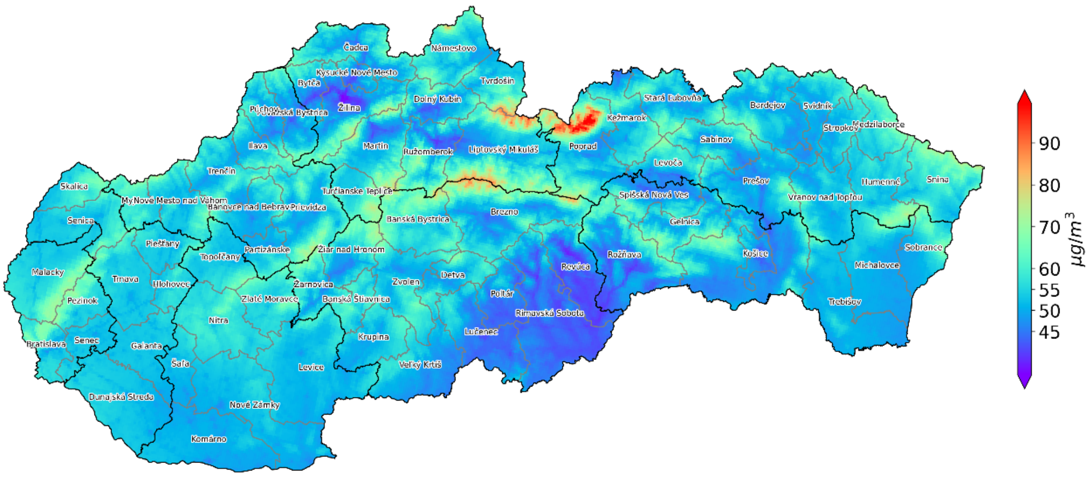


Fig. 4.6 *Number of days, in which eight-hour mean concentration of surface ozone exceeded value 120 µg·m^{-3} (mean during years 2019 – 2021).*

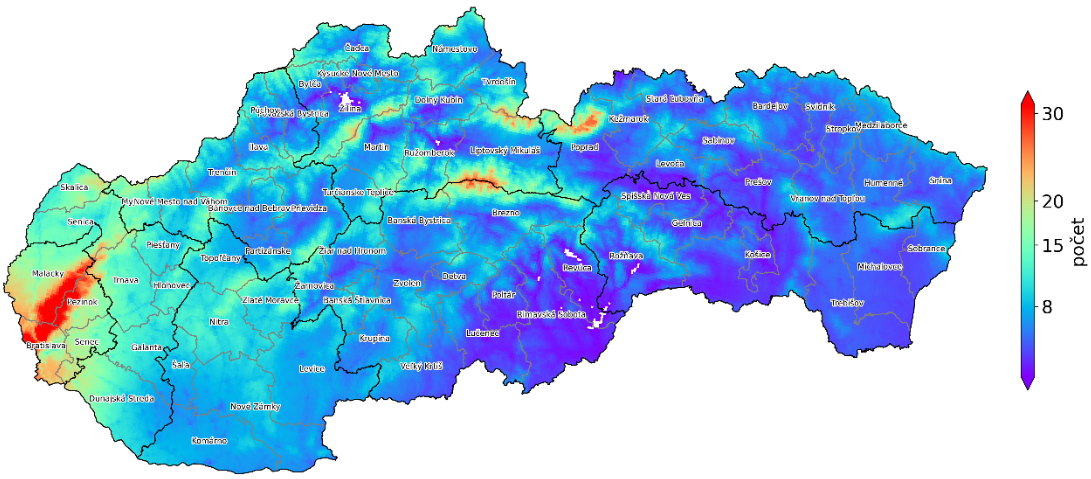
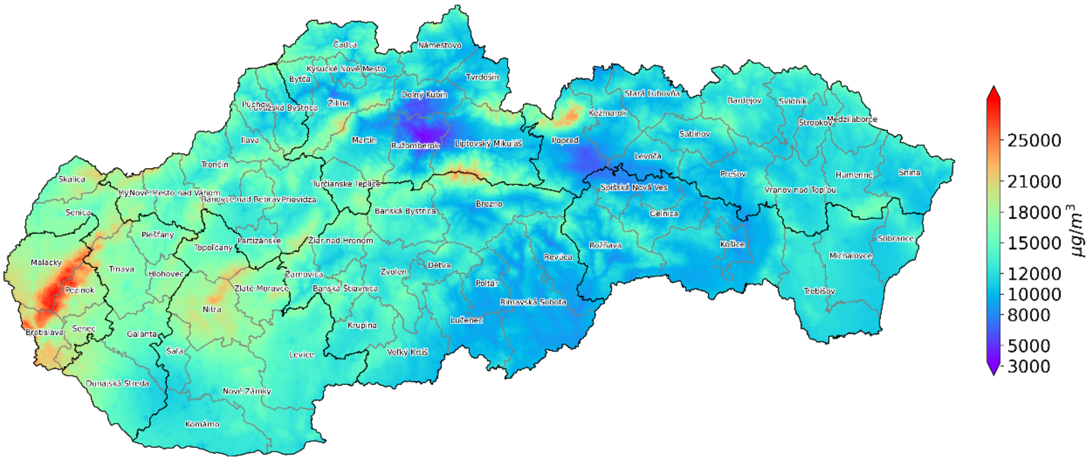


Fig. 4.7 *Mean values of AOT40 during period of five years (2017 – 2021).*



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 2021, as in the previous years, the maximum values were measured at the places with highest altitudes and the minimum values at stations in city centers, where ozone is destroyed by high concentrations of NO. Increased ozone values are also found in peripheral areas of larger urban agglomerations, or in industrial zones, where ozone is created mainly by photochemical reactions of nitrogen oxides with VOCs and CO. For a more detailed investigation of the spatial distribution of tropospheric ozone, it would be necessary to use a chemical-transport model with high resolution and high-quality emission inputs of ozone precursors. In order to better calibrate the model, it would be necessary to cover the territory with a denser network of stations, or to carry out a series of indicative measurements that would characterize several types of environments (locations directly affected by road repair, locations at different distances from the center of the agglomeration, or from sources of ozone precursors). Maps on **Fig. 4.5** to **Fig. 4.7** therefore do not capture the reality accurately enough.

■ SO_2

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

The spatial distribution of SO_{-2} concentrations in Slovakia was calculated by the CMAQ model, while meteorological data from the ALADIN model were used.

The most important SO_2 emissions are altitudinal 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. 711 chimneys (vents) were included in the calculation, the emissions of which represent a total of 99% of all SO_2 emissions from large and medium sources registered in NEIS database. The most important sources of SO_2 were U.S. Steel Košice, s.r.o., SLOVNAFT, a.s. (Bratislava), Slovalco, a.s. (Žiar nad Hronom) and Slovenské elektrárne, a.s. (Nováky power plant). According to preliminary data, SO_2 emissions registered in the NEIS database increased slightly in 2021 compared to 2020. Furthermore, SO_2 emissions from local heating (approximately 8% of total emissions) and emissions from road transport (which in the case of SO_2 represent less than 1% of total emissions) were also included in the simulation. Outside the Slovak Republic, emissions from the TNO-MAC III[18] database were used. Another necessary characteristic is changes in emissions during the year, which were

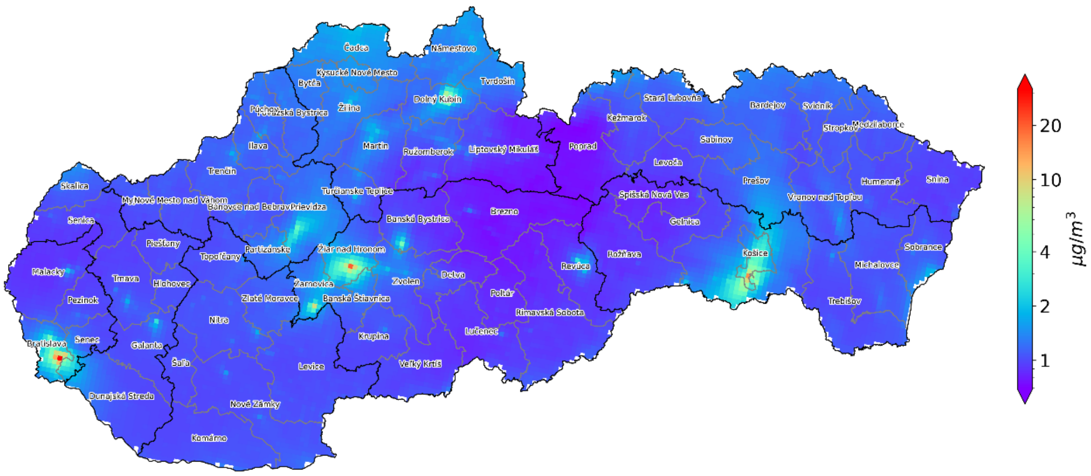
[18] *Kuenen, J.J.P., Visschedijk, A.J.H., Jozwicka, M., Denier van der Gon, H.A.C., 2014. TNOMACC_ II emission inventory; a multi-year (2003-2009) consistent high-resolution European emission inventory for air quality modelling. Atmos. Chem. Phys. 14, 10963–10976. https://doi.org/10.5194/acp-14-10963-2014*

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 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 several basic features:

1. The highest concentrations are in locations with direct reach of significant point sources.
2. Increased concentrations are also in the northwest of Slovakia, where the largest share of household heating by coal is suppose.
3. A weaker transboundary transport can also be recognized in the north and especially the northwest of Slovakia, which comes mainly from the Polish Malopoľska and Sliezko and the Czech Ostravsko.

Fig. 4.8 *Annual mean concentrations of SO_2 [$\mu g \cdot m^{-3}$] in the year 2021.*



Hourly mean SO_2 concentrations should not exceed 350 $\mu g \cdot m^{-3}$ more than 24 times in a calendar year. Therefore, the 99.7 percentile of the hourly values is calculated (this percentile corresponds roughly to the 25th highest hourly concentration). Interestingly, in the case of the 99.7 hourly percentile, our measurement results correlate reasonably well with the CMAQ model ($r = 0.78$). It can be assumed that the measurements capture the peak concentrations reasonably well. The concentrations calculated by the CMAQ model were then processed by the IDW-R method to obtain the best agreement with the measurements (RMSE = 3.9 μg-m^{-3} and BIAS = –0.4 $\mu g \cdot m^{-3}$). The resulting 99.7 hourly percentile of SO_2 concentrations is at **Fig. 4.9**, from which it can be seen that the 25th highest hourly concentration was well below the limit value of 350 $\mu g \cdot m^{-3}$.

The daily mean SO2 concentration should not exceed 125 $\mu g \cdot m^{-3}$ more than 3 times in a calendar year. This is represented by the 99.2 percentile of the average daily values, which corresponds to roughly the 4th highest daily concentration. As in the previous case, the CMAQ model results were further processed by the IDW-R method (RMSE = 2.9 $\mu g \cdot m^{-3}$ and BIAS = 0.04 $\mu g \cdot m^{-3}$). The resulting 99.2 percentile of the average daily SO_2 concentrations is shown in **Fig. 4.10**, from which it can be seen that the 4th highest average daily concentration was well below the limit value of 125 $\mu g \cdot m^{-3}$.

***Fig. 4.9**   99.7 percentile [$\mu g \cdot m^{-3}$] from hourly mean values of SO_2 concentrations in year 2021.*

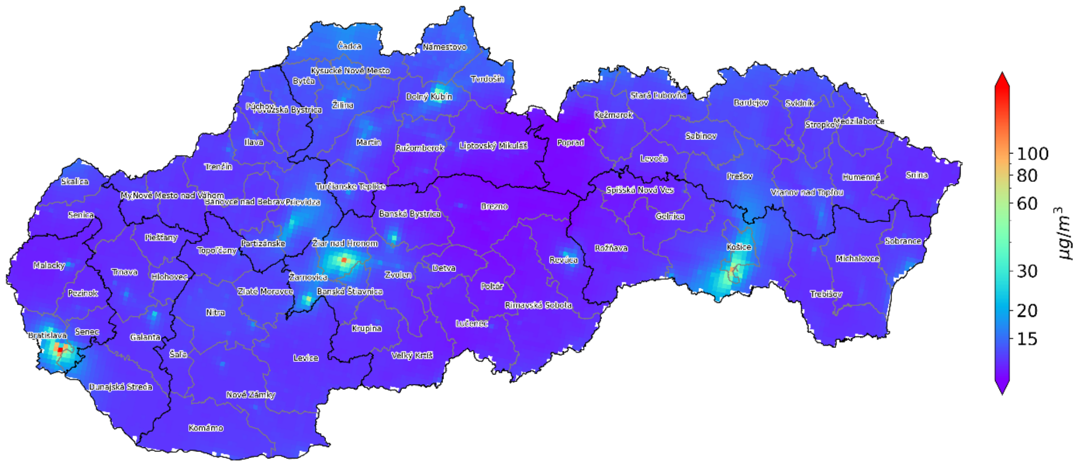
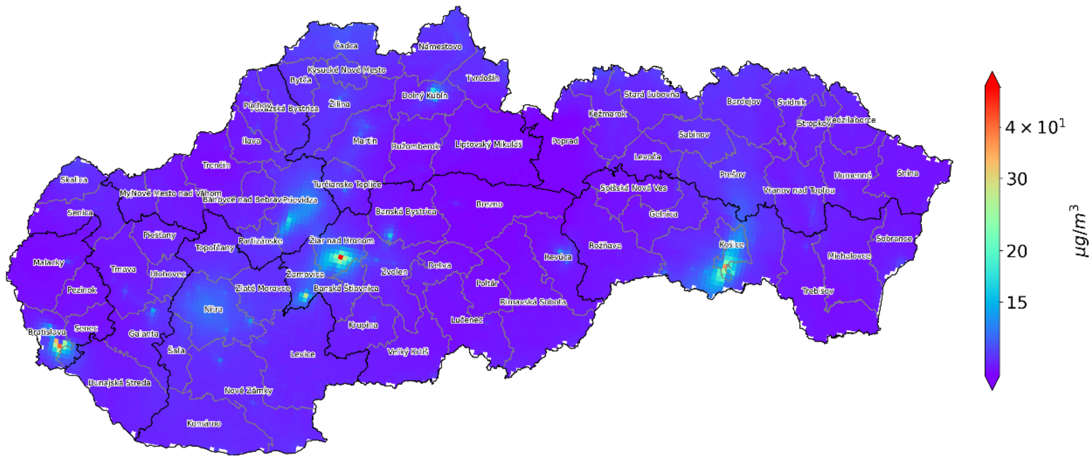


Fig. 4.10   *99.2 percentile [$\mu g \cdot m^{-3}$] from daily mean values of SO_2 concentrations in year 2021.*



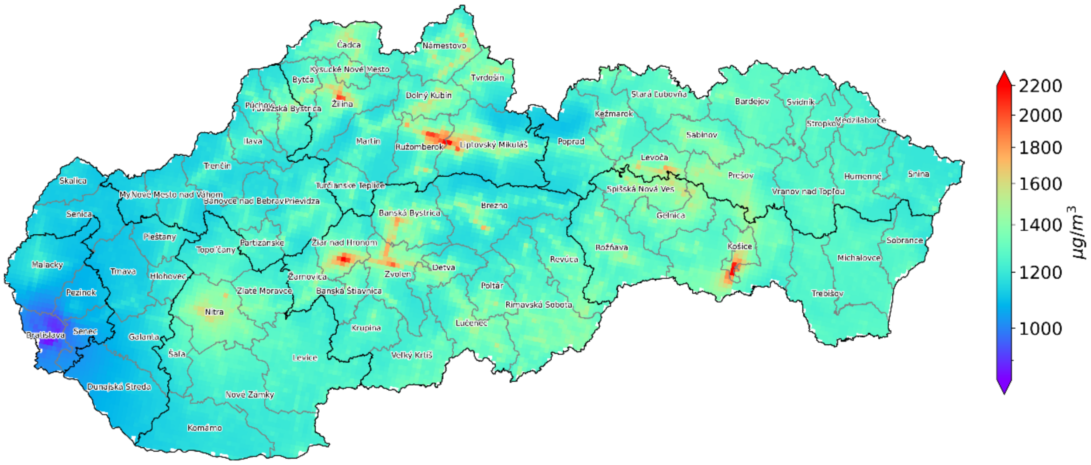
CO

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, while more than 80% of industrial sources are emissions from U.S. Steel Košice, s.r.o.; Slovalco, a.s. (Žiar nad Hronom) and CEMMAC a.s. (Upper Srnie). 912 chimneys (vents) were included in the calculation, whose total annual emissions make up 81% of all CO emissions from large and medium sources registered in NEIS database. 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 2020 on **Fig. 4.11** were gained from CMAQ model and consequently processed by the use of IDW-R method. Limit value of 10 000 $\mu g \cdot m^{-3}$ was not exceeded. When comparing model with measurements, RMSE is 41.5 $\mu g \cdot m^{-3}$ and BIAS is 0.05 $\mu g \cdot m^{-3}$. 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 transport and industrial monitoring stations, it is difficult to determine the actual background concentration, also because CO is chemically stable and remains in the atmosphere for a relatively long time. The lowest measured maximum 8-hour moving CO concentration reached the value of approximately 1000 $\mu g \cdot m^{-3}$, therefore the lower interval depicted is from 0 to 1000 $\mu g \cdot m^{-3}$.

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

Fig. 4.11 Maximum daily 8-hour moving concentrations of CO [µg·m⁻³] in year 2021.

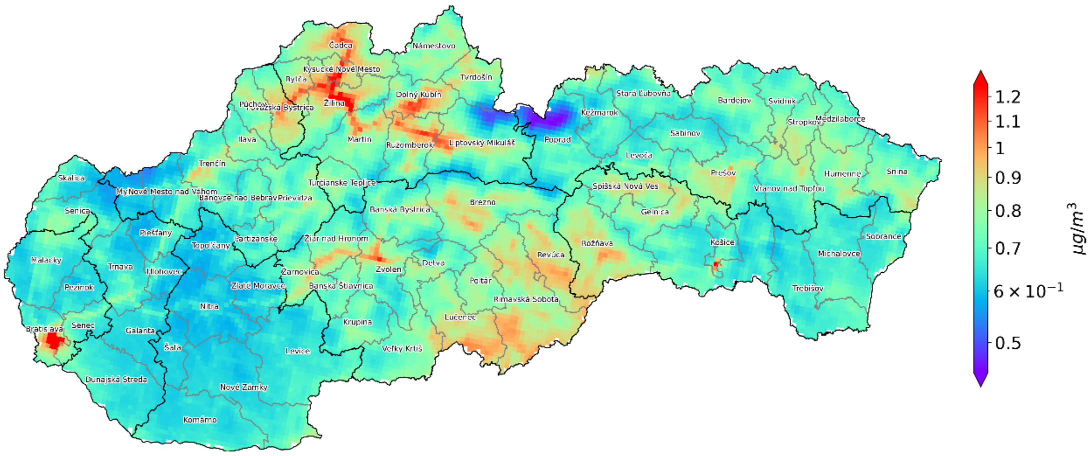


■ Benzene

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

The highest share on emission inputs for benzene modelling comes from road transport (approximately 66%), local heating (more than 19%) and industrial sources (more than 16%) while the most significant sources are SLOVNAFT, a.s., Bratislava a U. S. Steel Košice, s.r.o. Outside the territory of SR the emissions from TNO-MAC III[19] database were used. Annual mean concentrations of benzene in year 2021 on **Fig. 4.13** were obtained from CMAQ model and then processed by IDW- R method. Monitoring stations with relevant data were included in analysis. Comparison of model results with measurements gives RMSE = 0.1 µg·m^{-3} and BIAS = –0.05 µg·m^{-3}. It can be seen from **Fig. 4.12**, that the highest concentrations of benzene are in vicinity of significant roads, mainly in areas with adverse dispersion conditions and in domains affected by two industrial sources mentioned above. However, in total the benzene concentrations are below the limit value 5 µg·m^{-3} also in vicinity of the most significant sources.

Fig. 4.12 Annual mean concentrations of benzene [µg·m⁻³] in year 2021.



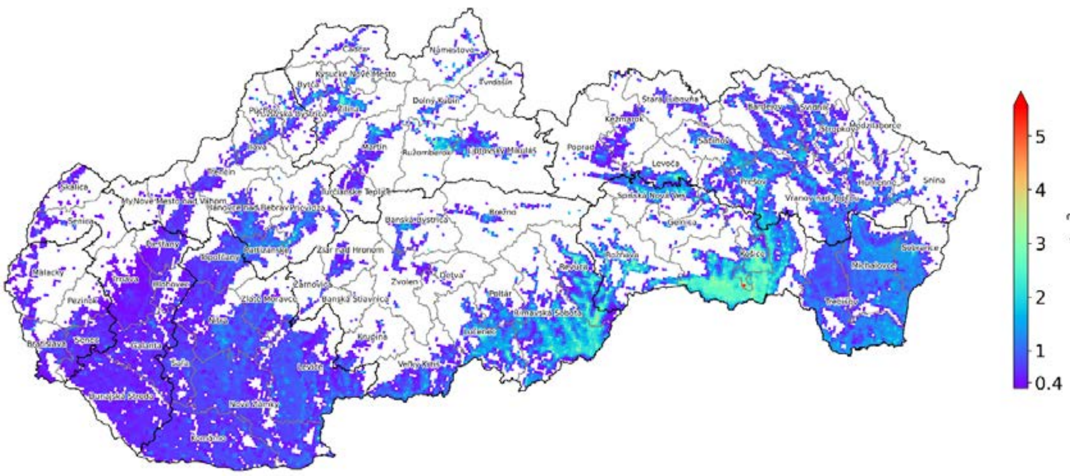
[19] *Kuenen, J.J.P., Visschedijk, A.J.H., Jozwicka, M., Denier van der Gon, H.A.C., 2014. TNOMACC_ II emission inventory; a multi-year (2003-2009) consistent high-resolution European emission inventory for air quality modelling. Atmos. Chem. Phys. 14, 10963–10976. https://doi.org/10.5194/acp-14-10963-2014*

Benzo(a)pyrene

The most significant source of benzo(a)pyrene emissions is, similarly to the case of $PM_{2.5}$, heating of households with solid fuels. The share of domestic heating in total benzo(a)pyrene emissions is close to 70%, while in 2017 (when there was a January with subnormal temperature[20]), for example, the share was more than 80%[21]. Of the industrial sources, the most pronounced is coke production, the effect of which can be seen in the high concentrations from measurements at the industrial monitoring station Veľká Ida, Letná. In 2021, the highest annual mean concentration of benzo(a)pyrene among monitoring stations in Slovakia was recorded here, namely 6.15 $ng \cdot m^{-3}$. Note that this station is in a village, where local heating and marginalised Roma community neighbourhood also plays a role. Household heating is almost exclusively reflected 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 2021 at this station was 2.8 $ng \cdot m^{-3}$, with a target value of 1 $ng \cdot m^{-3}$.

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[22]. However, due to the relatively small number of stations at which monitoring programme includes this pollutant, it is also quite difficult to perform a good regression and interpolation with the RIO model. Since the correlation between measured concentrations of benzo(a)pyrene and the annual mean $PM_{2.5}$ concentrations calculated at the monitoring station sites by the combination of RIO and IDW-R is quite high (correlation coefficient $r = 0.73$), 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 = 0.4 $ng \cdot m^{-3}$ and BIAS = –0.1 $ng \cdot m^{-3}$. The limit value for the annual mean concentration of benzo(a)pyrene of 1 $ng \cdot m^{-3}$ was exceeded at many measurement sites, except for rural background stations and sites in the Danube Plain. This is also reflected in the modelling results, with the highest concentrations in the east of the country. The model may overestimate benzo(a)pyrene concentrations particularly around Košice and the East Slovakian Lowland, as it is strongly influenced by the high annual average concentration measured at Veľká Ida, which together with Krompachy is one of only two stations in the Košice Region where benzo(a)pyrene is monitored.

Fig. 4.13 *Annual mean concentrations of benzo(a)pyrene [$ng \cdot m^{-3}$] in year 2021.*



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

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

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

4.3 CONCLUSION

Mathematical models, no matter how sophisticated, are only approximation of reality, and their results are associated with a relatively high degree of uncertainty that is highly dependent on the quality of the input data. The most important input data are meteorological fields and the spatial distribution of emissions. At present, meteorological data can be considered much more reliable than emission data in terms of annual assessment, so it can be said that emission data are the primary source of uncertainty in the outputs of mathematic air quality models. Another factor to consider when assessing the spatial distribution of concentrations using regional-scale models is their spatial resolution. The models used in our analysis have a horizontal spatial resolution of 1 km. Therefore, the calculated concentration represents the average concentration over a 1 x 1 km area. 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

Concentrations of the main pollutants at most locations in Slovakia in 2021 have slightly increased compared to the previous year, which is a consequence of colder winter (higher emissions from heating, less favourable dispersion conditions). PM_{10}, $PM_{2.5}$ and benzo(a)pyrene remain the most significant pollutants of concern, with domestic heating playing a significant role.

The situation is most complicated in mountain valleys, in areas with good availability of firewood and frequent occurrence of adverse dispersion conditions, especially during the heating season. The financial conditions of the local population often do not allow the use of natural gas for heating or the purchase of modern low-emission heating equipment. This fact also affects the air quality in the above-mentioned areas. Unfortunately, it can be expected that the situation will worsen due to the energy crisis.

5 AIR QUALITY ASSESSMENT – CONCLUSION

5.1 PROPOSAL OF ALLOCATION AREAS FOR AIR QUALITY MANAGEMENT IN 2022

The task of the SHMÚ is to propose an update of the definition of air quality management areas in the Slovak Republic for the year 2022 on the basis of the assessment of air quality in zones and agglomerations in the years 2019 – 2021, pursuant to Section 8(3) of Act No. 137/2010 Coll. on Air, as amended.

As in the previous year, risk areas were defined based on mathematical modelling in order to determine regions with possible poor air quality - i.e. also in places where there were no monitoring stations.

In 2021, a methodology was developed[23] to identify at-risk municipalities and districts (LAU 1 regions) with deteriorated air quality **due to local heating and adverse dispersion conditions**. In particular, these municipalities and districts (LAU 1 regions) may experience **higher concentrations of PM and benzo(a)pyrene in winter**. In the above-mentioned methodology, the proportion of fuel types used for heating of family houses has been processed based on data obtained from the Population and Housing Census (PHC) in the year 2011[24]. This methodology is now updated using the latest comprehensive information on the heating methods and type of fuels used in the Slovak Republic from the Population and Housing Census in the year 2021. However, the provided data is incomplete due to missing information on the number of unoccupied houses. Another weakness of the data is that it does not reflect the change in local heating practices caused by the current energy crisis, originating from the war in Ukraine. This fact should be considered when interpreting results.

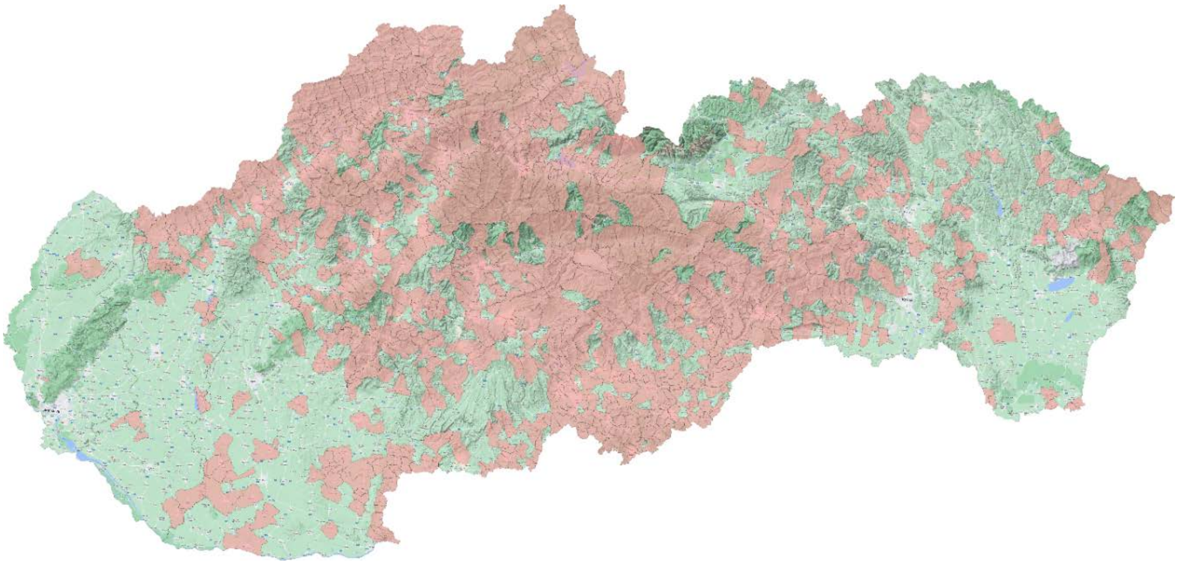
Based on PHC in 2021, the number of homes using solid fuel for heating increased by 45%. In order to assign emission coefficient to a given municipality, it was necessary to change the intervals of the number of houses heated with solid fuel from the original values of 23, 45, 95 and 200 to new values of 32, 64, 125 and 250, thus reflecting the respective percentiles. The other assumptions in the methodology have not been changed and are identical to the 2021[23] methodology. Municipalities, identified to be at risk only by using the old methodology and with a larger number of houses heated with solid fuels in 2021 than in 2011, were also classified to be at risk. There are 37 such municipalities.

At-risk municipalities are shown in **Fig. 5.1**. Compared to the previous methodology, 85 new municipalities were added and 40 municipalities were removed from the list of affected municipalities.

[23] *D. Štefánik: Určenie rizikových obcí s kvalitou ovzdušia ohrozenou lokálnym vykurovaním a zhoršenými rozptylovými podmienkami. SHMÚ, Bratislava, august 2021, https://www.shmu.sk/File/oko/studie_analyzy/Popis%20met%C3%B3dy%20na%20ur%C4%8Denie%20rizikov%C3%BDch%20oblast%C3%AD.pdf*

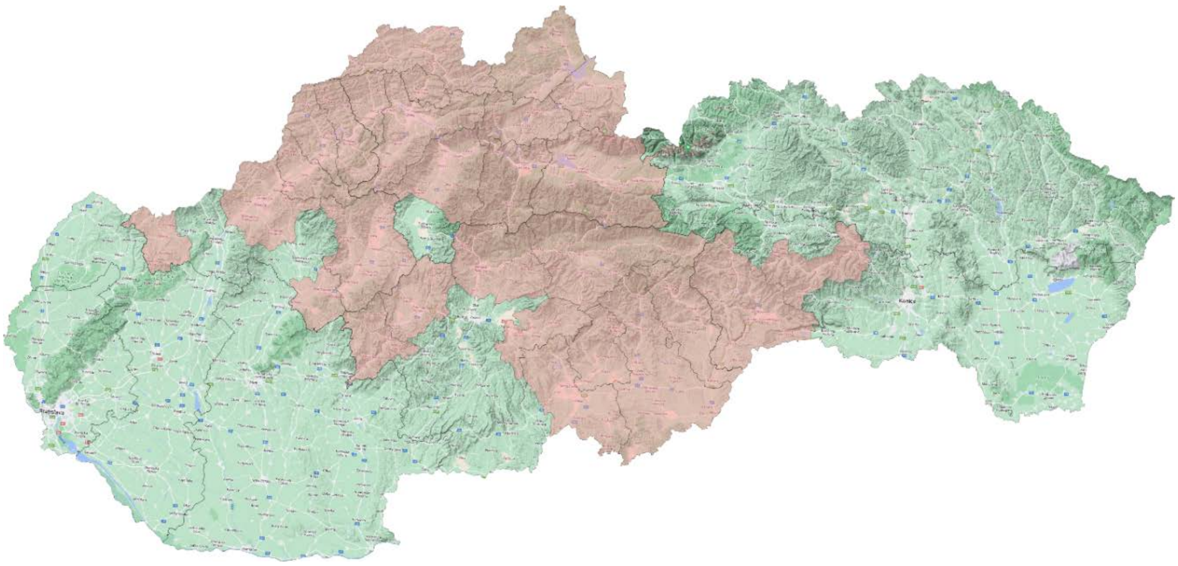
[24] *https://slovak.statistics.sk/wps/portal/ext/Databases/datacube/!ut/p/z0/04_Sj9CPykssy0xPLMnMz0vMAfIjo8ziw3wCLJycDB0NLEw9TA0cnZ0CTUJ9DIxMfAz1C7IdFQHnSkqO/*

Fig. 5.1 Map of at-risk municipalities according to the Population and Housing Census 2021.



Districts (LAU 1 regions) containing at least 40% of at-risk municipalities were defined as at-risk districts and are shown in **Fig. 5.2**. Compared to the older methodology, the district of Myjava was added to the at-risk districts and the district of Spišská Nová Ves was excluded.

Fig. 5.2 Map of LAU1 regions at risk according to the Population and Housing Census 2021.



Let us note that the uncertainties of mathematical modelling are greater than errors of measurements at monitoring stations. These uncertainties are mainly due to the ambiguity of emission inputs in the chemical-transport model and the distribution of monitoring stations in interpolation models. It is expected that with the increasing quality of input data the modelling results will be more precise.

Tab. 5.1 contains air quality management areas (AQMA) based on measurements of pollutant concentrations in the years 2019 – 2021. The definition of at-risk areas (areas determined based on mathematical modelling) has been updated as described at the beginning of this chapter and is based on Population and Housing Census 2021 data.

Tab. 5.1 *Air quality management areas for year 2022 defined according to the measurement of basic pollutants in the years 2019 – 2021 and mathematical modelling.*

AGGLOMERATION Zone	Air quality management area	Pollutant	AMS and year of exceedance of limit/target value
BRATISLAVA *	Risk areas have not been identified in the agglomeration on the basis of modelling[25]		
KOŠICE [26]	Territory of Košice city and municipalities Bočiar, Haniska, Sokoľany and Veľká Ida	PM_{10}, $PM_{2.5}$, BaP	PM_{10}: Košice, Štefánikova (2019); Veľká Ida (2019, 2021) $PM_{2.5}$: Veľká, Ida 2019 (20,7 μg·m^{-3}), 2021 (20.8 μg·m^{-3}) BaP: Veľká Ida (2009 – 2021)
	Risk areas have been identified in the agglomeration on the basis of modelling	PM_{10}, $PM_{2.5}$ BaP	
Banská Bystrica region	Territory of Banská Bystrica city	PM_{10}, BaP	PM_{10}: Banská Bystrica, Štefánikovo nábr, (2021) BaP: BB Štefánikovo nábr. (2019 – 2021), Zelená (2019 – 2021)
	Area of Jelšava and municipalities Lubeník, Chyžné, Magnezitovce, Mokrá Lúka, Revúcka Lehota	PM_{10}, $PM_{2.5}$, BaP	PM_{10}: Jelšava, Jesenského (2019 – 2021) $PM_{2.5}$: 2019 (20,9 μg·m^{-3}), 2021 (24.3 μg·m^{-3}) BaP: (2019 – 2021)
	Territory of Žarnovica city	BaP	Žarnovica, Dolná (2021)
	Risk areas have been identified in the zone on the basis of modelling.	PM_{10}, $PM_{2.5}$ BaP	
Bratislava region *	Risk areas have been identified in the zone based on modelling.	PM_{10}, $PM_{2.5}$ BaP	
Košice region [27]	Territory of Krompachy city	BaP	Krompachy, SNP (2019 – 2021)
	Risk areas have been identified in the zone on the basis of modelling.	PM_{10}, $PM_{2.5}$ BaP	
Nitra region *	Risk areas have been identified in the zone on the basis of modelling.	PM_{10}, $PM_{2.5}$ BaP	
Prešov region *	Risk areas have been identified in the zone on the basis of modelling.	PM_{10}, $PM_{2.5}$ BaP	
Trenčín region	Territory of Prievidza city	BaP	Prievidza, Malonecpalská (2020, 2021)
	Risk areas have been identified in the zone on the basis of modelling.	PM_{10}, $PM_{2.5}$ BaP	
Trnava region *	Risk areas have been identified in the zone on the basis of modelling.	PM_{10}, $PM_{2.5}$ BaP	
Žilina region	Territory of Martin city and Vrútky city	$PM_{2.5}$	2021 (20.8 μg·m^{-3})
	Territory of Ružomberok city and municipality Likavka	BaP	Ružomberok, Riadok (2021)
	Territory of Žilina city	BaP	Žilina, Obežná (2019 – 2021)
	Risk areas have been identified in the zone on the basis of modelling.	PM_{10}, $PM_{2.5}$ BaP	

Note: The assessment for $PM_{2.5}$ was calculated with respect to the limit value for the average annual concentration, which is valid from 1.1.2020 (20 μg·m^{-3}).

** There is currently no proposed air quality management area based on monitoring in this zone/agglomeration*

The target value for the protection of human health for ozone was exceeded in the evaluated years 2019 – 2021 in the Bratislava agglomeration and in the Slovakia zone.

[25] *Areas with deteriorated air quality due to local heating and adverse dispersion conditions*
[26] *Agglomeration Košice - territory of the Košice city and municipalities Bočiar, Haniska, Sokoľany and Veľká Ida http://www.shmu.sk/sk/?page=1&id=oko_info_az*
[27] *Zone Košice region - territory of Košice region without agglomeration Košice http://www.shmu.sk/sk/?page=1&id=oko_info_az*

5.2 SUMMARY

Both monitoring and modelling of air quality have shown that although the concentrations of the main pollutants have naturally decreased since the beginning of the measurements, many problems still remain, especially with high concentrations of benzo(a)pyrene and PM.

In 2021, the number of days with high PM_{10} concentrations has increased compared to 2020. The limit value for the average daily concentration was exceeded at the monitoring station in Jelšava, Veľká Ida and in Banská Bystrica, Štefánikovo nábrežie. The limit value for the annual average concentration of $PM_{2.5}$ (valid from 2020) was exceeded at the monitoring station in Jelšava, Veľká Ida and Martin.

Among the most alarming facts are high concentrations of benzo(a)pyrene. Based on preliminary measurement results the target value was exceeded at all stations except stations in the Danube Plain and the regional background stations in the Prešov region.

Interestingly, in 2021 several episodes of long-range transport of dust from the Sahara region and other arid areas were observed, resulting in higher PM concentrations in February and in the summer months.

At some of the new monitoring stations, established within the project “The Improvement of the National Air Quality Monitoring Network”, high values of PM_{10}, $PM_{2.5}$ and benzo(a)pyrene were measured. The choice of new sites has thus proved to be justified particularly in Plášťovce, Oščadnica and Púchov, where the impact of household heating with solid fuels was evident. A more detailed assessment for separate zones and agglomerations is provided in the Annexes to this publication – Air quality evaluations of NUTS-3 regions.

Annual evaluation of the measurements at the new stations can be made only the next year, as some of the stations measured only for a few months at the end of 2021. The new stations are important not only for the measurement-based air quality assessment, but also for the calibration of mathematical models, outputs of which provide the spatial distribution of pollutant concentrations and the analysis of the contribution of different emission sources to air pollution.

Given the ongoing energy crisis, we can probably expect a deterioration of air quality in the winter months due to an increase in the consumption of solid fuels. Let us try to save energy and, if we have own heating, follow advice that will help us reduce emissions.

LIST OF ANNEXES