AIR POLLUTION IN THE SLOVAK REPUBLIC 2021

ANNEX

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Air quality monitoring department
SLOVAK HYDROMETEOROLOGICAL INSTITUTE

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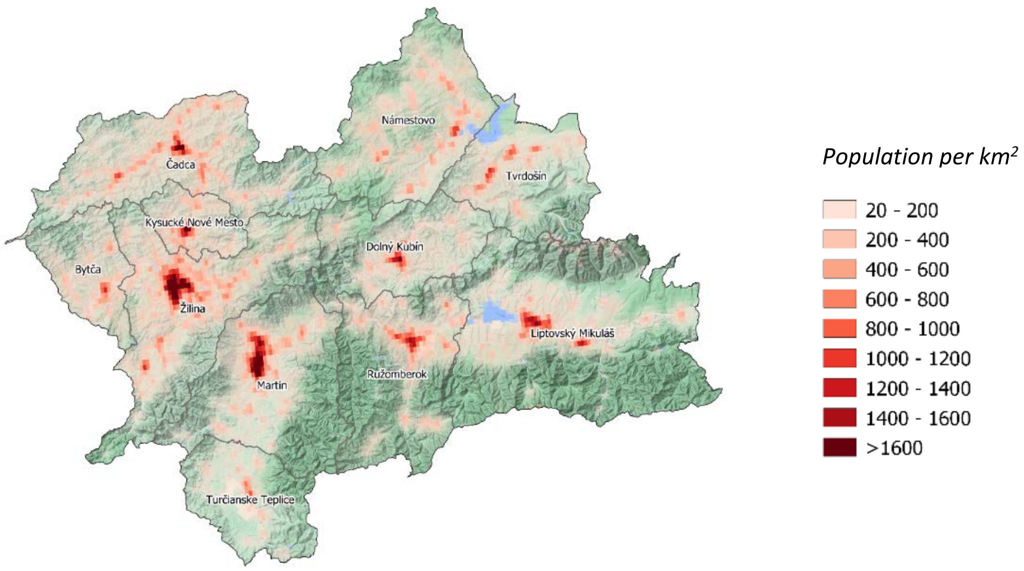
Version 2

1 DESCRIPTION OF ŽILINA REGION TERRITORY IN TERMS OF AIR QUALITY

The territory of the Žilina region is mostly mountainous, it belongs to the Western Carpathians. The Váh River divides the territory into northern and southern parts. In the northern part there are the High, Western and Belianske Tatras, Skorušinské vrchy-mountains, Oravské Beskydy, Oravská Magura, Oravská vrchovina-uplands, Chočské vrchy-mountains, Krivánska Fatra, Kysucké Beskydy, Kysucká vrchovina-uplands and Javorníky, in the southern part there are the Low Tatras, Veľká Fatra, Lúčanská Fatra and Strážovské vrchy-mountains. The highest point is Kriváň with an altitude of 2 494 m a. s. l., the lowest point is 285 m a. s. l. The area is also characterised by deep and closed basins, which adversely affects ventilation and thus the dispersion of pollutants in the air. **Fig. 1.1** shows the spatial distribution of population density in the zone.

The whole Žilina region is one zone in terms of air quality assessment for SO_2, NO_2, NO_X, PM_{10}, $PM_{2.5}$, benzene, polycyclic aromatic hydrocarbons and CO in the air.

Fig. 1.1 *Population density in the zone Žilina region (Source: EUROSTAT, 2018).*

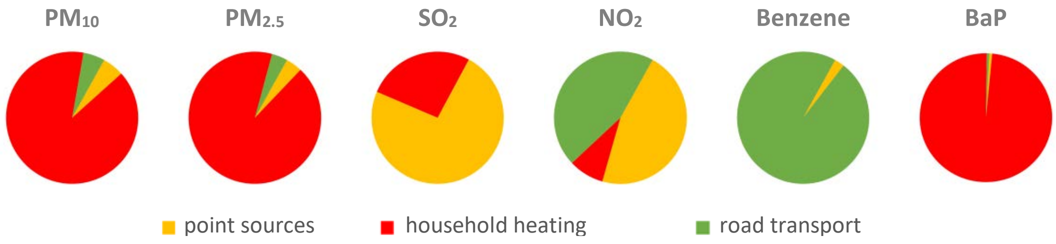


Air pollution sources in zone Žilina region

In the mountainous part of the region, household heating with solid fuel is a significant source of air pollution. Car traffic contributes most to air pollution in the districts of Žilina, Martin and Bytča. In the Žilina district, the road No. 11 has a daily average of 37 927 vehicles (6 867 trucks and 30 972 cars), the road No. 18 has a daily average of 32 334 vehicles (3 736 trucks and 28 523 cars), 30 659 vehicles are on the road No. 18A (6 080 trucks and 24 513 cars) and 23 579 vehicles are on the D3 motorway (5 661 trucks and 17 819 cars). In the Martin district, the average daily traffic on the road No. 65 is 22 973 vehicles (2 767 trucks and 20 153 passenger cars) and 23 002 vehicles (2 932 trucks and 19 982 passenger cars) are on the road No. 65 daily. In the Bytča district, the D1 motorway carries on average 23 956 vehicles per day (5 141 goods vehicles and 18 725 passenger cars) [1].

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

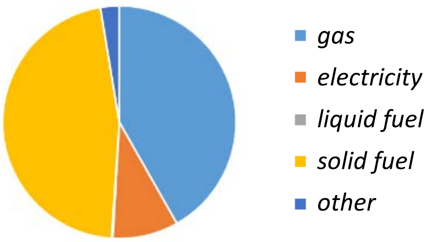
Fig. 1.2 *Share of different types of air pollution sources in total emissions in the Žilina region.*



Note: Medium and large air pollution sources registered in the NEIS database are identified for this purpose as "point sources".

Industrial sources of air pollution, such as paper mills, cement plants, lime and ferroalloy production, are less significant in the Žilina region in terms of their contribution to local air pollution by basic pollutant.

Fig. 1.3 *Share of different types of fuel used for heating in family houses [2].*



Both solid fuels and natural gas are used for heating in family houses in the zone, according to the Population and Housing Census (PHC) 2021 data. Žilina region has the highest share of solid fuels in family houses heating. Solid fuels are more likely to be used in rural settlement types with good availability of firewood. According to the PHC 2021, the districts of Námestovo, Martin and Čadca have the highest share of solid fuels in the zone.

2 AIR QUALITY MONITORING STATIONS IN ZONE ŽILINA REGION

In the Žilina region, air quality has been monitored at six monitoring stations, in Ružomberok since the 1980s. There is a monitoring station at Ružomberok, Riadok, which characterises air quality in an urban background location, close to a local road with low traffic intensity. The station in Žilina represents urban background pollution values. The monitoring station in Martin records the impact of road traffic near a busy access road.

In 2021, two monitoring stations were added in the zone. The station in Liptovský Mikuláš characterises urban background pollution and Oščadnica represents a rural type of built-up area where solid fuel heating plays an important role in air pollution.

The monitoring station at Chopok is the highest air quality monitoring station in the Slovak Republic. It is governed by the EMEP monitoring programme (*https://www.emep.int/*) and is also part of the GAW network (*https://community.wmo.int/activity-areas/gaw*).

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

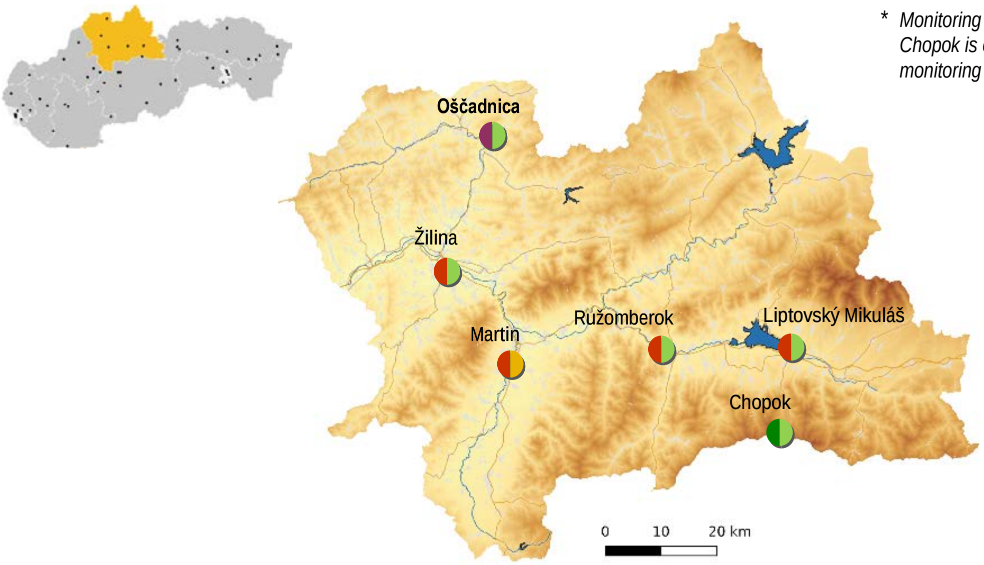
Tab. 2.1 contains information on air quality monitoring stations in the zone Žilina region:

- international EoI code, station characteristics according to the dominant sources of air pollution (traffic, background, industrial), type of monitored area (urban, suburban, rural/regional) and geographical coordinates;
- monitoring programme. Continuous monitoring automatic instruments provide hourly average concentrations of PM_{10}, $PM_{2.5}$, nitrogen oxides, sulphur dioxide, ozone, carbon monoxide, benzene and mercury. The SHMÚ test laboratory analyses heavy metals and polycyclic aromatic hydrocarbons as part of manual monitoring, resulting in 24-hour average values.

Tab. 2.1 Air quality monitoring programme in the zone Žilina region.

Zone Žilina region								Measurement programme									
								Continuously								Manually	
District	Code EoI	Name of station	Type of area	Type of station	Geographical longitude	Geographical latitude	Altitude [m]	PM_{10}	$PM_{2.5}$	NO, NO_2	SO_2	O_3	CO	Benzene	Hg	As, Cd, Ni, Pb	BaP
Liptovský Mikuláš	SK0002R	Chopok, EMEP	R	B	19°35'21"	48°56'37"	1990			■		■				■ *	
Liptovský Mikuláš	SK0067A	Liptovský Mikuláš, Školská	U	B	19°37'10"	49°05'02"	578	■	■	■	■						
Čadca	SK0071A	Oščadnica	S	B	18°53'01"	49°26'07"	465	■	■								
Martin	SK0039A	Martin, Jesenského	U	T	18°55'17"	49°03'35"	383	■	■	■			■	■			
Ružomberok	SK0008A	Ružomberok, Riadok	U	B	19°18'09"	49°04'45"	475	■	■	■	■	■	■	■		■	■
Žilina	SK0020A	Žilina, Obežná	U	B	18°46'17"	49°12'41"	356	■	■	■		■	■				■
							Total	5	5	5	2	3	3	2	0	2	3

* *Monitoring of heavy metals at the stations Chopok is carried out according to the EMEP monitoring programme (Tab. 2.2).*



Type of area:
U – urban
S – suburban
R – regional

Type of station:
B – background
T – traffic
I – industrial

The Chopok monitoring station characterises the regional background level of pollution, it is included in the EMEP monitoring programme[3] which covers extended air pollution monitoring as well as analysis of atmospheric precipitation.

The air quality monitoring programme at the EMEP station Chopok in 2021 is shown in **Tab. 2.2**. Heavy metals are analysed from weekly samples (sampling period is 7 days), other pollutants are analysed from 24-hour samples.

Tab. 2.2 *Monitoring programme at the EMEP station Chopok.*

	Sulphur dioxide (SO_2)	Nitrogen oxides (NO_X)	Sulphates (SO_4^{2-})	Nitrates (NO_3^-)	Nitric acid (HNO_3)	Chlorides (Cl)	Ammonia, Ammonium ions (NH_3, NH_4^+)	Alkaline ions (K^+, Na^+, Ca^{2+}, Mg^{2+})	VOC	PM_{10}	EC/OC	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	x	x	x

** TSP –Total Suspended Particles in air*

Precipitation quality (pH, conductivity, sulphate, nitrates, chlorides) is analysed from samples collected at EMEP stations according to the monitoring programme shown in **Tab. 2.3** on a daily basis. The analyses result in average daily values.

The sampling interval for heavy metal analysis is the calendar month. A "bulk" type precipitation collectors is used to collect precipitation, which records wet and dry deposition. Analysis of the samples thus collected is used to assess the total deposition.

Tab. 2.3 *Precipitation measurement programme at the EMEP station Chopok.*

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

[3] *https://www.emep.int*

3 ASSESSMENT OF AIR QUALITY IN ZONE ŽILINA REGION

This chapter contains an assessment of air quality in the zone Žilina region based on monitoring, supplemented by mathematical modelling results for PM_{10}, $PM_{2.5}$ and benzo(a)pyrene for the year 2021.

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

	Protection of human health									AT [2)]	
Pollutant	SO_2		NO_2		PM_{10}		$PM_{2.5}$	CO	Benzene	SO_2	NO_2
Averaging period	1 h	24 h	1 h	1 year	24 h	1 year	1 year	8 h [1)]	1 year	3 h in a row	3 h in a row
Parameter	number of exceedances	number of exceedances	number of exceedances	average	number of exceedances	average	average	average	average	number of exceedances	number of exceedances
Limit value [µg·m^{-3}]	350	125	200	40	50	40	20	10 000	5	500	400
Maximum number of exceedances	24	3	18		35						
Chopok, EMEP			0	2							0
Liptovský Mikuláš, Školská *	0	0	0	26	5	26	**23			0	0
Martin, Jesenského			0	21	28	29	21	1 232	0.95		0
Oščadnica *					6	39	**35				
Ružomberok, Riadok	0	0	0	16	15	24	19	2 113	1.20	0	0
Žilina, Obežná			0	19	24	25	19	2 050			0

≥ 90% of valid measurements *Exceedance of the limit value is marked in red.*

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

** AMS began measuring during 2021 - Liptovský Mikuláš 29. 10. 2021 and Oščadnica 7. 12. 2021*

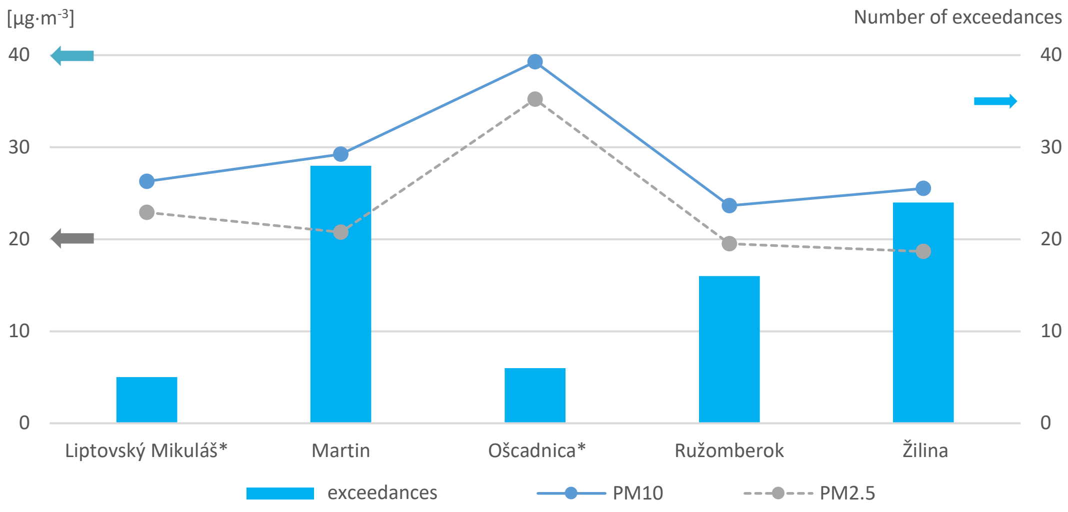
*** measurements started during 2021, there are not enough valid measurements to assess the exceedance of limit values on a yearly basis*

Except for the new monitoring stations (installed during the calendar year - Liptovský Mikuláš and Oščadnica), in accordance with the Regulation of MoE SR No. 244/2016 Coll. of Acts on air quality, as amended, the required proportion of valid values at the other stations has been fulfilled.

3.1 PM_{10} and $PM_{2.5}$

Fig. 3.1 shows the average annual concentrations of PM_{10}, $PM_{2.5}$ and the number of days with average daily PM_{10} concentrations above 50 µg·m^{-3} according to the results of measurements at monitoring stations in the Žilina region in 2021.

Fig. 3.1 Average annual concentrations of PM_{10}, $PM_{2.5}$ and the number of exceedances of the daily limit value for PM_{10}.



Number of exceedances - daily average concentrations higher than 50 µg · m^{-3}; the Liptovský Mikuláš station started measuring in October 2021 and Oščadnica in December 2021, therefore the number of exceedances at these two stations does not reflect air pollution for the whole year. Exceedances of the limit values for PM_{10} and $PM_{2.5}$ occur mainly in the winter months when the measuring stations Liptovský Mikuláš and Oščadnica were not in operation (January, February).

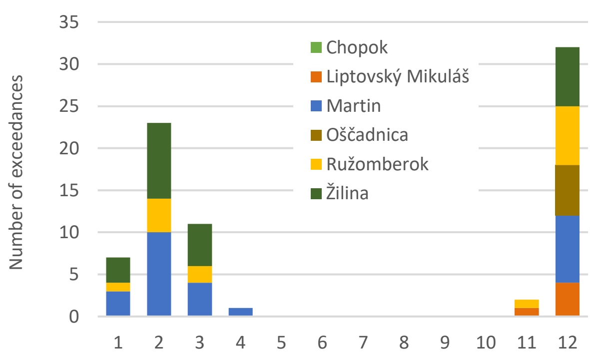
*The arrows show the limit values, **grey arrow** $PM_{2.5}$ (average annual concentration: 20 µg·m^{-3}); **blue left arrow** PM_{10} (average annual concentration: 40 µg·m^{-3}); **blue right arrow** number of exceedances (average daily PM_{10} concentration of 50 µg·m^{-3} must not be exceeded more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

PM_{10}

The limit value for the annual average concentration of PM_{10} (40 µg·m^{-3}) in the zone Žilina region was not exceeded. The limit value for the number of exceedances (35) of the average daily limit concentration of PM_{10} (50 µg·m^{-3}) was not exceeded by any station (**Fig. 3.1**).

The highest annual mean PM_{10} concentration (29 µg·m^{-3}) and the highest number of daily exceedances (28) were recorded at the traffic station in Martin. At the urban background stations in Ružomberok and Žilina, average concentrations of 24 µg·m^{-3} and 25 µg·m^{-3} were recorded in 2021, with 24 daily exceedances recorded at the Žilina station, which is significantly higher than the 15 in Ružomberok, which until 2012 was characterised by the highest number of exceedances in the Žilina region. **Fig. 3.2** shows the number of exceedances of the average daily limit concentration of PM_{10} in individual months in 2021. All exceedances are concentrated in the cold months, when dispersion conditions are worse and PM_{10} emissions are increased, especially from space heating.

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



From **Fig. 3.4** it can be seen that PM_{10} concentrations are lower in the warmer months of the year than in the cooler months during the heating season. The monthly average PM_{10} and $PM_{2.5}$ concentrations followed a similar pattern at the different station types, with a peak in February, when the influence of long-range transport of Sahara dust was also evident, with worsened dispersion under anticyclone.

Fig. 3.3 shows the modelling results for PM_{10} calculated for the year 2021 using the RIO model subsequently adjusted using the IDW regression method (for more details see Chapter 4 of *Air pollution in the Slovak Republic 2021 Report*).

Fig. 3.3 *Average annual PM_{10} concentration (left) and number of exceedances of the PM_{10} daily threshold (right) in 2021. Only values above 15 $\mu g \cdot m^{-3}$ and non-zero number of exceedances are shown.*

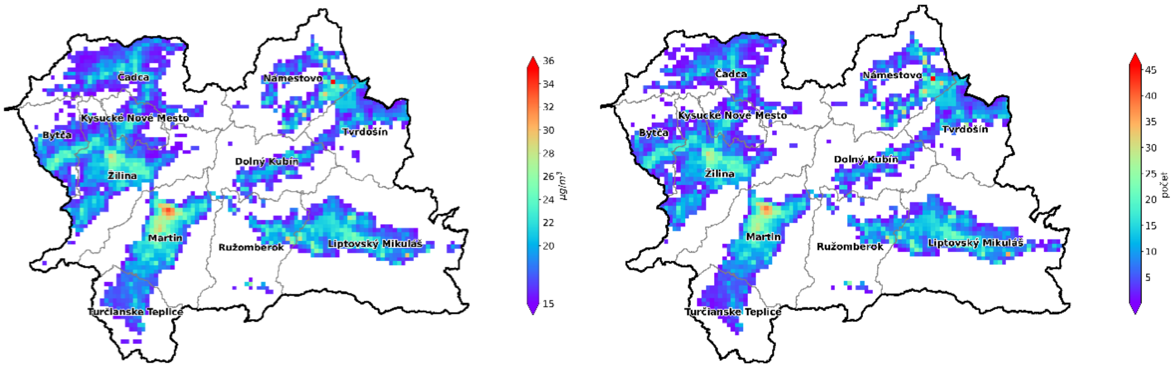
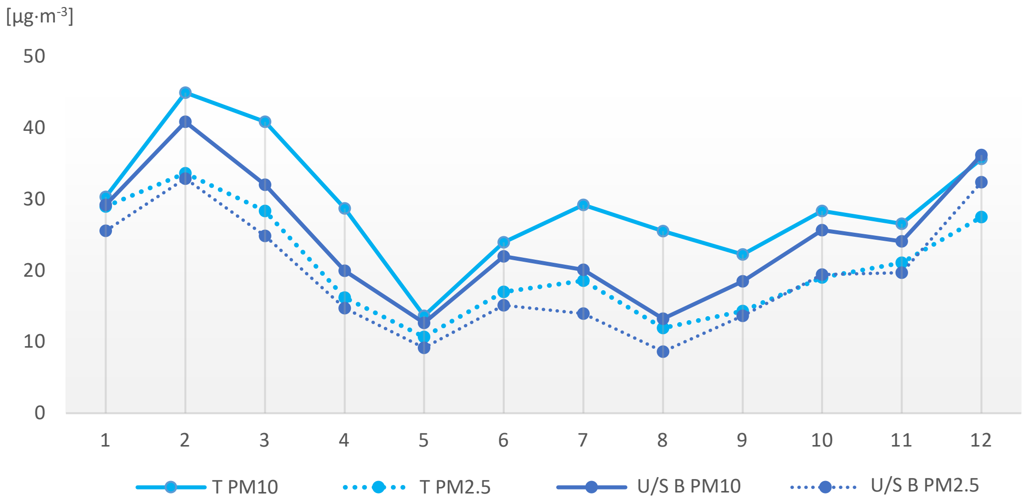


Fig. 3.4 *Average monthly concentrations of PM_{10} and $PM_{2.5}$ in the Žilina region by station type.*



***T PM10** and **T PM2.5** – average monthly concentration of PM_{10} and $PM_{2.5}$ at the traffic station Martin; **U/S B PM10** and **U/S B PM2.5** – average monthly concentrations of PM_{10} and $PM_{2.5}$ at the urban/suburban background stations: Liptovský Mikuláš, Oščadnica, Ružomberok, Žilina.*

■ $PM_{2.5}$

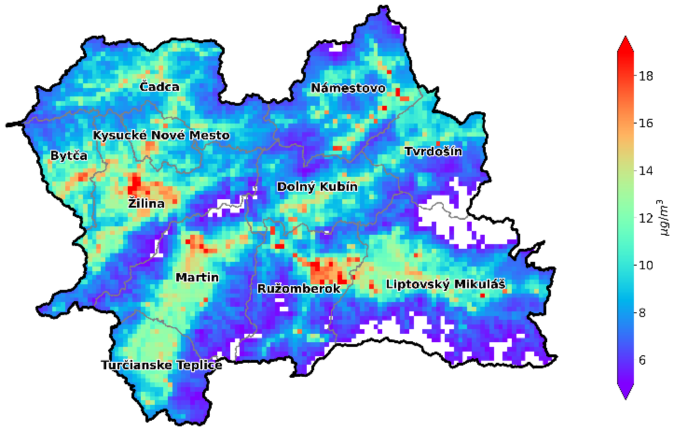
The annual average concentration of $PM_{2.5}$ in Martin 21 $\mu g \cdot m^{-3}$ exceeded the limit value for the protection of human health (20 $\mu g \cdot m^{-3}$). High average $PM_{2.5}$ concentrations were also recorded at stations in Ružomberok and Žilina, 19 $\mu g \cdot m^{-3}$. The trend of $PM_{2.5}$ concentrations is shown by the dotted line in **Fig. 3.4**. As with PM_{10}, $PM_{2.5}$ concentrations are higher in the colder months of the year. At all stations, the mean annual concentration was higher than the WHO recommendation[4] (5 $\mu g \cdot m^{-3}$), which was not

[4] *WHO GLOBAL AIR QUALITY GUIDELINES, 2021. Recommendations on classical air pollutants. (str. 4) https://apps.who.int/iris/bitstream/handle/10665/345334/9789240034433-eng.pdf*

met in any month of the year, including summer, when $PM_{2.5}$ concentrations tend to be lowest. Increased concentrations of $PM_{2.5}$ are risky mainly because of their adverse health effects.

As mentioned above for PM_{10}, air quality modelling has also been carried out for the pollutant $PM_{2.5}$. The map in **Fig. 3.5** is the output of the RIO model combined with IDW-R.

Fig. 3.5 *Average annual $PM_{2.5}$ concentrations.*

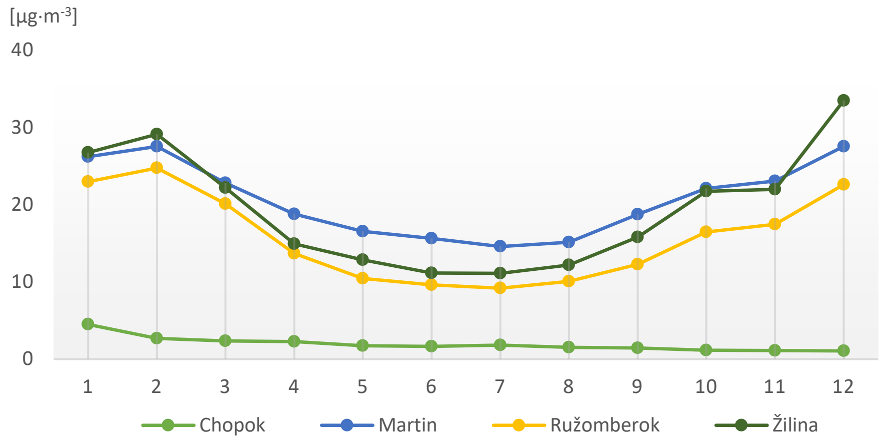


Average annual concentrations of $PM_{2.5}$ in 2021. Only values above 5 $\mu g \cdot m^{-3}$ are shown, which is the threshold recommended by the WHO.

3.2 Nitrogen dioxide

Nitrogen dioxide monitoring is carried out at five stations, the average monthly values for individual stations are shown in **Fig. 3.6**, with the exception of the AMS in Liptovský Mikuláš (put into operation on 29 October 2021).

Fig. 3.6 *Average monthly NO_2 concentrations.*



The main source of NO_2 emissions is road transport. The highest concentrations for this reason are recorded at the traffic station Martin, Jesenského, where the average annual value reached 21 $\mu g \cdot m^{-3}$. At the urban stations in Ružomberok and Žilina it was 16 $\mu g \cdot m^{-3}$ and 19 $\mu g \cdot m^{-3}$ respectively. The limit value for the annual mean concentration of 40 $\mu g \cdot m^{-3}$ is therefore not exceeded at any of the stations in this zone in 2021. Due to the worsened dispersion conditions, NO_2 concentrations are higher in winter, as illustrated in **Fig. 3.6**. The annual mean concentration at the rural background station Chopok reached 2 $\mu g \cdot m^{-3}$. In the zone, only this station meets the WHO recommendations (10 $\mu g \cdot m^{-3}$), which are significantly stricter than the EU limits.

3.3 Ozone

Ozone monitoring is carried out in this zone at three monitoring stations - in Chopok, Žilina and Ružomberok. The highest ozone concentrations are measured at the Chopok station and some of the lowest concentrations within the National Air Quality Monitoring Network are measured at the stations in Ružomberok and Žilina. This is due to the characteristics of the stations. Chopok is a high-altitude station where ozone input from the upper troposphere is more significant, and urban stations close to roads show ozone titration by NO. At the Ružomberok station, the 90% limit for the number of valid measurements was not reached for ozone in the year.

The highest concentrations of ground-level ozone generally occur in warm months with high sunshine intensity (**Fig. 3.7**). **Fig. 3.8** and **Fig. 3.9** show the so-called daily course of O_3 concentration. It shows that concentrations increase with sunrise, peak around midday and gradually decrease in the evening to a minimum that occurs early in the morning. Large differences in ground-level ozone concentrations are also observed in the warm and cold seasons.

Fig. 3.7 *Monthly average O_3 concentrations.*

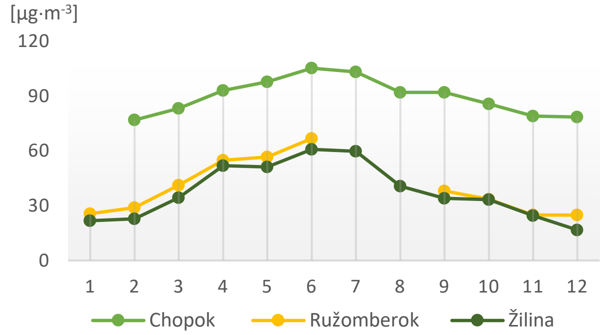


Fig. 3.8 *Daily O_3 concentration in January 2021.*

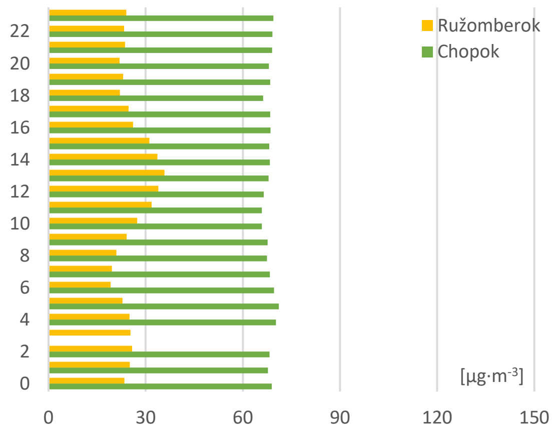
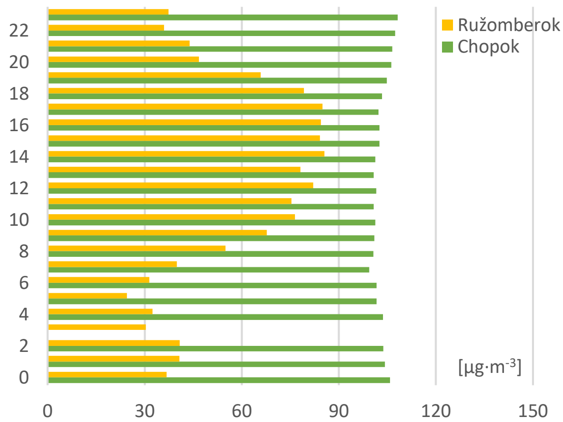


Fig. 3.9 *Daily O_3 concentration v July 2021.*



No exceedances of the ground-level ozone information or alert threshold were observed at any station in the zone in 2021. This is due to the fact that 2021 was relatively cold even in the summer and especially in the spring.

3.4 Benzo(a)pyrene

Benzo(a)pyrene is monitored at three monitoring stations in the Žilina region - in Žilina, Ružomberok and from the end of 2021 also in Oščadnica. The target value for benzo(a)pyrene (1 ng·m^{-3}) is regularly exceeded in Žilina (**Tab. 3.2**), where it has been measured since 2018. In Ružomberok, benzo(a)pyrene monitoring started in 2020, and 2021 was the first assessed year with sufficient measurements. The target value here was exceeded more than twice.

The annual pattern of concentrations has an even more pronounced peak in the cold half of the year compared to PM, with the exceptionally cold December 2021 reflected not only in the number of daily PM exceedances, but especially in the high concentrations of benzo(a)pyrene (**Fig. 3.10**). This is also reflected in the extremely high values measured in Oščadnica, where BaP monitoring started in December 2021. Although it can be expected that when the low values of benzo(a)pyrene concentrations in the summer months are included in the year-round monitoring in the following years, the average annual concentration will be lower, it can be assumed with high probability that Oščadnica is another area where benzo(a)pyrene is a problem. This is an area with relatively higher altitudes and thus higher demands for heating; dispersion conditions in winter may also be problematic. It can be assumed that in areas with a high share of solid fuels in domestic heating and poor dispersion conditions, similarly high levels of benzo(a)pyrene would be measured.

Tab. 3.2 *Assessment of air pollution by benzo(a)pyrene.*

	2017	2018	2019	2020	2021
Target value [ng·m^{-3}]	1.0	1.0	1.0	1.0	1.0
Žilina, Obežná		6.0	2.0	1.9	1.9
Ružomberok, Riadok				4.5	2.3
Oščadnica*					*12.0

≥ 90% of valid measurements
The red colour indicates that the target value has been exceeded in case of sufficient data coverage (≥ 90%) in a given year.
** Measurements started during the year, there are not enough valid measurements for a full year assessment.*

Fig. 3.10 *Results of benzo(a)pyrene measurements in 2021.*

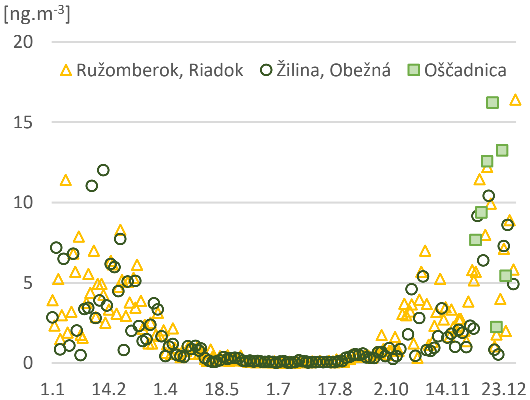
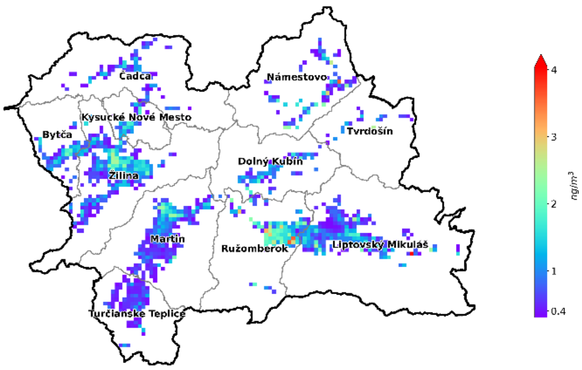


Fig. 3.11 *Average annual concentration of benzo(a)pyrene from RIO model output, IDW-R (2021).*



The most significant source of benzo(a)pyrene is domestic heating with solid fuels, especially under-dried wood or unsuitable fuels (various types of waste). In the vicinity of major transport hubs, traffic is also a source of emissions. The latter may mainly influence concentrations at the stations in Žilina and Ružomberok. **Fig. 3.11** shows the average annual concentration according to the mathematical modelling outputs. In areas with unfavourable dispersion conditions, pollution by this carcinogenic pollutant is a significant problem.

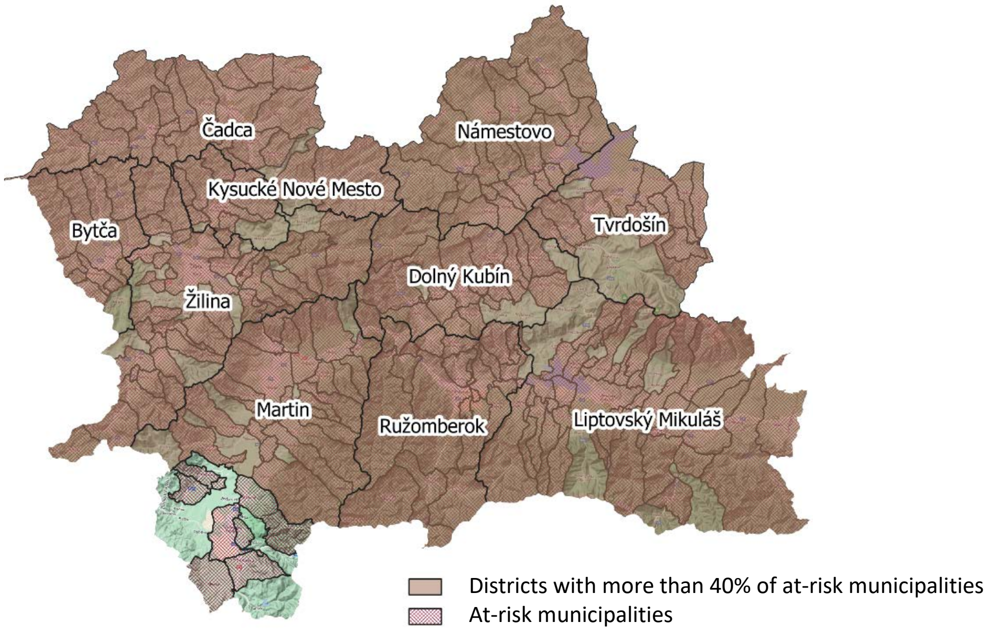
3.5 Chemical composition of precipitation

At the Chopok rural background station, the quality of precipitation is monitored on a daily basis. The qualitative composition of basic ions, pH parameters and conductivity are monitored. The annual average pH value was 5.48 and the monthly averages did not fall below pH 5. Sulphate and nitrate concentrations were at low levels throughout the year. It can therefore be concluded that there is no excessive acidification of the environment in the Žilina region. Detailed monitoring results are presented in Chapter 3 in the Regional Monitoring section of *Air pollution in the Slovak Republic 2021 Report*.

3.6 Risk areas

Fig. 3.12 shows the areas at risk of air quality deterioration due to pollutants (PM and benzo(a)pyrene) from domestic heating based on the modelling results. The modelling results were obtained by using the methodology of *D. Štefánik: Identification of at-risk municipalities with air quality threatened by local heating and adverse dispersion conditions* (updated in 2022)[5]. This methodology is based on data from *Population and Housing Census (PHC) 2021 (*usage of solid fuels for *household heating)*, and it also takes into account high PM concentrations obtained from mathematical modelling and adverse dispersion conditions. There are no available input data with high spatial resolution covering the whole country for mathematical modelling. Therefore, we assume that the area is at risk is if it has a high proportion of solid fuel heating even though this was not indicated by mathematical modelling.

Fig. 3.12 *Risk areas in the Žilina region.*

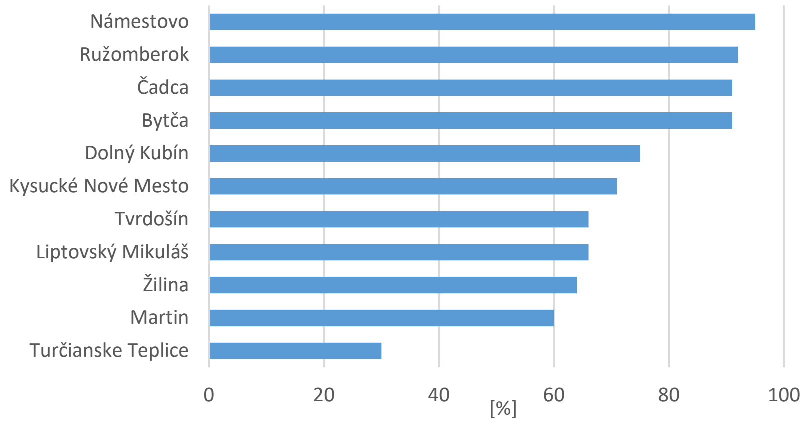


The Žilina region has the highest share of municipalities at-risk from all the regions. This results from the high proportion of solid fuels usage for domestic heating (based on available data), from the complex orography, which creates conditions for the formation of temperature inversions, especially in the winter period. The mean wind speed is also important parameter. It should be noted that this assessment is based on data from PHC 2021, which does not yet reflect the impact of the energy crisis.

[5] *https://www.shmu.sk/File/oko/studie_analyzy/Popis_metody_na_urcenie_rizikovych_oblasti_aktualizacia.pdf*

The percentage of at-risk municipalities in individual districts is shown in **Fig. 3.13**. If a district has more than 40% of the municipalities at risk, the whole district is defined as at risk. In Žilina region all districts are at risk, except district of Turčianske Teplice.

Fig. 3.13 Percentage proportion of at-risk municipalities in the districts of Žilina region.



The highest proportion of at-risk municipalities in the Žilina region is in the Námestovo district, the highest number of at-risk municipalities is in the Liptovský Mikuláš district. Especially problematic are mountain basins with good availability of firewood. More than 70% of at-risk municipalities in Žilina region have less than 2 000 inhabitants, which confirms the assumption that the problem is considerably greater in areas with a rural type of settlement. More detailed data is available on the interactive map[6].

3.7 Summary

In 2021, no exceedances of the limit values for SO_2, NO_2, CO benzene and PM_{10} were measured in the Žilina region. The limit value for the annual average concentration of $PM_{2.5}$ was exceeded at the monitoring station in Martin. The target value for the annual average concentration of benzo(a)pyrene according to measurements was exceeded at the stations in Ružomberok and Žilina.

The territory of Ružomberok, the municipality of Likavka and the territory of Žilina have therefore been defined as air quality management areas for benzo(a)pyrene on the basis of monitoring. The territory of Martin and Vrútky has been defined as an air quality management area for $PM_{2.5}$ on the basis of monitoring.

Based on the results of the mathematical modelling, we can assume that in the Žilina region, high concentrations of PM and benzo(a)pyrene may also occur, especially in winter months, in other areas, especially in mountain valleys with unfavourable dispersion conditions and a high share of solid fuels in household heating.

[6] *https://ruraj-git.github.io/folium_html/*