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ASSESSING THE PROBABILITY OF CARCINOGENIC RISK CAUSED BY PM_{10} AND $PM_{2.5}$ PARTICLES IN THE CITY OF NIŠ

Abstract: *Analysis of air quality in the city of Niš indicates a presence of increased concentrations of pollutants in outdoor air. In the period from 2019 to 2023 air quality in the area of the city of Niš was in the category of excessively polluted air, because of increased concentrations of PM_{10} and $PM_{2.5}$ particulate matter. Multiple exceedances of the limit and tolerance values of PM_{10} and $PM_{2.5}$ particulate matter are the basis for the emergence of a health risk that manifests itself through various types of pathological conditions. The physicochemical properties and chemical composition of PM_{10} and $PM_{2.5}$ particulate matter are the criteria for classifying these particles as carcinogenic substances. This paper presents the probability of the occurrence of cancerous diseases during exposure to suspended PM_{10} and $PM_{2.5}$ particles. The risk of cancer development (Ri) was determined based on intake dose and unit risk. The calculated probability is in the range of the level of possible and the level of probable carcinogenic risk, depending on the length of exposure. The probability was determined using the methodology provided by US EPA.*

Keywords: PM_{10} and $PM_{2.5}$ particulate matters, health risk, cancer risk, unit risk, exposure

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INTRODUCTION

Air pollution results from a series of complex and interrelated occurrences and processes, connected in terms of content, space, time and developmental origin. In the process of air pollution, one occurrence often leads to the emergence of another (e.g. air pollution – decreased air quality – increased health risks).

The analysis of air quality in the Republic of Serbia indicates the dominant impact of suspended PM_{10} and $PM_{2.5}$ particles on air pollution. Certain global studies indicate that the composition of suspended PM_{10} and $PM_{2.5}$ particles in urban environments most commonly includes: Si, Al, Ca, K, Fe, Zn, Na, Mg, Cu, Ba, Ti, V, Mn, Cr, Ni, As, Pb, NO^{3-}, SO_4^{2-}, NH_4^+, Cl^- and polycyclic aromatic hydrocarbons (Xue, 2021; Roy et al., 2019). Increased concentrations of heavy metals and metalloids (Cr, As, Ni, Pb, Cd) and certain polycyclic aromatic hydrocarbons in outdoor ambient air, which constitute suspended PM_{10} and $PM_{2.5}$ particles, increase the risk of cancer development.

Suspended PM_{10} and $PM_{2.5}$ particles in outdoor ambient air also increase the risk of respiratory and cardiovascular diseases. It was estimated, using the model Alpha–RiskPoll (ARP), that the presence of fine suspended particles in the air in Serbia leads to 4,261 hospitalizations annually due to respiratory issues and 5,144 hospitalizations due to cardiovascular problems, and has resulted in 9,773 premature deaths (Government of the Republic of Serbia, 2022). $PM_{2.5}$ emissions in the Republic of Serbia in 2019 amounted to 45.6 kt $PM_{2.5}$, an increase of 2.3% compared to 2015. Total $PM_{2.5}$ and PM_{10} emissions have been increasing since 2015. According to the Air protection program in the Republic of Serbia for the period 2022–2030 with an Action Plan (Government of the Republic of Serbia, 2022), the prescribed limit values for suspended particles in outdoor ambient air, from a health risk perspective, were exceeded at 15 out of 32 analysed locations in the Republic of Serbia in 2019. Multiple exceedances of the limit values for suspended particles in outdoor ambient air were also recorded in the city of Niš, which is the third largest city in the Republic of Serbia with approximately 250,000 inhabitants. The dominant emissions of suspended particles in the area of Niš are a result of the combustion of fossil fuels used for the operation of heating plants and for heating individual buildings. Suspended particle emissions also originate from traffic and the application of specific technological processes in industry.

METHODS

Concentrations of suspended PM_{10} and $PM_{2.5}$ particles in the area of Niš are recorded above the daily and annual permitted limit values. In the air quality monitoring network of the city of Niš, concentrations of suspended PM_{10} and $PM_{2.5}$ particles are monitored at two measuring locations (Figure 1), the Institute of Public Health Niš and the "Sveti Sava" primary school.

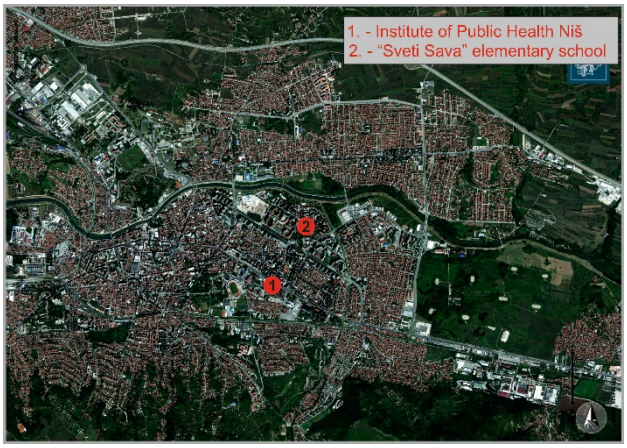

Figure 1. *Location of measuring points where PM_{10} and $PM_{2.5}$ particles are monitored in the city of Niš*

In accordance with the Law on Air Protection of the Republic of Serbia, (National Assembly of the Republic of Serbia, 2009), the air quality in the city of Niš, observed over the period from 2019 to 2023 is classified into the third category (excessively polluted air) due to elevated concentrations of suspended PM_{10} and $PM_{2.5}$ particles (Environmental Protection Agency, 2024).

The causality between the occurrence of air pollution and health risks can be analysed based on the database formed through continuous monitoring of pollutant concentrations. Health risk is defined as the probability of occurrence of adverse health effects in humans, which depend on exposure to a specific concentration of a pollutant and the duration of exposure to that substance in the air. Exposure refers to the relationship between the concentration of a specific pollutant in the air and the time interval of exposure to that pollutant and is defined by the following equation (Đorđević et al., 2013):

$$E = \int_{t_1}^{t_2} C(t)\,dt, \qquad (1)$$

where: E – exposure magnitude [mg/m^3/time], C(t) – pollutant concentration as a function of time [mg/m^3], and t_2-t_1 – duration of exposure [ED]. ED is the continuous time period of exposure (Đorđević et al., 2013).

The assessment of health risk, according to the methodology of the US EPA, is specifically determined for the exposure of a given individual to carcinogenic and non-carcinogenic substances, starting with the calculation of the intake dose (Đorđević et al., 2013; Đorđević & Stevanović, 2020; Greene & Morris, 2006):

$$Intake\ dose = C_{i,x} \cdot \left(\frac{IR_y}{BW_y}\right) \cdot \left(\frac{ED_i \cdot ET_i \cdot EF_i}{AT_x}\right), \qquad (2)$$

where: $C_{i,x}$ – the concentration of the pollutant substance *x* in the environment *i* [mg/m^3], IR_y – the intake rate (breathing rate) at rest per unit of time for a representative individual in subgroup *y* in the environment *i* [m^3/day], ET_i – the exposure time of the representative individual in the environment *i* [hour/day], EF_i – frequency of exposure [day/year], BW_y – the body weight of the representative individual in the corresponding group, represented as *y* [kg], ED_i – the duration of exposure of the representative individual in the environment *i* [years], and AT_x – the average duration of the pollutant's effect *x* [days].

When assessing the health risk conditioned by an individual's exposure to suspended PM_{10} and $PM_{2.5}$ particles, a separate risk assessment is conducted for the development of carcinogenic diseases and non-carcinogenic diseases, such as respiratory and cardiovascular diseases.

The risk of cancer development is represented by the following equation (Đorđević & Stevanović, 2020; Greene & Morris, 2006):

$$R_i = Intake\ dose \cdot UR, \qquad (3)$$

where: R_i – the risk of cancer development for the *i-th* individual and UR – the unit risk for a substance in the exposure to suspended PM_{10} and $PM_{2.5}$ particles.

RESULTS AND DISCUSSION

The Institute of Public Health Niš monitors the concentrations of suspended PM_{10} and $PM_{2.5}$ particles once a week. Table 1 shows the annual average and maximum concentrations of suspended PM_{10} particles monitored at the "Sveti Sava" primary school and the Institute of Public Health Niš, and the number of days with exceedances of the daily limit values (Table 1).

Table 1. *Measured concentrations of suspended PM_{10} particles for the 2019-2023 period in the city of Niš (Institute of Public Health Niš, 2024)*

Monitoring period	Annual average concentrations [μg/m^3]	Maximum concentrations [μg/m^3]	The number of days with exceedances of the limit values
June 2019 – May 2020	42.5	272.3	90
June 2020 – May 2021	46.3	241.8	119
January – December 2022	44.3	186.9	11
January – December 2023	56.6	217.3	16

In the period from 2019 to 2023, the annual average values of suspended PM_{10} particles were exceeded in relation to the allowed annual exposure limit, which is 40 μg/m^3. In the period from January to December 2023, the concentration of suspended PM_{10} particles was the highest and amounted to 56.6 μg/m^3 (Institute of Public Health Niš, 2024). Analysis of the trend of concentrations throughout the year has shown that high concentrations are present during the heating season. The daily exposure limit for concentrations of suspended PM_{10} particles should not be exceeded for more than 35 days during a calendar year (Government of the Republic of Serbia, 2010). In the period from June 2020 to May 2021, the highest number of days with exceedances of the daily exposure limit was recorded, amounting to 119 days (Institute of Public Health Niš, 2024).

The annual average and maximum concentrations of suspended $PM_{2.5}$ particles were monitored at the measuring site of the Institute of Public Health Niš and presented in Table 2.

Table 2. *Measured concentrations of suspended $PM_{2.5}$ particles for the 2019-2023 period in the city of Niš (Government of the Republic of Serbia, 2010)*

Monitoring period	Annual average concentrations [μg/m^3]	Maximum concentrations [μg/m^3]
June 2019 – May 2020	49.5	246.3
June 2020 – May 2021	41.4	244.7
January – December 2022	34	90.4
January – December 2023	30.9	146.1

In the period from 2019 to 2023, the annual average values of suspended $PM_{2.5}$ particles were exceeded in relation to the allowed annual limit value of 25 μg/m^3. The highest recorded value was 49.5 μg/m^3 in the period from June 2019 to May 2020 (Institute of Public Health Niš, 2024). High concentration values are recorded during the heating season. The number of days with exceedances of the limit values for concentrations of suspended $PM_{2.5}$ particles is not available in the presented database of the Institute of Public Health Niš, which is publicly accessible. The inadequate database, because of a lack of records on the number of days with exceedances of the limit values for suspended $PM_{2.5}$ particles, as well as the insufficient number of measurements for PM_{10} and $PM_{2.5}$ concentrations throughout a calendar year (approximately 50 days), does not allow for a precise and representative assessment of the health risk for the exposed population. Considering that for the analysed time period there is a noticeable upward trend in the annual concentrations of suspended PM_{10} particles and that the annual average concentrations of suspended $PM_{2.5}$ particles are above or near the limit values, the risk assessment was performed with regard to the probability of developing carcinogenic diseases, in line with the trend of concentration changes. During the analysed period, the concentrations of suspended PM_{10} particles were 450% above the allowed daily limit values. The probability of cancer development was determined for increased exposure values relative to the limit values, specifically for 50%, 100%, 150%, and 200%. This was based on the assumption that working-age adults, during normal breathing, were exposed to the substances for 4 hours daily (Table 3).

Table 3. *The probability of developing carcinogenic diseases due to exposure to suspended PM_{10} and $PM_{2.5}$ particles*

Increased concentrations above the limit values	The probability of cancer development due to exposure to PM_{10}	The probability of cancer development due to exposure to $PM_{2.5}$
50%	$5.84 \cdot 10^{-6}$	$3.68 \cdot 10^{-6}$
100%	$7.76 \cdot 10^{-6}$	$4.88 \cdot 10^{-6}$
150%	$9.6 \cdot 10^{-6}$	$6.08 \cdot 10^{-6}$
200%	$12 \cdot 10^{-6}$	$7.3 \cdot 10^{-6}$

The risk of cancer development can be classified into specific categories depending on the probability of carcinogenic diseases occurring in the population exposed to suspended particles. The cancer levels are the following:

- *acceptable cancer risk level* (the risk of cancer development lower than $1 \cdot 10^{-6}$);
- *possible cancer risk level* ($1 \cdot 10^{-6} \sim 1 \cdot 10^{-5}$);
- *probable cancer risk level* ($1 \cdot 10^{-5} \sim 1 \cdot 10^{-4}$);
- *definite cancer risk level* ($> 1 \cdot 10^{-4}$) (Xue, 2021; Idolo et al., 2018).

Based on the calculated probability of cancer risk for the exposed adult population in the city of Niš, it can be stated that the risk falls into the 'possible' category (Table 3). With the increase in daily hourly exposure and with exposure values above 200% relative to the daily limit values, the probability of cancer development can be classified into the category of probable cancer risk, with a probability of 10^{-5}.

CONCLUSION

The noted annual average concentrations of suspended PM_{10} and $PM_{2.5}$ particles in the external ambient air of the city of Niš during the 2019-2023 period were above the prescribed allowable limit values or close to the limit values. High concentrations of suspended PM_{10} and $PM_{2.5}$ particles have caused the air quality in the city of Niš to be classified as excessively polluted. Establishing a causal relationship between air pollution and health risks associated with suspended particles

requires continuous monitoring of concentrations in the outdoor ambient air. As the number of days for monitoring the concentrations of suspended particles in Niš during the calendar year is less than 365 and due to the lack of continuity in monitoring concentrations, as well as the absence of an adequately accessible publicly available database of daily concentrations, the assessment of health risks related to the development of cancerous diseases is disrupted. Considering that the recorded daily average concentrations were multiple times above the allowed limit values, with a rising trend at the annual level, it can be expected that the health risk in Niš in the upcoming period will fall into the 'probable' cancer risk. Based on the trend of annual average concentrations of suspended particles monitored during the 2019-2023 period and the lack of measures to reduce air pollution, it can be expected that in the upcoming years, there will be an increase in the annual average concentrations of fine suspended particles. The probability of cancer development in the exposed adult population, with the increase in annual concentrations of fine suspended particles by 50% to 200%, ranges from $3.68 \cdot 10^{-6}$ to $12 \cdot 10^{-6}$.

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