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ARTICLE

The Impact of the New Year Celebration on the Air-Pollution in Slovakia

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ABSTRACT

Fireworks and pyrotechnics are an integral part of the New Year celebration that take place both in cities and rural areas as well. Depending on the meteorological conditions, these activities can raise air pollutant concentrations in ambient atmosphere. In order to estimate the size of this increase, air pollutant concentrations from up to 61 air quality stations situated in the Slovak Republic in period from 2010 to 2023 are analysed. Pollutant concentrations of PM_{10}, $PM_{2.5}$, CO, NO_2, SO_2, O_3 and benzene from New Year's Eve evening to New Year's morning are compared with data from 25 December to 7 January. In case of PM_{10} 557 cases were analysed. Among them in 64% the significant exceedance in concentrations which can be attributed to the New Year celebration with high probability was observed. The statistical difference between mean PM_{10} concentrations during the New Year celebration hours and during the surrounding days was strong ($p \leq 0.001$). For $PM_{2.5}$ the situation was similar. The New Year celebration affects other pollutant concentrations studied in this work in less extend. For them it is difficult to attribute the exceedance to the fireworks. This analysis provides clear evidence of the negative impact of fireworks and pyrotechnics on the air quality, which can lead to public health risks. This work can support policy makers to implement more stringent strategies to reduce air pollution and its effects on health.

Keywords: PM_{10}; $PM_{2.5}$; Public health; New Year's Day; Particulate matter; Fireworks

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1. Introduction

1.1 Pollution of air

Over the past few years, the air quality has been of high concern due to the impact it may have on human health. The major sources of air pollution are transportation, industries, powerplants, and waste burning[1]. The air pollution creates a major threat to human health even though the pollution caused by combustion of traditional fossil fuels is present in lower concentrations than it was 50 years ago. Since then, other components belonging in a group of pollutants gained prominence such as oxides of nitrogen and sulfur (NO_x and SO_x), carbon monoxide, ozone, or particulate matters (PM). Sulfur dioxide is formed during combustion of fuels containing sulfur such as coal or oil, during industrial processes like extraction metals from their ores or even naturally from volcanoes. Sulfur dioxide undergoes a variety of photochemical and catalytic reactions. It is very well soluble in water (11.28 g/100 ml at 20 °C) even water vapor with subsequent formation of sulfuric acid which may then interact with other gases and particles in the atmosphere to form sulfates. During the daytime and also under conditions of low humidity, the predominant reaction is the oxidation of sulfur dioxide in mixture of hydrocarbons and oxides of nitrogen to form aerosol of sulfuric acid. At night or under humid conditions, the major reaction is the absorption of SO_2 to water droplets (catalyed by NH_4^+) and the oxidation of SO_2 to SO_4^{2-}[2]. Exposure to SO_2 is associated with variety of symptoms including dyspnea and cough[3]. Several studies have also found association between sulfate particles and increased mortality[4,5]. Oxides of nitrogen are commonly present pollutants in atmosphere. The major nitrogen containing compounds are N_2O, NO, NO_2, NH_3 and in forms of aerosols are NH_4^+ and NO_3^-. Gaseous compounds arise from biological processes and organic decomposition in soil and oceans. The non-natural source of NO and NO_2 is combustion. Nitrous oxide is the most abundant atmospheric nitrogen compound emitted also from soil in a process of bacterial denitrification. It is very stable and chemically inert gas undergoing no chemical conversions in atmosphere. Its mean residence time in atmosphere is estimated to be 4 years and its destruction is by photo-dissociations at wavelengths expected only at altitudes above the ozone layer (about 210 nm). Eventhough that nitrous oxide is very stable component of atmosphere with negligible consequences in tropospheric photochemistry it still does contribute to climate changes and greenhouse effect[6]. Among other pollutants is also ozone. Ozone is a strong oxidising agent formed in troposphere by a series of complex reactions with precursors including oxides of nitrogen, carbon monoxide, volatile organic compounds, and sunlight[7]. Only a few compounds such as fluorine, perxenate ion, atomic oxygen or hydroxyl radial are more powerful oxidising agents. The atmosphere surrounding us contains around 20 % of dioxygen and also atrace amounts of ozone. Even in trace amounts ozone is a toxic gas creating a potential threat to human health[8]. Ozone enters human body through respiratory system causing variety of problems like chest pains, coughing or throat irritation. It can worsen bronchitis or asthma even reduce function of lungs or cause inflammation[9]. Other threat to human health is particulate pollution of air which is a complex mixture of solid, liquid or solid and liquid particles in the air. Primary particles are emitted directly from the source whereas secondary particles are formed in the atmosphere from gaseous emissions. Both primary and secondary particles are emitted naturally or anthropogenically. Naturally and anthropogenically emitted particles may have a potential effect on human health. Natural emission of particles into the atmosphere is emission of gases containing sulfur from volcanoes as well as decaying vegetation, dust storms or forest fires. Anthropogenic sources include the combustion of coal and oil releasing elemental carbon, heavy metals and organic species[10]. Size of these particles varies from a few nanometers to tens of µm. The largest particles are formed by abrasion of larger particles. Small particles with diameter of less than 1 µm are formed from gases and the smallest particles, in diameter less than 0.1 µm also called ultrafine particulates, are formed by nucleation resulting from condensation or chemical reactions that form new particles[11]. The size of particles has been linked to their potential to cause health problems. EPA has been monitoring the particles mainly of two sizes based on their penetration capacity into the lungs. Particles with a diameter of 1 µm called coarse particulate matter (PM_{10}) and particles with diameter of 2.5 µm called fine particulate matter ($PM_{2.5}$). Coarse particles (PM_{10}) are composed of resuspended gas, soil and street dust, coal and oil ashes, oxides of Si, Al, Mg, Ti, Fe, sea salts or naturally occurring pollen, mold spores or part of plants with a lifetime of days to weeks in the atmosphere. Fine particles ($PM_{2.5}$) contain sulfate, nitrate, and ammonium salts, elemental carbon, metals like Pb, Cd, V, Ni, Cu, Zn but also biogenic organics with perseverance in the atmosphere from minutes to hours. The sources of coarse particles are farming, mining, construction, coal and oil combustion or ocean spray and the sources for fine particles occurring in atmosphere are combustion of coal, oil, and gasoline, transformation products of nitrogen oxides and SO_2. Major source of particulate matter is traffic originating from the wear of vehicle components like brakes and tires, or the inorganic particles from pavement abrasion. Particles created by abrasion of pavements are rich in minerals containing silicon, aluminum, potassium, sodium, and calcium, and particles created by wear of vehicle components are rich in copper, antimony, lead, cadmium, or zinc[12]. PM is associated with a variety of cardiovascular and respiratory health effects depending on whether the exposure is acute or chronic. The mechanism of how PM affects the health is a subject of intense investigation and is still unclear[13] . In general the exposure effectiveness of PM is influenced by local conditions such as weather, seasons, source of particles or the emitted concentrations. The effect of PM exposure depends on the physical characteristics of individuals like breathing mode or the size of a person in general the smaller the particle is, the deeper is the penetration to deposit of respiratory tract. In nasal breathing, cilia and mucus of respiratory tract act as a very effective filter for particles exceeding 10 µm. These particles settle quickly, they lodge in trachea or in the bronchi and the body eliminates these particles by sneezing or coughing. The most impact on human health have particles which diameter is less than 10 µm which penetrate deep within the lungs due to their excessive penetrability. Particles with diameter approximately from 5–10 µm are most likely to deposit in tracheobronchial tree, while particles with diameters between 1–5 µm deposit in bronchioles and alveoli where the gas exchange takes place. Eventually, these particles escape in blood stream causing significant health issues. Particles even smaller than 1 µm behave similarly to gas molecules and penetrate down the alveoli and translocate into the cell tissue or circulatory system. It has been reported that metals act as a mediators of PM induced airway injury and inflammation through the Fenton reaction. During the Fenton reaction, highly reactive hydroxyl radicals are generated by decomposition of hydrogen peroxide using ferrous ions[14]. Transition metals included in the PM particles increase production of reactive oxygen species (ROS) in vivo which can result in cellular and tissue damage. Even though the mechanism of action of these particles is rather unclear, the exposure to PM has been identified as a cause of numerous health problems ranging respiratory problems, decreased lung function, cardiovascular diseases to premature mortality. Scientists have also suggested that exposure to high level concentrations of PM may lead to low birth weights in infants, pre-term deliveries and possibly death of infants[12]. Exposure to ultrafine particles may induce vascular and systemic inflammation, oxidative stress, cellular damage, mitochondrial damage. Exposure to fine particles may lead to alveolar inflammation. It is also associated with respiratory disorders such as blocked nose, sneezing, cough or hyperacidity. Coarse and fine particulate matter exposure is associated with increased hearth diseases among elderly, acute respiratory disorders such as sinusitis, asthma or allergy[15].

1.2 Impact of fireworks on air pollution and human health

One of the most unusual sources of pollution in the atmosphere are fireworks for celebration of festivities or other specific events. Fireworks displays of various types are seen around the world throughout the year, with the only constraints being cost. While large public pyrotechnic shows are common, smaller, often illegal, fireworks are also frequently set off in residential areas. According to the American Pyrotechnics Association, the amount of consumer fireworks purchased in the U.S. (258.4 million pounds) for general public use (1.4G explosives) is over ten times that used by professional pyrotechnicians for large celebratory displays (19.1 million pounds; 1.3G explosives), posing a significant risk of adverse health effects. While the most significant health risk associated with fireworks has traditionally been injury, particularly among male teenagers, which can result in physical and burn injuries, loss of digits, limbs, and eyesight, and even death, with an estimated 10,000 to 25,000 people in the U.S. affected each year[16] .Burning of fireworks is a huge source of gaseous pollutants such as oxides of sulphur or nitrogen as well as particulate matter[17]. Particulate matter (PM) emitted by burning fireworks are composed of metals (K, Mg, Sr, Ba, Cu), elemental carbon, and secondary compound like organic substances. The implications of exposure to high levels of particles during firework displays area concern in numerous countries around the world, particularly during extended pyrotechnic events like the Diwali Festival in India, Las Fallas in Spain, Lantern Festival in Beijing, and New Year's celebrations worldwide. Although the intricate composition of particles discharged during fireworks can result in negative health consequences, certain authors have asserted that fireworks are not a substantial public health threat since they are infrequent, explode at high altitudes, and typically burn outside, allowing the released pollutants to diffuse into a large volume of air [18,19]. Additionally, fireworks generate a thick smoke cloud that obstructs visibility and gradually dissipates downwind. The effects of fireworks on visibility and human health are especially noticeable when the pyrotechnic display occurs during stable weather conditions [17]. The harmful effects of ambient air pollutants are due to the creation of reactive oxygen species, which cause oxidative stress in the lungs, leading to a potent cellular and mediator inflammatory response. When fireworks are ignited, the chemicals used in their composition react, creating a visible and odorous cloud of PM in the air. Inhalation of these particles is one of the primary means of exposure to increased concentrations of these emissions. The deposition of PM in the respiratory system is mainly influenced by the particle size [20]. Numerous harmful health effects have been linked to short-term exposure to air pollution, including cardiovascular morbidity, respiratory morbidity, hospital admissions [21], cardiovascular mortality [22], respiratory mortality [23], and non-accidental mortality. Recent studies have further revealed that air pollution is also linked to health problems other than cardiorespiratory morbidity and mortality, such as dementia, cognitive impairment and brain structural changes in children, and diabetes mortality. Additionally, the elderly and infants are particularly vulnerable to short-term, acutely elevated air pollution concentrations and are at higher risk of mortality due to this exposure [24–28].

So far, no comprehensive study has been carried out on the impact of fireworks on air quality in the Slovak Republic. At the same time, we have not seen a similarly extensive work focusing on the whole country in a time span of 13 years. We analysed concentrations data from up to 61 air quality monitoring stations situated in the Slovak Republic from 2010 to 2023. We analysed pollutant concentrations for PM_{10}, $PM_{2.5}$, CO, NO_2, SO_2, O_3, and benzene, from New Year's Eve evening to New Year's morning and compared them with data from 25 December to 7 January. In view of this fact and inspired by the findings of studies from other countries around the world, we consider this study to be an important basis for the development of Slovak, European, and global policy in the field of fireworks and pyrotechnics.

2. Methods and results

2.1 Location and sampling

The study was conducted in the Slovak Republic. Depending on the type of the pollutants we analyzed data up the 61 air quality monitoring stations in the Slovak Republic from 2010 to 2023. The considered air quality monitoring stations consist mostly from referenced air quality stations which are part of the National Air Quality Monitoring System Network operated by Slovak Hydrometeorological Institute (**Figure 1**) and few other industrial monitoring stations which belongs to some important heavy industrial sources mostly situated near the Bratislava and Košice.

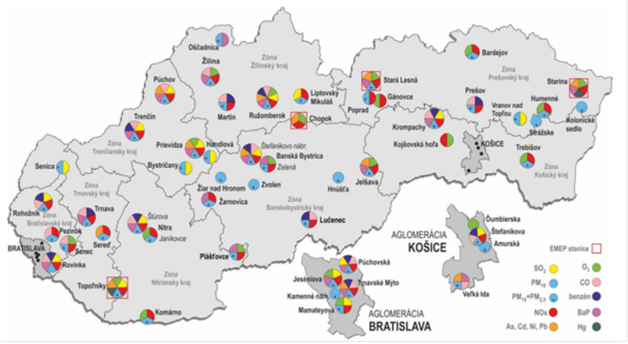

Figure 1. The National Air Quality Monitoring System Network operated by Slovak Hydrometeorological Institute in 2023.

2.2 Pollutant analysis

We analysed pollutant concentration data from the Silvestre evening to the New Year morning hours and compare them with the data from 25 December to 7 January as follows.

1. We selected the data from 5:00 UTC 31 December to 17:00 UTC 1 January. This selected time series is considered to be the mostly affected by the Silvestre activities and we will called them as Silvestre data.
2. The background Silvestre concentrations are afterward selected from 13:00 to 17:00 UTC 31 December

and from 13:00 to 17:00 UTC of 1 January.

3. We calculated the mean background Silvestre concentrations (bg_{mean}) and its standard deviation (σ_s).
4. We compare the signal which is calculated as signal = max (Silvestre data - bg_{mean}), if:

   signal/ $\sigma_s > 4$ = very strong signal
   signal/ $\sigma_s > 3$ = significant signal
   signal/ $\sigma_s > 2$ = weak signal
   signal/ $\sigma_s <= 2$ = no signal
5. For each hour in day we calculated the nonSilvestre data mean defined as the mean concentrations from weak before and after Silvestre night from 25 December to 7 January (we excluded data from 13:00 UTC 31. December to 12:00 UTC 1 January) and its deviation σ_b. We compute the maximal difference between the Silvestre data and nonSilvestre data mean as signal-bg = max (Silvestre data – nonSilvestre data mean) and compare it to the maximum of $\sigma_b$which we denoted asσ_{bmax}. The attribution to the Silvestere activities is then following

   signal-bg/$\sigma_{bmax} > 4$ = very strong contribution from Sil. Activities

   signal-bg/$\sigma_{bmax} > 3$ = significant contribution from Sil. activities

   signal-bg/$\sigma_{bmax} > 2$ = weak contribution from Sil. activities

   signal-bg/$\sigma_{bmax} < = 2$ = no contribution from Sil. Activities
6. The final signal confidence level (very strong, significat, weak or no) is taken as the worser from the steps 4. and 5.
7. To demonstrate the impact of firework use during New Year celebrations on air quality, we also used a statistical evaluation of the data in Statistica, version 12 using Friedman's ANOVA and Kendall's concordance coefficient. A statistically significant difference was considered to be a p-value less than ($p \leq 0.05$). For the statistical comparison, we only evaluated stations at which we measured most from the pollutants PM_{10}, $PM_{2.5}$, CO, NO_2, SO_2, O_3, and benzene at the sametime and and have similarly data aviability. Therefore we selected in this analysis following 12 stations (Banska_Bystrica_Stefanikovo_Nabrezie, Bratislava_Trnavske_Myto, Kosice_Stefanikova, Krompachy_SNP, Malacky_Mierove_Namestie, Martin_Jesenskeho, Nitra_Sturova, Presov_Arm_Gen_L_Svobodu, Rovinka_(Slovnaft), Ruzomberok_Riadok, Trencin_Hasicska, Trnava_Kollarova). For this analysis we used the mean concentrations from New Year's Eve evening to New Year's morning (17:00 UTC–05:00 UTC) and compared them with data from 25 December to 7 January

To illustrate the previous procedure we include several examples of analysed data for PM_{10} in **Figure 2**. There are typical situations with very strong signals with strong confidence and also situations with no confidence or no signal.

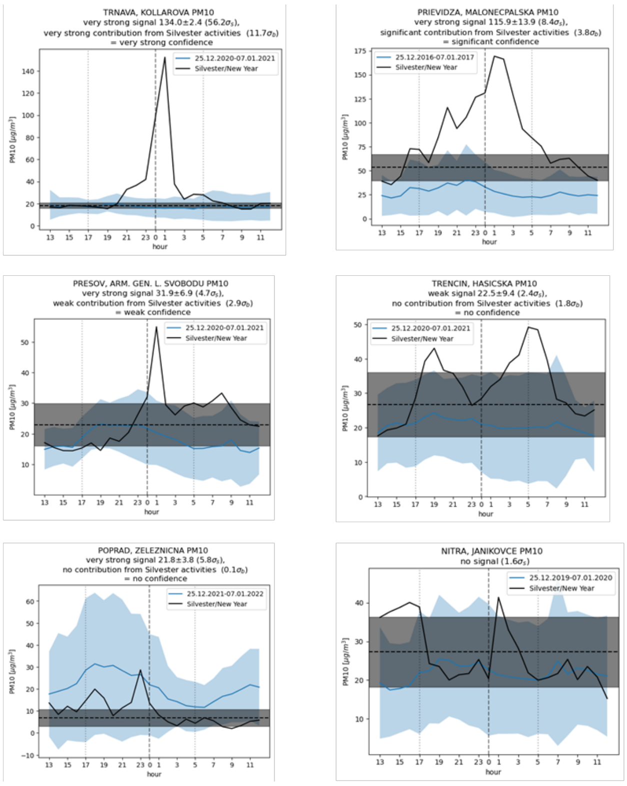

Figure 2. The examples of final confidence of signal in Silvestre data for PM10.

Analysing pollutants PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, benzene, and O_3, we can see from Table 1 that Silvestre activities mostly affected concentrations of PM_{10} and $PM_{2.5}$, on the other hand they do not increase the O_3 concentrations at all. The black line represents the concentrations from 13:00 UTC 31 December to 12:00 UTC 1 January. The black dashed line represents the mean background Silvestre concentrations and black shaded area its respective standard deviation calculated in steps 2. and 3. in Section 2.2. The blue line represents the mean concentrations from

Table 1. Number of analysed situations for selected pollutants and number of signals with specific confidence interval.

Pollutant	No	Weak	Significant	Very strong signal	Total analyzed cases
PM_{10}	201	104	79	173	557
$PM_{2.5}$	161	58	49	118	386
SO_2	256	11	7	16	290
NO_2	360	29	10	3	402
CO	172	28	17	8	225
BEN	125	18	6	7	156
O_3	260	1	0	0	261

week before and after Silvestre night and blue shaded area its respective standard deviation calculated in steps 5. in Section 2.2.

In case of PM_{10} we introduce in the **Figure 2** with signals for individual stations coloured by the confidence of the signal attributed to New Year night. We can see that in case of PM_{10} the very high concentrations during the New Year night which are not occurred in other days are presented. The peak concentrations can be even more than 200 µg m^{-3} above common value at given time and period of year with maximum of 1111 µg m^{-3} recorded in USS private monitoring station in Velka Ida in 2016/2017 New Year night. Note that this station is also close to the USS steel factory which can also accidently affect the air in given time. For $PM_{2.5}$ situation is rather similar as for PM_{10}, but less of the data are presented. From **Table 1**, we can see that while for PM_{10} and $PM_{2.5}$ we observe exceedance in concentration during the New Year night in 64 % and 58 % of analysed cases, respectively, for other pollutant this number is much lower. In case of SO_2 is just 11% and in case of benzene and CO around 20%, but less than 5 % analysed cases were categorized as strong signal. The significant source of that pollutants are emissions from the high point sources, so in those cases some of the signals may also come from random emission of large heavy industry. In case of SO_2 the observed signal are indeed low, the highest signal is 56 µg m^{-3} and the 10th highest is just 21 µg m^{-3}, which is negligible with hourly limit value for SO_2 which is 350 µg m^{-3}. In case of benzene the observed signal not exceed to much the yearly averaged limit value which is 5 µg m^{-3}. The maximum of the signal is 11 µg m^{-3} and the 10th highest is just 6 µg m^{-3}. Generally, the CO measured concentrations has greater values than other mentioned pollutants. The limit for 8 hour maximum CO concentration is 10 000 µg m^{-3}. Maximal signal during the Silvestre night just reached 2 721 µg m^{-3}. In case of NO_2 also only small number of signals was appear during the New Year night. Those signals can be connected also with the heavy industry, but also with the traffic activity at the early night. As was expected the New Year night does not have measurable effect on the ozone concentration, only 1 weak signal was observed by the automated algorithm, but this weak signal appeared in the mountain station Chopok and we can considered it as the random noise.

2.3 Statistical evaluation of average concentrations for PM_{10} and $PM_{2.5}$

We further statistically processed the data using Friedman's ANOVA and Kendall's coefficient of agreement. We compared the years 2017 to 2023, since only in these years did we have complete data for all pollutants. We statistically processed the data using Friedman's ANOVA and Kendall's coefficient of agreement, showing a statistically significant difference between ordinary days (W) and New Year's celebration (S). For PM_{10} concentrations, we noted a statistically significant difference in favor of the new year in 2017, 2018, 2019, 2021, 2022 and 2023 ($p \leq 0.001$). We did not notice a statistically significant difference in 2020 ($p \geq 0.05$). In the cumulative average comparison, we noted a statistically significant difference ($p \leq 0.001$) (**Figure 3**).

We used the same approach when analysing $PM_{2.5}$. We demonstrated a statistically significant difference in all years 2017, 2018, 2019, 2021, 2022 and 2023 ($p \leq 0.001$), except for 2020 ($p \geq 0.05$). In the cumulative mean comparison, we demonstrated a highly statistically significant difference ($p \leq 0.001$) (**Figure 4**).

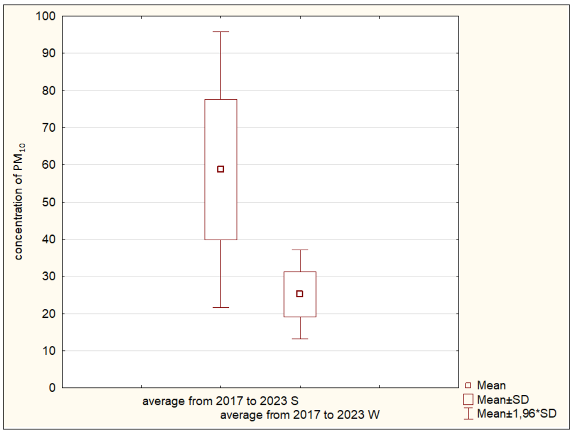

Figure 3. Comparison of data from New Year's Eve to New Year's morning for PM_{10}.

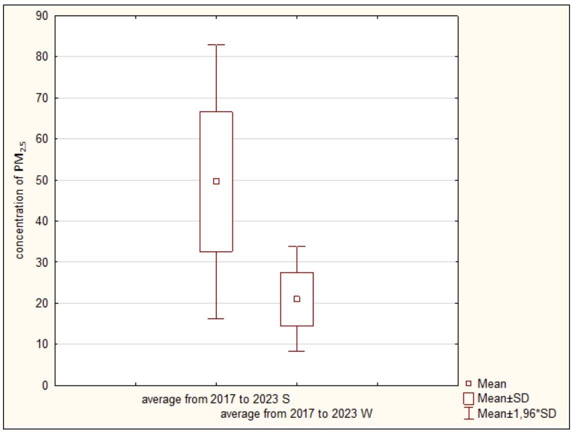

Figure 4. Comparison of data from New Year's Eve to New Year's morning for $PM_{2.5}$.

2.4 Benzene, CO, O_3, SO_2, NO_2

We used the same approach for the analysis of benzene. We demonstrated statistically significant in the years 2017, 2018, 2020 and 2023 ($p \leq 0.001$). We did not demonstrate a statistically significant difference in the years 2019, 2021 and 2022 ($p \geq 0.05$). Comparing the cumulative average, we showed a statistically significant difference ($p \leq 0.05$). We came to similar results in the CO analysis, while we demonstrated a statistically significant difference in the years 2017, 2020 and 2022 ($p \leq 0.001$). We did not demonstrate a statisticallysignificant difference in the years 2018, 2019, 2021 and 2023 ($p \geq 0.05$). When comparing the cumulative average, we demonstrated a statistically significant difference ($p \leq 0.05$). In the analysis O_3 we demonstrated a statistically significant difference in 2017, 2018, 2021 and 2022 ($p \leq 0.001$). We did not demonstrate a statistically significant difference in years 2019, 2020 and 2023 ($p \geq 0.05$). When comparing the cumulative average, we demonstrated a statistically significant difference ($p \leq 0.001$). In the cumulative analysis of SO_2 and NO_2 ($p \geq 0.05$) particles, we did not demonstrate a statistically significant difference, we did not demonstrate it in any of the monitored years.

3. Discussion

Study conducted by Greven et al., 2019 [29] states that in the Netherlands, fireworks are only set off by the general public throughout the country during New Year's Eve. During this period, the PM_{10} concentrations resulting from fireworks significantly exceed those observed during the rest of the year. According to Buijsman and colleagues, between 1993 and 2012, the average PM_{10} concentration measured by urban monitoring stations in the first hour after New Year's Eve was approximately 550 $\mu g/m^3$, while hourly PM_{10} concentrations throughout the rest of the year rarely exceeded 100 $\mu g/m^3$. Additionally, the background PM_{10} concentration in the Netherlands in 2011, averaged annually, was 24 $\mu g/m^3$ [29] . In addition to changes in PM concentrations, the composition of PM also varies significantly during periods of fireworks displays. For example, Vecchi et al., 2008 [17] discovered that during the FIFA WorldCup 2006 celebration, ambient PM_{10} in Milan, Italy, contained considerably higher concentrations of metals, such as Sr (120-fold), Mg (22-fold), K (12-fold), Ba (11-fold), and Cu (6-fold). Similarly, Yang et al., 2014 [30] observed higher ion concentrations in $PM_{2.5}$, including K^+, Mg^2, Cl^-, SO_4^{2-}, F^-, and Na^+, during fireworks display periods than during non-display periods. Despite this, little is known about their acute cardiorespiratory toxicity. Evidence of the potential toxic effects of fireworks on the environment, human health and wildlife is examined in their study Islam 2024 [31]. An online analysis of individual aerosol particles by Carranza et al. 2001 [32] revealed that during holiday periods, there were order-of-magnitude increases in Mg and Al mass concentrations attributed directly to the discharge of fireworks. During diwali in Nagpur, Central India, recorded a 4–10 times increase in PM_{10} concentration [33]. Similarly, in northeast India, a prior study found an increase in the concentrations of metals, anions, and cations during festival days compared to other days [34]. Moreover, Garaga and Kota, 2018 [35] observed that the mean

PM_{10} concentration during Diwali was 311 µg m^{-3}, which was 81% higher than other days and 3.1-times higher than the Indian National Ambient Air Quality Standards. The drastic increase in PM_{10} and $PM_{2.5}$concentrations during New Year's Day was demonstrated in their study Khedr et al., 2022[36]. In 2015, a study found that $PM_{2.5}$concentrations were increased on 4th July in the United States, and remained high until the morning of 5th July. The study analyzed data from 315 air quality monitoring sites and revealed a 42% increase (5 µg m^{-3}) in 24 hr $PM_{2.5}$concentrations during Independence Day[37]. Similarly, in Beijing, China, Wang et al., 2007[38] reported a six-fold increase in $PM_{2.5}$concentrations during the Chinese Lantern Festival on the Lantern Day, compared to normal days. Furthermore, a study conducted in Beijing documented the highest $PM_{2.5}$ concentrations during firework days at 248.9 µg·m^{-3} in the 2015 Spring Festival[39]. During the Montreal International Fireworks Competition in Quebec, Canada, researchers observed that $PM_{2.5}$levels can reach as high as 1000 µg m^{-3} during the display period of about 45 minutes[40]. Additionally, in New Delhi, India, during the Diwali festival, $PM_{2.5}$levels were found to be 588 µg m^{-3} in 2007 and 389 µg m^{-3} in 2008[41].

4. Conclusions

The significant impact of the New Year's celebrations on the air quality in Slovakia was confirm by the observations of the clear increased peaks in pollutant concentrations measured in the 61 air quality monitoring sites in period from 2010 to 2023. These sites are distributed in the whole Slovakia in order to monitor ambient air quality and impacts of conventional emission sources such as traffics, industry, and local heating. These sites were not aimed to monitor such randomly distributed sources like New Year's fireworks, but nevertheless for PM_{10} and $PM_{2.5}$, significant increase of concentrations during the New Year night was observed in 64% and 58% of analysed cases, respectively. The size of these increments depends on the meteorological situations, site position, and specific year. The increments can be mostly attributed to the fireworks, since it appears also in the locations were the other impacts like local heating and traffic does not play significant role. Another factor which indicate that local heating is not significant contributor to above mentioned increments is that concentrations data during the New Year's Eve are compared with the data from surrounding days in which the activity data for local heating should be similar to the New Year's Eve. However it can not be excluded that in some cases the local heating can affect the observed increments. From the fact, that traffic is the most important contributor to the NO_2 concentrations and we observe just few cases of raised NO_2 concentrations during the New Year, we can definitely confirm that the traffic has not significant impact on the observed raised PM concentrations. For PM_{10} it was observed that quite often the fireworks can increase it concentrations more than 100 µg m^{-3} in comparison of common day. Statistical difference between mean PM_{10} concentrations during the New Year celebration hours and respective period during the surrounding days was strong also ($p \leq 0.001$). For $PM_{2.5}$the situation was similar. The New Year celebration affects other pollutant concentrations (CO, benzene, NO_2, SO_2) in less extend and it almost no affect the ozone concentrations although some slightly decrease corresponding slightly increase of NO_2 was observed. Since the fireworks can raise the short-term concentrations of PMs in the breath zone by great extent it can have negative impact also on the human health, especially when one realise that thousands of celebrating people are exposed to this adverse air. Therefore, it is important to adapt the legislation which will regulate the condition for using fireworks which cause adverse air quality in the breath zone mostly during the worse dispersion conditions often presented during winter time in Central Europe.

Author Contributions

Conceptualization by [Ivan Iľko, Viera Peterková, Dušan Štefánik]. Writing—preparation of the original manuscript: [Ivan Iľko, Dušan Štefánik, Viera Peterková, Jozef Maniak]. All authors revised, read and approved the final version of the manuscript.

Conflict of Interest

No conflict of interest.

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