AIR POLLUTION IN THE SLOVAK REPUBLIC 2022

ANNEX

AIR QUALITY ASSESSMENT IN ZONE ŽILINA REGION

Air quality monitoring department
SLOVAK HYDROMETEOROLOGICAL INSTITUTE

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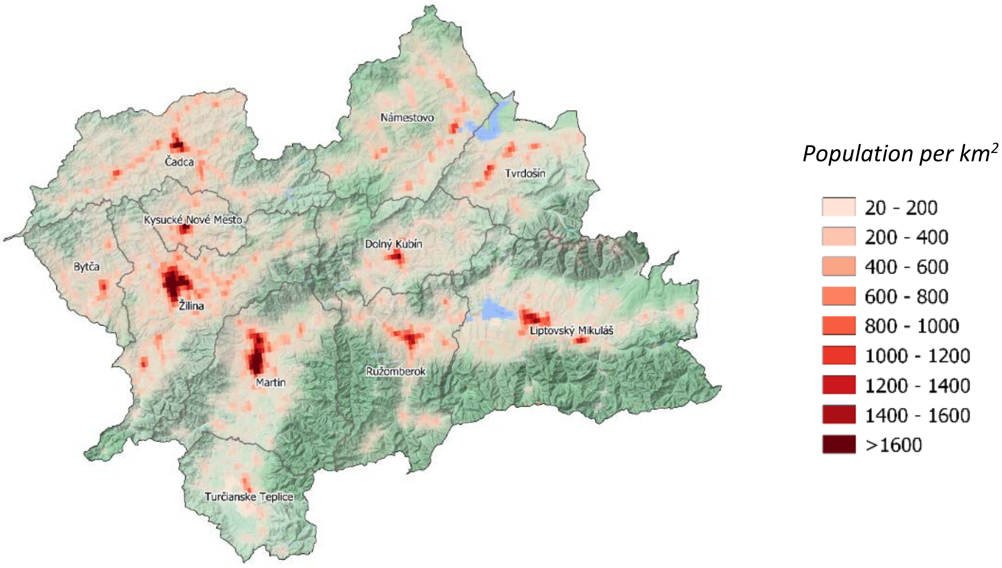
Version 1

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).*

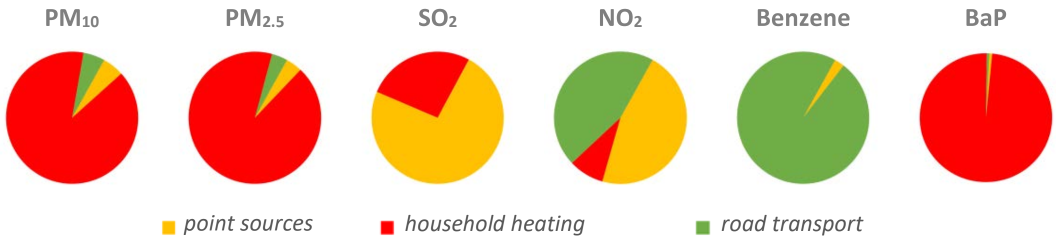


Air pollution sources in zone Žilina region

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*

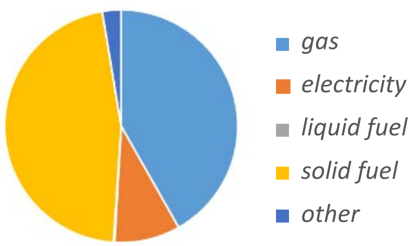
Fig. 1.2 *Share of different types of air pollution sources in total emissions in the Žilina region.*



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 of 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 household 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 follows the EMEP monitoring programme (*https://www.emep.int/*) and is also part of the GAW network (*https://community.wmo.int/activity-areas/gaw*).

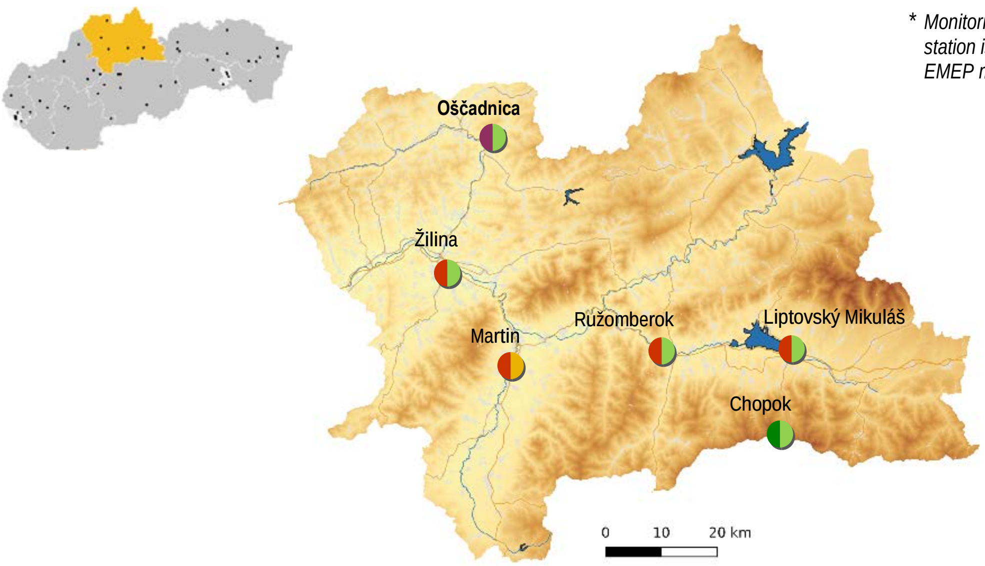
[2] *https://www.scitanie.sk*

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 devices provide hourly average concentrations of PM_{10}, $PM_{2.5}$, nitrogen oxides, sulphur dioxide, ozone, carbon monoxide and benzene. The SHMÚ test laboratory analyses heavy metals and polycyclic aromatic hydrocarbons as part of manual monitoring, resulting in 24-hour average concentrations.

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

Zone Žilina region								Measurement programme									
								Continuously								Manually	
District	EoI code	Station name	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	6	3	4	3	2	0	2	3



* *Monitoring of heavy metals at the Chopok station 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 wider air pollution monitoring as well as analysis of atmospheric precipitation.

The air quality monitoring programme at the EMEP station Chopok in 2022 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.*

	Ozone (O_3)	Sulphur dioxide (SO_2)	Nitrogen oxides (NO_X)	Sulphates (SO_4^{2-})	Nitrates (NO_3^-)	Nitric acid (HNO_3)	Chlorides (Cl)	TSP*	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

** 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 both wet and dry deposition (in the period when no precipitation occurs, it does not close). Analysis of the samples thus collected is used to assess the total (dry and wet) 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 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

[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 2022.

Tab. 3.1 *Assessment of air pollution according to limit values for protection of human health and smog warning system for PM_{10} in the zone Žilina region – 2022.*

	Protection of human health									IT[2)]	AT[2)]
Pollutant	SO_2		NO_2		PM_{10}		$PM_{2.5}$	CO	Benzene	PM_{10}	PM_{10}
Averaging period	1 h	24 h	1 h	1 year	24 h	1 year	1 year	8 h[1)]	1 year	12 h	12 h
Parameter	number of exceedances	number of exceedances	number of exceedances	average	number of exceedances	average	average	average	average	duration of exceedance [h]	duration of exceedance [h]
Limit value [$\mu g \cdot m^{-3}$]	350	125	200	40	50	40	20	10 000	5	100	150
Maximum number of exceedances	24	3	18		35						
Chopok, EMEP			0	2							
Liptovský Mikuláš, Školská	0	0	0	13	6	19	14			4	0
Martin, Jesenského			0	17	10	26	17	1 355	0.77	6	0
Oščadnica	0	0	0	7	9	22	17			19	0
Ružomberok, Riadok	0	0	0	16	17	23	18	2 234	1.11	15	1
Žilina, Obežná			0	20	18	24	17	2 160		38	12

≥ 90% of valid measurements

1) eight-hour maximum concentration

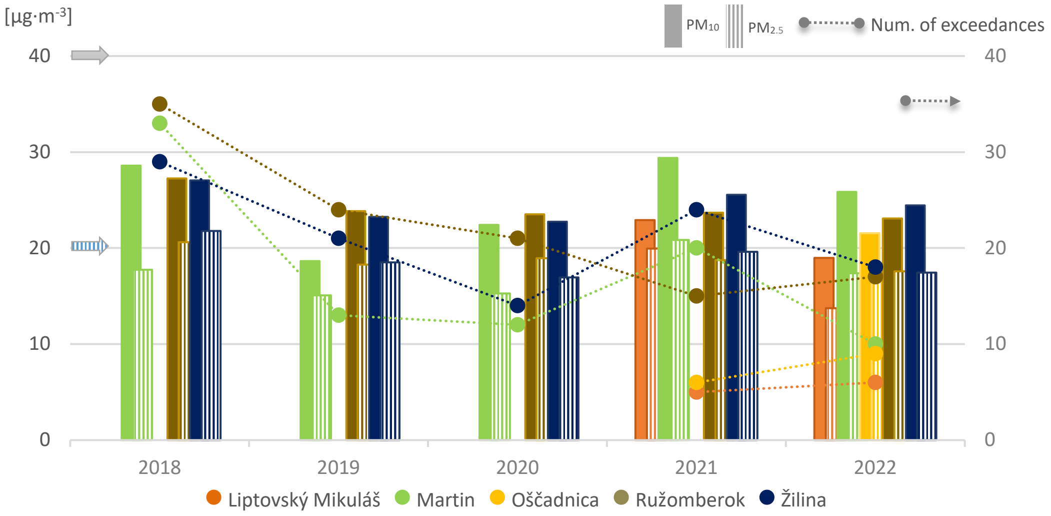
2) IT, AT – duration of exceedance (in hours) of the information threshold (IT) and alert threshold (AT) for PM_{10}

With the exception of SO_2 and NO_2 measurement in Oščadnica (this station, however, reached 88% and 89% of the valid values for both pollutants, i.e. almost the required 90%, and therefore the measurement of SO_2 and NO_2 in Oščadnica is also included in the assessment), the required proportion of valid values was observed at the other monitoring stations in accordance with the Decree of the Ministry of the Environment of the Slovak Republic No. 244/2016 Coll. on air quality, as amended.

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 2022.

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};

*Arrows show limit values, **blue striped** $PM_{2.5}$ (annual average concentration: 20 µg·m^{-3}); **grey solid** PM_{10} (annual average concentration: 40 µg·m^{-3}); **grey dotted** right number of exceedances (daily average 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. Similarly, 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 at any station (Fig. 3.1). The traffic station in Martin recorded both the highest annual average PM_{10} concentration (26 µg·m^{-3}, a year-on-year decrease of 3 µg·m^{-3}) and the highest number of daily exceedances (10; 28 exceedances in 2021). At the urban background stations in Ružomberok and Žilina, average concentrations of 23 µg·m^{-3} and 24 µg·m^{-3} were measured in 2022, with similar numbers of exceedances recorded at both stations (17 and 18, respectively). Fig. 3.2 shows the number of exceedances of the daily average PM_{10} limit concentration in each month of 2022. All exceedances are concentrated in the cold months (except for one exceedance in Martin in August), when dispersion conditions are worse and PM_{10} emissions are increased, especially from local heating. From Fig. 3.4, it can be seen that PM_{10} concentrations are lower in the warmer months of the year than in the colder months during the heating season. The average monthly concentrations of PM_{10} and $PM_{2.5}$ followed a similar pattern at the different station types, with local peaks in March and December.

Fig. 3.2 *Number of PM_{10} daily limit value exceedances per month in 2022.*

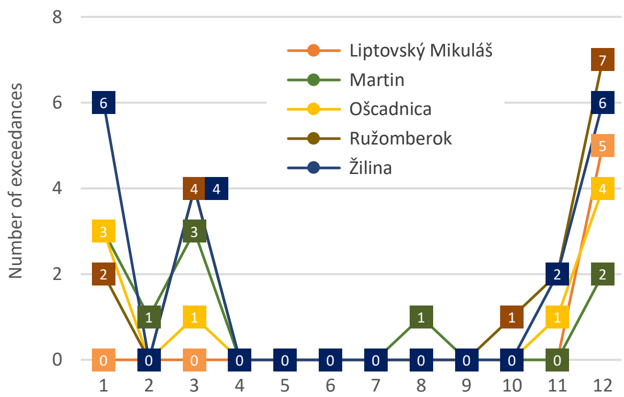


Fig. 3.3 shows the modelling results for PM_{10} calculated for the year 2022 using the RIO model subsequently adjusted by the IDW regression method (for more details see Chapter 4 of *Air pollution in the Slovak Republic 2022 Report*).

Fig. 3.3 *Annual average PM_{10} concentration (left) and number of PM_{10} daily limit value exceedances (right) in 2022.*

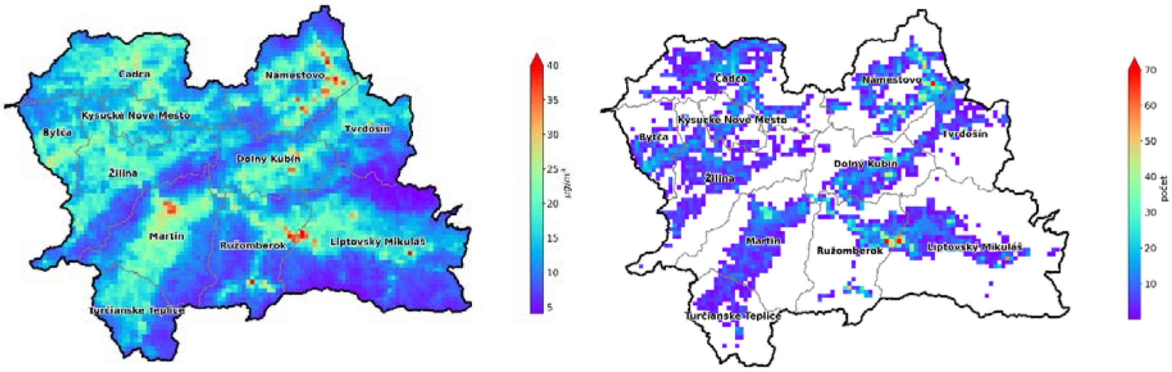
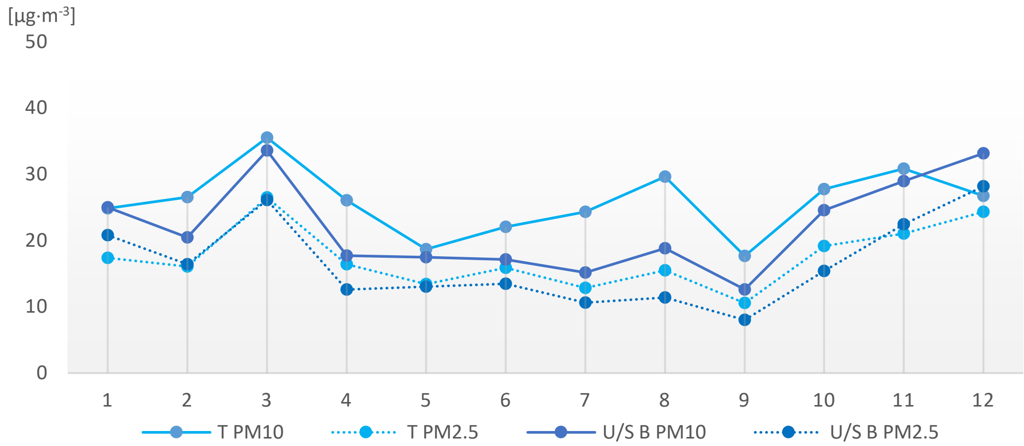


Fig. 3.4 *Average monthly concentrations of PM_{10} and $PM_{2.5}$ in Žilina region by station type.*



***T PM10** and **T PM2.5** – average monthly concentration of PM_{10} and $PM_{2.5}$ at the traffic station Martin;*
***U/S 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.*

■ $PM_{2.5}$

Increased concentrations of $PM_{2.5}$ are particularly risky because of their adverse effects on health. The average annual concentration of $PM_{2.5}$ at the traffic station in Martin reached 17 $\mu g \cdot m^{-3}$ (the year before it was 21 $\mu g \cdot m^{-3}$). Similar average concentrations were also recorded at (sub)urban background stations in Ružomberok (18 $\mu g \cdot m^{-3}$), Žilina (17 $\mu g \cdot m^{-3}$) and Oščadnica (17 $\mu g \cdot m^{-3}$). The $PM_{2.5}$ concentration trend is shown in **Fig. 3.4** by the dotted line. 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 met in any month of the year, including summer, when $PM_{2.5}$ concentrations tend to be lowest.

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.

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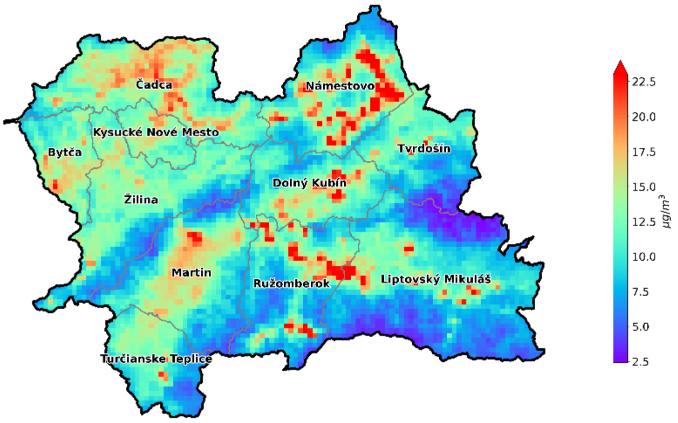
[4] *WHO GLOBAL AIR QUALITY GUIDELINES, 2021. Recommendations on classical air pollutants. (str. 4) https://apps.who.int/iris/bitstream/handle/10665/345334/9789240034433-eng.pdf*

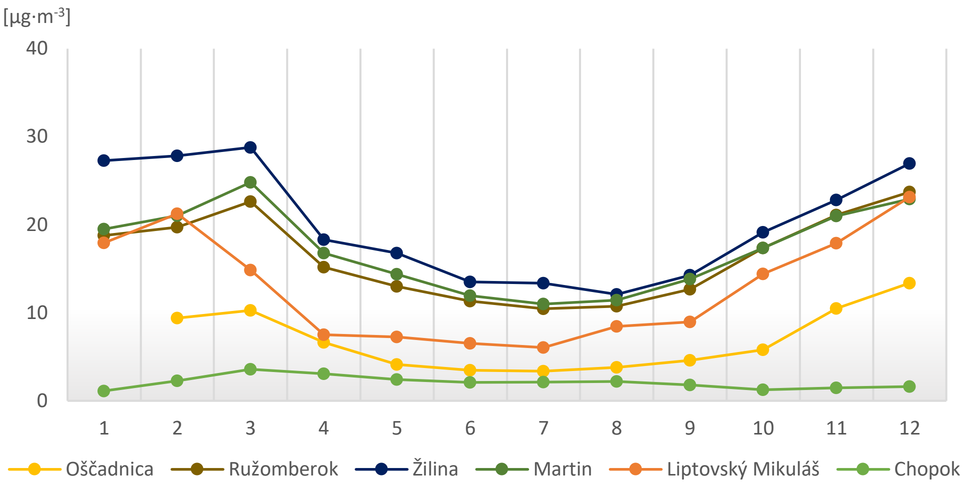
Fig. 3.5 *Average annual $PM_{2.5}$ concentrations in 2022.*



3.2 Nitrogen dioxide

Nitrogen dioxide monitoring is carried out at six stations, the average monthly values for individual stations are shown in **Fig. 3.6**.

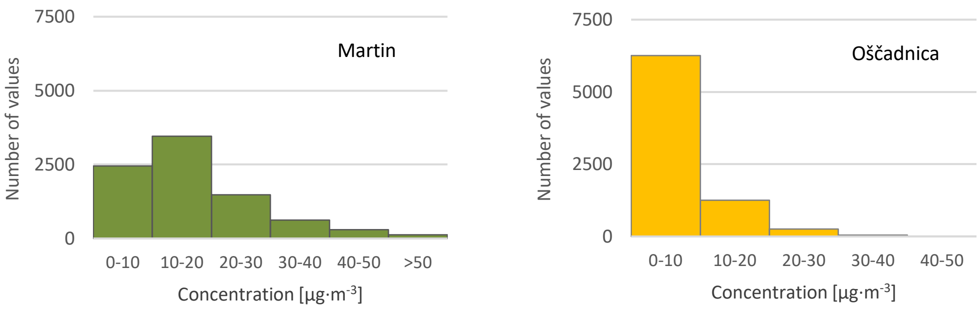
Fig. 3.6 *Average monthly NO_2 concentrations.*



The main source of NO_2 emissions is road transport. It is therefore interesting that the highest concentrations are recorded in 2022 at the urban background station Žilina, Obežná, where the average annual value reached 20 $\mu g \cdot m^{-3}$ (19 $\mu g \cdot m^{-3}$ in 2021), while at the traffic station in Martin it was 17 $\mu g \cdot m^{-3}$ (21 $\mu g \cdot m^{-3}$ in 2021). Lower values of this indicator were measured at the remaining urban background stations: in Ružomberok 16 $\mu g \cdot m^{-3}$ and in Liptovský Mikuláš 13 $\mu g \cdot m^{-3}$. Thus, the limit value for the annual average NO_2 concentration (40 $\mu g \cdot m^{-3}$) is not exceeded at any of the stations in this zone in 2022. Due to the deteriorated dispersion conditions, NO_2 concentrations are higher in winter, as illustrated in **Fig. 3.6**. We can see that the monthly concentrations at the traffic station in Martin almost copy the values measured at the urban background station in Ružomberok. The average annual concentration at the suburban background station Oščadnica was 7 $\mu g \cdot m^{-3}$ (the number of valid data here reached 89%, i.e. almost the desired level of 90%, so we include the NO_2 measurement in the assessment) and at the rural (regional) background station Chopok 2 $\mu g \cdot m^{-3}$. In 2022, in the Žilina region, only these two stations met the WHO recommendations (up to 10 $\mu g \cdot m^{-3}$) for annual average NO_2 concentrations, which are significantly stricter than the EU limits.

Fig. 3.7 compares the frequency distribution of hourly concentrations at the traffic station in Martin and the suburban background station in Oščadnica, which meets the WHO recommendation for an annual mean NO_2 concentration (up to 10 µg·m^{-3}). While the station in Martin recorded 29% of the hourly data in the band up to 10 µg·m^{-3}, AMS Oščadnica 80%.

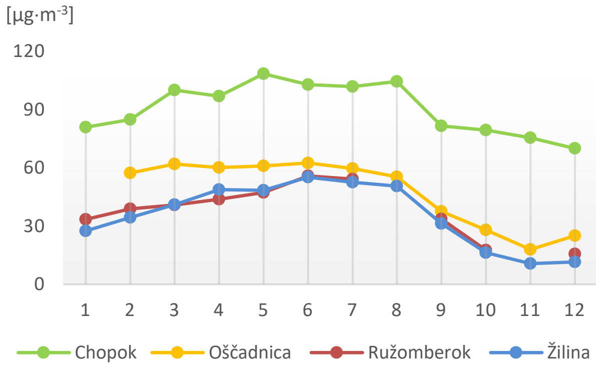
Fig. 3.7 *Histogram of hourly NO_2 concentrations at AMS Martin and Oščadnica.*



3.3 Ozone

Ozone monitoring is carried out in this zone at four monitoring stations - in Chopok, Žilina, Ružomberok and Oščadnica. The highest ozone concentrations are measured at the Chopok station and at the stations in Ružomberok and Žilina some of the lowest within the National Air Quality Monitoring Network. This is due to the characteristics of the stations. Chopok is a high-altitude AMS where ozone input from the upper troposphere is more significant, and urban stations close to roads show ozone titration by NO.

Fig. 3.7 *Average monthly concentrations O_3 in 2022.*



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. This illustrates 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.

We did not observe any stations exceeding the information or alert threshold for ground-level ozone in 2022.

Fig. 3.8 *Daily O_3 concentration in July 2022.*

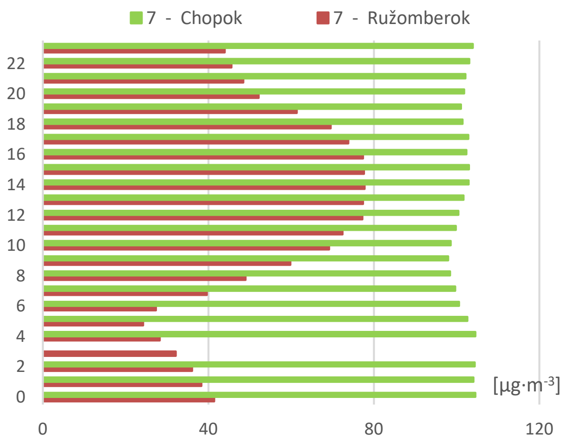
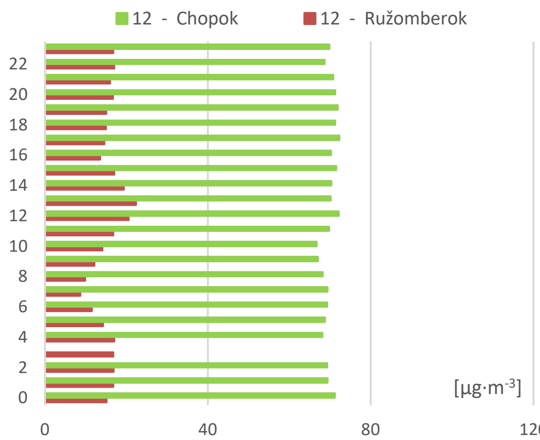


Fig. 3.9 *Daily O_3 concentration in December 2022.*



3.4 Benzo(a)pyrene

Benzo(a)pyrene is monitored at three monitoring stations in the Žilina region – in Žilina, Ružomberok and Oščadnica. The target value for benzo(a)pyrene (1 ng·m^{-3}) exceeded all three AMS (**Tab. 3.2**). In Žilina, this pollutant has been monitored since 2018, in Ružomberok since 2020, where the target value was exceeded more than twice in 2022 (similar to 2021).

It was confirmed that Oščadnica is another area where BaP is a problem. It is a location with relatively higher altitude and thus higher heating requirements, with probably problematic dispersion conditions in winter. Similarly high BaP values were measured in Oščadnica as in Ružomberok, and even significantly higher in March and April. The data coverage in Oščadnica reached 88%, which is close to the required 90%, and therefore the measurement is used in the evaluation. AMS did not measure the whole month of December due to a device malfunction, when BaP usually reaches the highest concentrations of the year. It is almost certain that the target value would have been exceeded in Oščadnica.

However, as a point of interest, in January and December 2022, BaP concentrations at these three stations were much lower than a year ago.

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

	2017	2018	2019	2020	2021	2022
Target value [ng·m^{-3}]	1.0	1.0	1.0	1.0	1.0	1.0
Žilina, Obežná		6.0	2.0	1.9	1.9	1.9
Ružomberok, Riadok				4.5	2.3	2.2
Oščadnica					*12.0	*2.5

≥ 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.

* *In 2021, BaP measurements were started during the year (there were not enough valid measurements for a full year assessment in 2021), and in 2022 the recovery was 88% (device malfunction during the whole December).*

Fig. 3.10 *Results of benzo(a)pyrene measurements in 2022.*

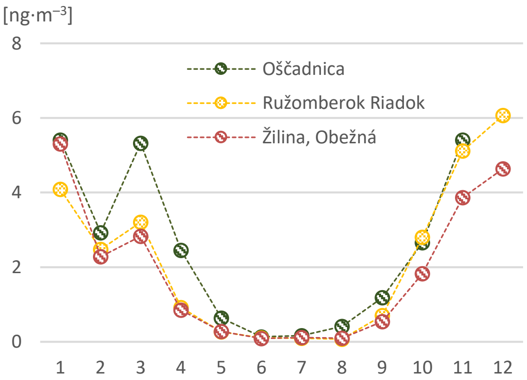
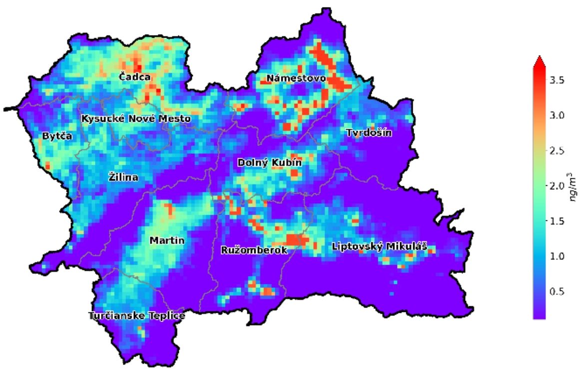


Fig. 3.11 *Average annual concentration of benzo(a)pyrene from RIO model output, IDW-R (2022).*



The most significant source of benzo(a)pyrene is domestic heating with solid fuels, especially underdried wood or unsuitable fuels (various types of waste). In the vicinity of major road junctions, traffic is also a source of emissions. It 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

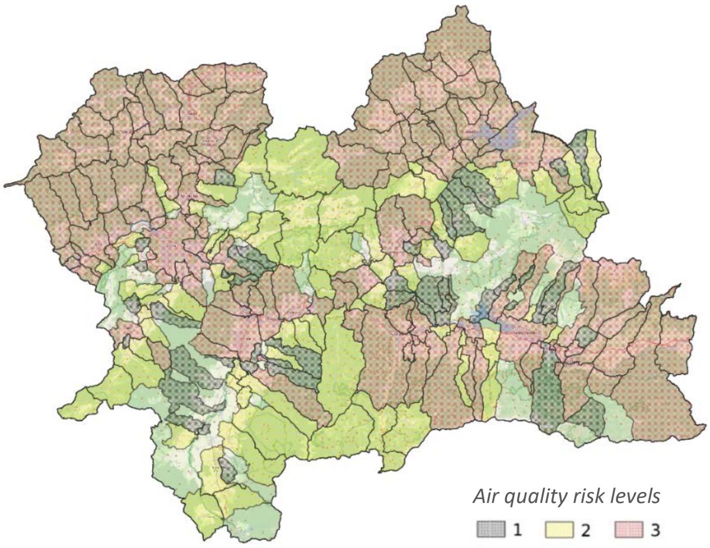
At the Chopok rural background station, the quality of precipitation is monitored on a daily basis. The qualitative composition of basic ions, pH parameters and conductivity are monitored. The annual average pH value was 5.49 and the monthly averages did not fall below pH 5. Wet SO_4^{2-} deposition was 0.3 g S/m^2/year and NO^{3-} was 0.2 g N/m^2/year. Wet lead deposition of lead was at 2 mg/m^2/year. Detailed monitoring results are presented in Chapter 3 in the Regional Monitoring section of *Air pollution in the SR 2022 Report*.

3.6 Risk municipalities

Fig. 3.12 displays municipalities at risk due to deteriorated air quality as determined by the Integrated Assessment Method[5]. Level 3 corresponds to the highest probability of air pollution risk. The methodology includes the level of household heating with solid fuels, the impact of worsened dispersion conditions from both short-term and long-term perspectives, results from the chemical transport model CMAQ, the interpolation model RIO, and high-resolution modelling results using the CALPUFF model in selected domains with an assumed deteriorated air quality.

Municipalities in which the limit value for PM, NO_2, or the target value for BaP was exceeded based on high spatial resolution modelling were automatically assigned a risk level 3, similar to municipalities where the limit or target value exceedance was detected through measurement. The list of municipalities and their risk levels can be found on the SHMÚ website[6].

Fig. 3.12 *Risk municipalities in zone Žilina region.*



Zones and agglomerations that include at least one municipality with a risk level 3 will develop an Air Quality Plan. In this regard, municipalities with a risk level 3 correspond to air quality management areas. However, measures to reduce emissions must be implemented in all municipalities within this designated zone with a risk level 2 or 3, ideally also in municipalities with a risk level 1.

The assessment using the Integrated Assessment Method aims to identify areas where action to improve air quality needs to be targeted. Given the distribution of air pollution sources and considering the microclimatic characteristics of the region, it is likely that pollution levels vary at different locations within the risk area. Spatial distribution of air pollution is provided by high-resolution modelling results, which are updated on the SHMÚ website[7].

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[5] *Štefánik, D., Krajčovičová, J.: Metóda integrovaného posúdenia obcí vzhľadom na riziko nepriaznivej kvality ovzdušia, Slovenský hydrometeorologický ústav, 2023, available at https://www.shmu.sk/sk/?page=996*

[6] *https://www.shmu.sk/sk/?page=2768*

[7] *https://www.shmu.sk/sk/?page=2699*

3.7 Summary

In 2022, no exceedances of the limit values for SO_2, NO_2, CO benzene, PM_{10} and a $PM_{2.5}$ were measured in the Žilina region. The target value for the annual average concentration of benzo(a)pyrene according to measurements was exceeded at the stations in Ružomberok, Žilina and, with a probability close to certainty, also in Oščadnica.

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.