ORIGINAL ARTICLE

UDC: 614.71:616.2-053.2
DOI: 10.2298/VSP140910025D

Respiratory diseases in preschool children in the city of Niš exposed to suspended particulates and carbon monoxide from ambient air

Respiratorne bolesti dece predškolskog uzrasta u Nišu izložene čestičastim materijama i ugljen-monoksidu iz vazduha okoline

Amelija Djordjević*, Goran Ristić*, Nenad Živković*, Branimir Todorović[†], Sladjan Hristov[‡], Lidija Milošević*

***Faculty of Occupational Safety, University of Niš, Niš, Serbia; [†]Faculty of Natural Sciences and Mathematics, University of Niš, Niš, Serbia; [‡]Serbian Armed Forces, Army Command, Niš, Serbia**

Abstract

Background/Aim. Analysis of air quality in Serbia indicates that the city of Niš belongs to a group of cities characterized by the third category of air quality (excessive air pollution). The aim of the study was to analyze the degree of causality between ambient air quality affected by particulate matter of 10 μm (PM_{10}) and carbon monoxide (CO) and the incidence of respiratory diseases in preschool children in the city of Niš. **Methods.** We quantified the influence of higher PM_{10} concentrations and carbon monoxide comprising motor vehicle exhausts in the city of Niš on the occurrence of unwanted health effects in preschool children by means of the hazard quotient (HQ), individual health risk (Ri), and the probability of cancer (ICR). The methodology used was according to the US Environmental Protection Agency (EPA), and it included basic scientific statistical methods, compilation methods, and the relevant mathematical methods for assessing air pollution health risk, based on the use of attribute equations. **Results.** Measurement of ambient air pollutant concentrations in the analyzed territory for the entire monitoring duration revealed that PM_{10} concentrations were significantly above the allowed limits during 80% of the days. The maximum measured PM_{10} concentration was 191.6 μg/m^3, and carbon monoxide 5.415 mg/m^3. The incidence of respiratory diseases in the experimental group, with a prominent impact of polluted air was 57.17%, whereas the incidence in the control group was considerably lower, 41.10 %. There were also significant differences in the distribution of certain respiratory diseases. **Conclusion.** In order to perform good causal analysis of air quality and health risk, it is very important to establish and develop a system for long-term monitoring, control, assessment, and prediction of air pollution. We identified the suspended PM_{10} and CO as ambient air pollutants causing negative health effects in the exposed preschool children population.

Key words:
air pollution; air pollutants; serbia; child, preschool; respiratory tract diseases.

Apstrakt

Uvod/Cilj. Analiza kvaliteta vazduha u Srbiji pokazuje da grad Niš spada u grupu gradova sa trećom kategorijom kvaliteta vazduha (značajno zagađenje). Cilj rada bila je analiza stepena uzročne povezanosti kvaliteta vazduha okoline iskazanog kroz sadržaj čestičastih materija (*particulate matter* prečnika 10 μm ili manje – PM_{10}) i ugljen-monoksida (CO) i učestalosti bolesti disajnih organa kod dece predškolskog uzrasta u Nišu. Prikazane su karakteristike vazduha okoline u Nišu i istaknut uticaj saobraćajnih tokova na aerozagađenje. **Metode.** Uticaj povišenih koncentracija PM_{10} i ugljen-monoksida koji se nalaze u sastavu izduvnih gasova motornih vozila na području grada Niša, na pojavu neželjenih zdravstvenih efekata kod dece predškolskog uzrasta, kvantifikovan je pomoću hazardnog koeficijenta (HQ), individualnog zdravstvenog rizika (Ri) i verovatnoće pojave kancera (ICR). Za procenu zdravstvenog rizika korišćena je metodologija Agencije za zaštitu životne sredine SAD (US EPA). **Rezultati.** Merenje koncentracija zagađujućih supstanci u ambijentalnom vazduhu na analiziranoj teriritoriji u celokupnom periodu praćenja pokazalo je da su koncentracije suspendovanih čestica PM_{10} bile znatno iznad dozvoljenih tokom 80% dana. Maksimalna izmerena koncentracija PM_{10} iznosila je 191,6 μg/m^3, a CO 5,415 mg/m^3. Učestalost respiratornih bolesti u eksperimentalnoj grupi, sa izraženim uticajem zagađenog vazduha, iznosila je 57,17%, dok je kod kontrolne grupe ta vrednost bila znatno niža i iznosila je 41,10%. Uočene su i značajne razlike u zastupljenosti pojedinih respiratornih bolesti. **Zaključak.** Za dobru analizu uzročne povezanosti kvaliteta vazduha i zdravstvenog rizika od posebnog je značaja uspostavljanje i razvoj sistema za dugoročno praćenje, kontrolu, procenu i prognozu stanja aerozagađenja. Suspendovane čestice PM_{10} i CO zagađuju vazduh okoline što dovodi do pojave negativnih zdravstvenih efekata izložene populacije dece predškolskog uzrasta.

Ključne reči:
vazduh, zagađenje; vazduh, zagađivači; srbija; deca, predškolska; respiratorni trakt, bolesti.

Correspondence to: Amelija Djordjević, Faculty of Occupational Safety, University in Niš, 18 000 Niš, Serbia.
E-mail: amelija.djordjevic@znrfak.ni.ac.rs

Introduction

Analysis of air quality in Serbia conducted by the Serbian Environmental Protection Agency (SEPA) revealed that the city of Niš belongs to a group of cities characterized by the third category of air quality (excessive air pollution) [1]. This air quality category implies that during annual monitoring of the presence of ambient air pollutants one or more pollutants exceed not only the limit values, but also the tolerable concentration levels [2]. Degradation of ambient air quality in the city of Niš is primarily caused by high particulate matter of 10 μm (PM_{10}) concentrations, which are monitored at two measuring points in the city within the state network for automatic air quality monitoring. According to the "Annual Report on the Environment in the Republic of Serbia" by the Ministry of Environment, Mining, and Spatial Planning, the mean annual ambient air PM_{10} concentration in 2010 was 51 μg/m^3 (maximum allowed level: 50 μg/m^3), whereby limit values were exceeded during 123 days [1].

There is a qualitative and quantitative correlation between the emission of pollutants produced by fuel combustion and the air quality in the city of Niš.

Studies of road traffic flows in the city of Niš on the primary road networks showed a particularly high vehicle flow on main city roads. Access roads and highways are dominated by passenger vehicles, which comprise 80% of the total traffic participants. According to the annual reports on air quality in the city of Niš and Niška Banja Spa by the Public Health Institute in the city of Niš, during the latest monitored years, 2008–2011, carbon monoxide (CO) concentration on busy roads exceeded the allowed limits [3, 4].

In order to harmonize the criteria for qualitative-quantitative assessment of urban air quality in EU countries, the CITEAIR project was carried out from 2004 to 2007 with the purpose of determining pollutant concentration levels that would be represented as index values to be used in all EU countries (common air quality index – CAQI). The common air quality index was recommended for use in 2006, and in 2010 it was developed into a system for online comparison of air quality in EU cities. The index was created for easy comparison of air quality and health risk in European cities in real time and it was defined within the Ambient Air Quality Directive 2008/50/EC. The highest index value is determined in relation to the highest concentration of a specific pollutant in ambient air and it is taken as the authoritative factor for the final assessment of air quality and health risk. In order to harmonize domestic legislation with the Directive 2008/50/EC, Serbian official bodies adopted the Regulation on Monitoring Conditions and Air Quality Requirements ("Official Gazette of the Republic of Serbia, No. 11/2010, 75/2010, and 63/2013). The need to proceed with the research that was initiated with the CITEAIR project spurred a couple of domestic projects financed by the Serbian Ministry of Education, Science, and Technological Development as of 2011. The first of these is the project No III-43014, entitled "Improving the System for Monitoring and Assessment of Long-term Population Exposure to Environmental Pollutants By Means of Neural Networks", which was launched by the Faculty of Occupational Safety in the city of Niš. The second one is the project No III-42008, entitled "Assessment of Energy Properties and Quality of Building Interiors in Serbian Educational Institutions with Their Health Effects" and carried out by the Vinča Nuclear Institute in Belgrade.

There are multiple relationships between air quality and health, but their interaction has not yet been sufficiently established and their nature is very difficult to quantify. Certain pollutant concentration levels in ambient air need to be updated regularly and monitored for their health effects as far as current scientific development will allow it [5]. The impact of pollutants on the health of exposed population can be highly complex, which is why air quality assessment is typically determined based on exposure to a single pollutant with the highest concentration [6].

Since no detailed analysis of suspended particulate presence in the immediate vicinity of roads had not been conducted and bearing in mind that PM_{10} concentrations at the measuring points belonging to the state network for automatic air quality monitoring were above the allowed limits, the aim of this paper was to determine a causality between suspended particulates and CO from motor vehicle exhausts and the health of the exposed preschool children aged six or under.

In 2012, as part of the abovementioned projects by the Ministry of Education, Science, and Technological Development, we conducted a research on the causality between the level of ambient air pollution by suspended PM2.5 in and around "Bambi" kindergarten in the city of Niš and the occurrence of respiratory diseases in the exposed preschool children. The available Serbian literature does not cover this type of research, which examines the causality between spatial and temporal relation of measured pollutant concentrations at kindergarten locations and the occurrence of respiratory diseases. The research we conducted showed justifiable to proceed with further research and analysis of the cause-and-effect relationship between increased suspended particulate concentrations and the occurrence of respiratory diseases in preschool children. There is a valid probability that the trend of children suffering from respiratory diseases and the trend of ambient air pollutant concentrations are correlated, which would confirmn a direct causality between air pollution and health risk. The results of this research were published at the Fourth International WeBIOPATRE Workshop & Conference Particulate Matter: Research and Management [7].

The relationship between air quality and the occurrence of health issues in the exposed population is highly complex and this interaction is still in the domain of ongoing scientific research. Health risk has not yet been quantified with complete precision and accuracy, as it cannot be fully ascertained what levels of exposure to an air pollutant would lead to acute or chronic respiratory diseases or to carcinogenic diseases. The complexity of interaction between exposure to pollutants and unwanted health effects depends on whether pollutants are synergistic or additive. Adaptation to new conditions of environmental pollution is fundamentally non-existent; rather, we may speak of tolerance that is qualitatively, quantitatively, and temporally limited. Exhausting the adap-

tation mechanisms, crossing the tolerance threshold, and exceeding the capacity of protective and defence mechanisms causes pathophysiological reactions that manifest, to a greater or lesser extent, through various forms of pathological conditions or diseases of modern civilization, often referred to as environmental diseases.

Methods

The United States Environmental Protection Agency (USEPA) has developed a methodology to assess health risk from air pollution in which all other factors affecting the development of environmental diseases are eliminated. For the assessment of health risk, this paper utilized the US EPA methodology, beginning with hazard identification, risk characterization, and risk quantification [8–10].

Since PM_{10} and CO concentrations monitored in the city of Niš up to 2011 exceeded the allowed limits at most measuring points, they can be considered as ambient air pollutants detrimental to the health of the exposed population. In order to quantify substance hazard in the risk assessment stage, it is necessary to analyze the relationship between different doses and the occurrence of unwanted health effects – risk characterization (Figure 1) [9].

the representative individual in the observed subgroup, represented as y (kg); EDi – exposure duration for the representative individual in environment i (year); ATx – average time of effect duration of pollutant x (days); and EFi – exposure frequency (day/year).

Respiratory rate and distribution and resorption of the inhaled air pollutant vary according to the features of individuals in a subgroup. The average uptake of air pollutants was assessed through parameters for a representative individual in a subgroup. Exposure in relation to average uptake of airborne pollutant x and in relation to the representative individual with average anatomical and physiological features in their subgroup, in environment i, was calculated with the following physical equation [6]:

$$E_{i,x,y} = 0{,}001 \cdot C_{i,x} \left(\frac{IR_y}{BW_y} \right) \left(\frac{ED_i \cdot ET_i \cdot EF_i}{AT_x} \right) \text{mg/kg/day} \quad (2)$$

Ei,x,y – exposure, or the average uptake of pollutant *x* as a function of time, for the representative individual *y* in the observed subgroup in environment *i*.

For air pollutant exposure, the EPA established a reference concentration (R*f*C), which represents the exposure

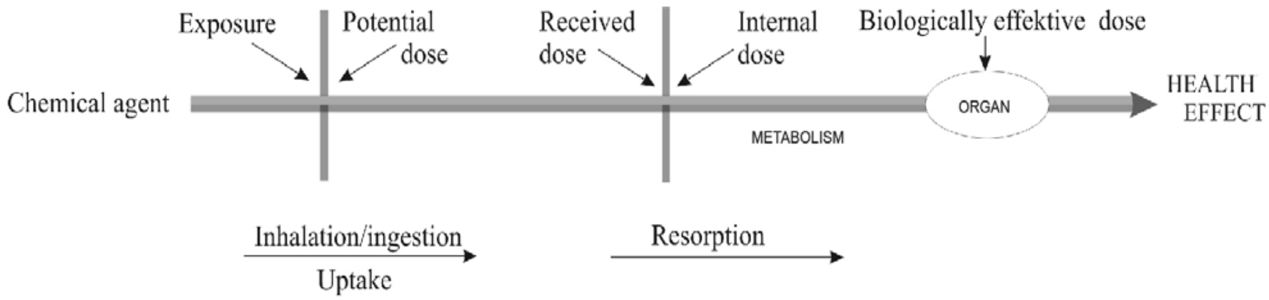

Fig. 1 – Exposure-dose risk characterization.

It is difficult to determine with complete certainty the relationship between a received dose and the response it causes (response or internal dose) because there are certain absorption barriers inside the exposed individual's body that are inaccessible for direct determination of dose level.

According to the methodology for health risk assessment provided by the US EPA [8], the quantity of the exposing chemical agent is related with the uptake dose and its contact with the exposed person's body *per* unit body weight *per* unit time (expressed as mg/kg/day), according to the defined uptake pathway. The uptake dose can be expressed with the equation [5].

$$\text{Uptakedose} = C_{i,x} \left(\frac{IR_y}{BW_y} \right) \left(\frac{ED_i \cdot ET_i \cdot EF_i}{AT_x} \right) [\text{mg/kg/day}] \quad (1)$$

Ci,x – concentration of pollutant x in environment i (mg/m^3); IRy – individual respiratory rate at rest per unit time for a representative individual in the subgroup y in environment i (m^3/day); ETi – exposure time of the representative individual in environment i (days/years); BWy – body weight of

concentration threshold below which, even with continuous inhalation, there are no detrimental health effects, including the highly-sensitive population. R*f*C can be equated with the reference dose (*RfD*) by multiplying the R*f*C with the individual respiratory rate of the individual y (*IRy*) and dividing it with the individual's body weight (*BWy*). When assessing the probability of non-carcinogenic diseases, the risk of non-carcinogenic diseases can be assessed as the ratio of exposure and the corresponding R*f*D for a given pollutant. The increased probability of health risk in the individual y exposed to non-carcinogenic pollutant x in a given subgroup in environment i can be obtained by calculating the health risk hazard quotient (*HQ*) [11–13].

$$HQ_{i,x,y} = \frac{E_{i,x,y}}{RfD} \quad (3)$$

$HQ_{i,x,y}$ – health risk hazard quotient for non-carcinogenic substances (dimensionless quantity).

If the exposure level exceeds this limit, i.e. if the *E/RfD* ratio exceeds 1, there is a possibility of negative non-carcinogenic effects. The bigger the *E/RfD* ratio, the bigger the possibility of detrimental effects.

According to the EPA methodology, health risk assessment for exposure to substances classified as carcinogenic involves quantifying individual health risk based on known exposure using the equation: [7, 10, 14].

$$R_i = Ei,x,y \cdot \text{Toxicity} \quad (4)$$

Individual health risk was expressed as one in a million (10^{-5}) of the probability of occurrence of health risk for asthma or lung cancer, for instance. Individual health risk Ri can be calculated through the potential dose and the SFI (Inhalation Slope Factor) [7, 8, 15]:

$$\text{SFI} = \text{unit risk } (\mu g/m^3)^{-1} \cdot \text{BW (kg)} \cdot \text{IR } (m^3/\text{day})^{-1}. \quad (5)$$

For the assessment of carcinogenic effects due to long-term exposure to pollutants, the potentially higher risk of carcinogenic diseases can be determined as the product of exposure and carcinogenic coefficient, established for every carcinogenic pollutant [8, 16]. The potentially higher risk of an individual in subgroup *y* developing cancer due to exposure to pollutant *x* is:

$$ICR_{i,x,y} = E_{i,x,y} \cdot SF_x \text{ (mg/kg/day)} \quad (6)$$

ICRi,x,y – probability of individual cancer risk for the individual y exposed to pollutant x in environment i; SFx – carcinogenic coefficient of pollutant x.

This paper presented the results of monitoring of suspended PM_{10} in one of the busiest intersections and the assessment of consequent health risk for the exposed group of children through calculation of individual cancer risk probability with the equation (6).

Since concentrations of suspended particulates near busy roads in the city of Niš were not officially monitored, for the 2012 and 2013 study we performed ambient air concentration measurements of particulates 2.5 μm ($PM_{2.5}$) and 10 μm (PM_{10}) in diameter with the help of the Air Pointer automatic measuring station and monitored respiratory diseases in 305 children at the kindergarten "Bambi", subsidiary of the Preschool Institution "Pčelica". The kindergarten "Bambi" is located in a densely populated part of the city with prominently heavy road traffic due to the vicinity of the intersection of Bulevar Nemanjića and Vojvode Mišića Street (Figure 2).

Results

The results of $PM_{2.5}$ monitoring in 2012 and the occurrence of respiratory diseases in the exposed children were published in the paper "Health Effects of Ambient Particulate Matter on Preschool Children in the City Center of Niš" [7].

Since high concentrations of $PM_{2.5}$ suspended particulates, which cause health risk, were registered at the kindergarten "Bambi" in 2012, in 2013 we measured PM_{10}, as well as CO, NO_2, and SO_2 concentrations. Measuring was performed from November 28 to December 27 (data from August are missing because kindergartens are closed during August). The results are given in diagrams (Figures 3–6) as mean 24-hour concentrations.

The results of measured concentrations shown in Figures 3–6 indicate that during the entire monitored month the PM_{10} concentrations significantly exceeded the allowed concentrations or were near the threshold limit values. The maximum registered concentration was 191.6153 μg/m^3, which is triple the allowed value.

Concentrations of CO were also high, occasionally exceeding or nearing the threshold limit values (Figure 4). NO_2 concentrations were below the limit values for the monitored period, with a note that on certain days they neared

Fig. 2 – Micro-location of the kindergarten "Bambi" in the city of Niš.

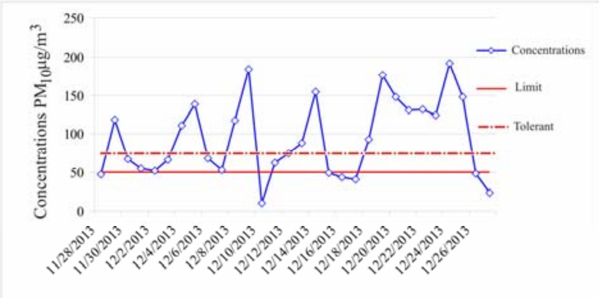

Fig. 3 – Trend of daily mean PM_{10} concentrations between November 28 and December 27, 2013.

Fig. 4 – Trend of daily mean CO concentrations between November 28 and December 27, 2013.

Fig. 5 – Trend of daily mean NO_2 concentrations between November 28 and December 27, 2013.

Fig. 6 – Trend of daily mean SO_2 concentrations between November 28 and December 27, 2013.

the threshold limit values (Figure 5). The SO_2 concentrations were well below the limit values (Figure 6). Such trend of pollutant concentrations can objectively be related to the activity of mobile pollution sources. This is evident in the graphic representation of the direction of pollutants in relation to "Bambi" kindergarten (Figure 2). Emitted PM_{10} concentrations from the east of the kindergarten, where the traffic roundabout is located, exceeded 100 μg/m^3, whereas concentrations emitted from the northwest, where bus stops are located, remained in the proximity of 100 μg/m^3 (Figures 2 and 7). The emission directions for other monitored pollutants were similar to the direction of suspended PM_{10}, which helps us draw a general conclusion that mobile pollution sources are the dominant pollutant emitters in the studied area (Figure 7).

In 2013 we also monitored the monthly incidence of the abovementioned respiratory diseases in children attending the kindergarten "Bambi". The percentage of sick children

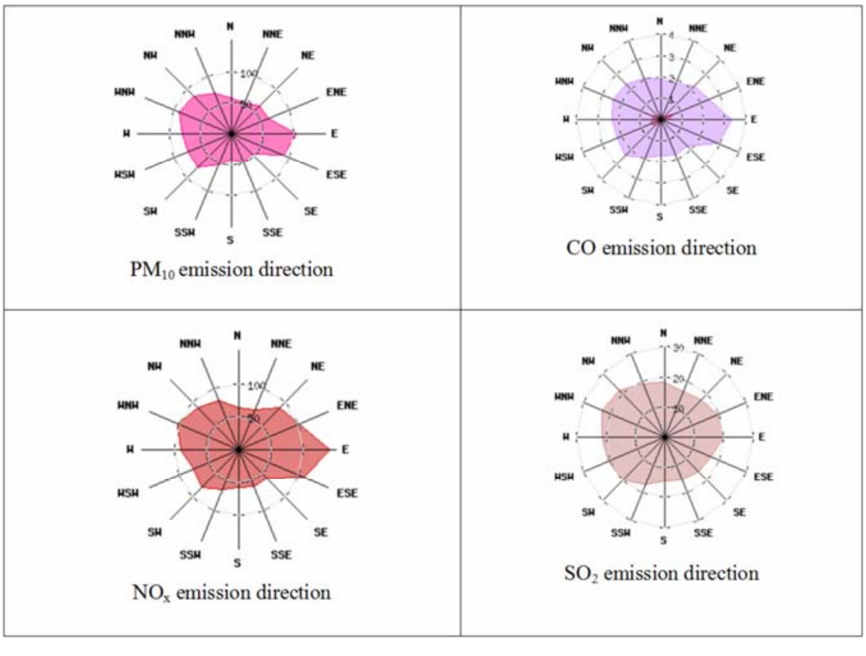

Fig. 7 – Emission directions of pollutants in relation to the kindergarten "Bambi".

was very high, exceeding 30% for the entire monitored period, with the exception of July and September. In February, March, and April, the number of children suffering from respiratory diseases was highest and ranged from 50% to 58% (Figure 8).

Fig. 8 – Percentage of respiratory diseases in the exposed preschool children between January and November 2013.

The incidence of respiratory diseases in preschool children at "Bambi" kindergarten in 2013 is shown in Table 1 by monthly and annual level.

Numerous foreign epidemiological and toxicological studies have proven that suspended PM2.5 and PM_{10} in ambient air contribute to the occurrence and development of carcinogenic diseases, as they contain substances with varying levels of toxicity, depending on their place of origin.

Table 2 shows the individual risk (Ri) calculated by the equations (4) and (5) in relation to measured PM_{10} concentrations at "Bambi" kindergarten (Figure 3) [8, 15, 17]. It is necessary to stress that, according to the US EPA methodology for individual risk assessment, calculated with the equations (4) and (5), risk is determined solely based on exposure to a given pollutant from ambient air, disregarding other risk factors. This allows for exclusive determination of the impact of air pollution on the development of specific respiratory diseases. The probability of individual cancer risk was also calculated by the equation (6) (Table 2). The individual risk and the probability of cancer were calculated for a two-hour exposure to PM10 concentrations for the mean daily concentration of 97.1 $\mu g/m^3$, under the assumption that the children were exposed to the given concentration twice a month during a year. The assumption is based on a long-standing analysis of monitoring the concentration of particulate matter PM10 in ambient air in the city of Niš, at the measuring point located 600 m from the examined kindergarten.

The calculated probability of individual cancer risk ranges from $5.060 \cdot 10^{-5}$ to $9.170 \cdot 10^{-5,}$ which means that 5–9 *per* million exposed preschool children can contract the disease at this level of exposure.

Considering that we registered high daily CO concentrations (for children) at the kindergarten "Bambi" during our monitoring period (November and December 2013) (Figure 4), it is necessary to determine the expected health risk for the

Table 1

Incidence of respiratory diseases in preschool children from the kindergarten "Bambi" in Niš in 2013, monthly and annual levels (%)

Respiratory disease name and ICD	Disease (%)										Annually
	Month										
	I	II	III	IV	V	VI	VII	IX	X	XI	
Laryngitis acuta et Tonsillitis acuta – J02-J03	55.56	52.78	41.67	29.78	30.30	48.89	55.17	35.71	39.47	57.14	44.78
Bronchitis et Bronchiolitis acuta – J20-J21	22.21	5.56	12.50	19.14	27.27	13.32	20.69	42.85	11.76	28.57	20.00
Infectiones tractus respiratorii superioris – J00-J01, J05-J06	0	16.67	25	27.65	27.27	22.22	20.69	7.14	23.68	2.38	18.22
Laryngitis acuta and tracheitis acuta – J04	7 .41	5.56	8.34	3.36	3.03	11.11	0	14.28	15.78	4.76	7.47
Tracheitis and other obstructive lung diseases – J40-J44	7.41	2.78	8.34	3.36	3.03	2.22	3.45	0	0	4.76	3.88
Other nose and paranasal sinus diseases - J30-J31. J33-J34	7.41	0	0	3.36	9.09	2.22	0	0	0	2.38	2.98
Influenza – J10-J11	0	8.33	4.17	2.12	0	0	0	0	0	0	1.49
Pneumonia – J12-J18	0	5.56	0	2.12	0	0	0	0	0	0	0.89
Chronic tonsillar disease and vegetative syndrome – J35	0	2.78	0	0	0	0	0	0	0	0	0.29
Sinusitis chronica – J32	0	0	0	0	0	0	0	0	0	0	0
Bronchial asthma – J45-J46	0	0	0	0	0	0	0	0	0	0	0
Mean incidence:	50.00	66.67	41.38	79.66	58.92	72.58	36.25	28.00	69.09	72.41	57.17

ICD – International classification of diseases.

Table 2

Individual risk and probability of cancer in children exposed to PM_{10} particulates at the kindergarten "Bambi"

Children's age (years)	Individual risk R_i (%)	Probability of individual cancer risk (ICR)
Under 1	2.124	$5.060 \cdot 10^{-5}$
1 to 3	11.59	$7.880 \cdot 10^{-5}$
3 to 6	28.51	$9.170 \cdot 10^{-5}$

exposed children. To assess health risk from carbon monoxide, we used the mean annual concentrations monitored at 16 measuring points in 2011 (the last monitored year in the city of Niš), with the help of which we predicted the concentrations at the kindergarten "Bambi" using a radial basis function (RBF) network and subsequently mapped air quality. It is worth noting that no air pollutant was monitored in kindergarten locations in the monitoring network of the city of Niš. Accordingly, as the result of the project No III-43014, we implemented an original methodology of mapping air quality, which enabled us to predict CO diffusion in the analyzed territory by using an radial basic function (RBF) network. The map of air quality is shown in Figure 9, with the purple, red, and orange fields representing health risk zones in which CO concentrations range from 3 to 9.7 mg/m^3. Such high CO concentrations cause unwanted health effects, especially in highly sensitive population groups such as preschool children. The effects could be heavy breathing, chest "pressure", and fatigue and chest pain in people with respiratory diseases.

If we use the mean annual concentration for 2011, which is 7.769 mg/m^3, to assess health risk, we can calculate the health risk HQ for long-term exposure of preschool children at the kindergarten "Bambi". The health risk HQ calculated by the equation (3), equals 2.96 for children aged 3 to 6, assuming they were exposed for two hours during a day, which places the risk in the "high" category. If we assume that preschool children aged 3 to 6 are exposed to mean annual CO concentrations of 7.769 mg/m^3 for 4 hours *per* day, the HQ is 5.88 and the health risk is considered to be "very high" [10, 18, 19].

In order to obtain the best possible assessment of the causality between health risk from CO exposure and the occurrence of respiratory diseases in preschool children, we also monitored the number of children with respiratory disease at the kindergarten "Maslačak" in 2013. We selected the children from the kindergarten "Maslačak" to be the control group, as this kindergarten, similarly to "Bambi", is located in a central densely-populated part of the city and is surrounded with high-rise residential buildings (Figure 10).

The number of analyzed children at the kindergarten "Maslačak" was 310, which was very close to the number of analyzed children at the kindergarten "Bambi" (305). Hygienic-sanitary and socio-economic conditions in both kindergartens were almost identical, and the percentage of

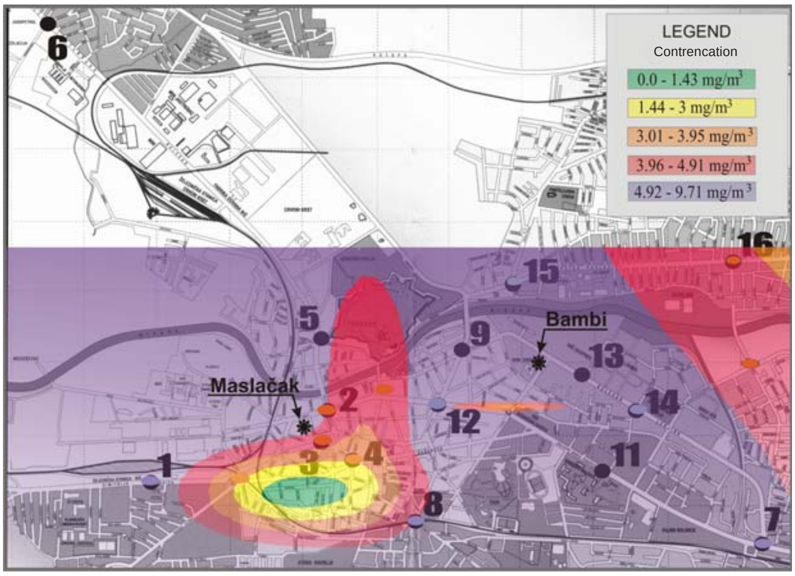

Fig. 9 – Air quality zone map with approximate CO concentrations at kindergartens "Bambi" and "Maslačak" in the city of Niš, 2011.

Fig. 10 – Micro-location of the kindergarten "Maslačak" in the city of Niš.

non-smoking family members of the exposed children was also approximately the same (Table 3).

The only significant difference between the two kindergartens was their distance from busy roads. The busiest road along the dominant wind direction in relation to the kindergarten "Maslačak" is 126 m away, whereas the busiest road near "Bambi" is only 15 m away. Table 4 shows the mean 15-minute CO emission concentrations as well as concentrations at distances of 15 and 100 metres from the nearest road to the kindergartens "Bambi" and "Maslačak". The calculation of concentrations was done by means of the Screening Air Dispersion Model (SCREEN) [11].

The mass of CO emission on the road near the kindergarten "Bambi" was larger than the mass near "Maslačak". Based on the above calculations, CO concentration at the kindergarten "Maslačak" was significantly lower compared to "Bambi", which is in keeping with the CO concentration prediction for "Maslačak" by means of the RBF network (Figure 9).

Using the RBF network at the kindergarten "Maslačak", we predicted the mean annual CO concentration to be 4.91 mg/m^3 (Figure 9). Based on mean annual concentrations, the health risk HQ, calculated by the equation (3), equals 1.87 for children aged 3–6, assuming they were exposed for 2 h per day (health risk is "moderately high"). For 4-hour daily exposure, the HQ is 3.72 (health risk is "high") [19].

In 2013 we also monitored the monthly occurrence of respiratory diseases in children attending the kindergarten "Maslačak", and the percentage is shown in Figure 11.

The flowchart of respiratory diseases shown in Figure 11 reveals that the number of affected children is higher during the winter months. The winter percentage of diseases ranges from 26.80% to 40.21%. Table 5 shows the incidence of respiratory diseases found in children at the kindergarten "Maslačak".

Discussion

According to the Regulation on Monitoring Conditions and Air Quality Requirements ("Official Gazette of the Re-

Fig. 11 – Percentage of respiratory diseases in the exposed preschool children at the kindergarten "Maslačak" between January and November 2013.

Table 3
Percentage of smokers in the families of children from the "Bambi" and "Maslačak" kindergartens in the city of Niš

Children's age (years)	Number of smoking family members							
	"Bambi" kindergarten				"Maslačak" kindergarten			
	One	Two	Three or more	No smokers	One	Two	Three or more	No smokers
3	26.09	3.35	4.38	66.18	16.20	2.70	-	81.10
4	20	6.15	3.07	70.78	32.65	16.32	2.05	48.98
5	18.66	4	0	77.34	21.06	14.70	-	64.24
6	39.34	4.92	0	55.74	19.64	17.85	1.78	60.73
Average percentage	26.02	4.6	3.72	65.66	22.39	12.98	1.91	62.72

Table 4
Calculated 15-minute CO emission concentrations on busy roads in the city of Niš

Location	Distance from source [m]	Concentration [mg/m^3]	Emission [kg]
Roundabout near the kindergarten "Bambi"	15 100	35.66 1.72	3.935
Road near the kindergarten "Maslačak"	15 100	22.99 0.691	2.546

Table 5

Incidence of respiratory diseases in preschool children (control group) at the kindergarten "Maslačak" in the city of Niš in 2013, monthly and annual level (%)

Respiratory disease name and code	Disease (%)										Annually
	Month										
	I	II	III	IV	V	VI	VII	IX	X	XI	
Laryngitis acuta and Tonsillitis acuta – J02-J03	0	0	0	83.34	60.00	51.87	61.11	50.00	53.85	56.53	46.63
Infectiones tractus respiratorii superioris - J00-J01, J05-J06	96.67	7.14	0	11.11	22.86	14.81	38.89	27.78	30.76	13.04	32.21
Bronchitis et Bronchiolitis acuta – J20-J21	0	57.15	0	5.55	8.57	14.81	0	11.11	15.39	21.74	12.50
Laryngitis acuta and tracheitis acuta – J04	3.33	35.71	0	0	5.71	14.81	0	0	0	8.69	6.73
Tracheitis and other obstructive lung diseases – J40-J44	0	0	0	0	0	0	0	11.11	0	0	0.96
Sinusitis chronica – J32	0	0	0	0	2.86	0	0	0	0	0	0.48
Bronchial asthma – J45-J46	0	0	0	0	0	0	0	0	0	0	0.48
Other nose and paranasal sinus diseases – J30-J31. J33-J34	0	0	0	0	0	0	0	0	0	0	0
Influenza – J10-J11	0	0	0	0	0	0	0	0	0	0	0
Pneumonia – J12-J18	0	0	0	0	0	0	0	0	0	0	0
Chronic tonsillar disease and vegetative syndrome – J35	0	0	0	0	0	0	0	0	0	0	0
Mean incidence:	57.70	26.92	0	34.61	67.30	51.92	34.61	33.33	74.28	53.49	41.10

public of Serbia, No. 11/2010, 75/2010, and 63/2013) [2], the PM_{10} concentration of 50 μg/m^3 must not exceede that value more than 35 times within a single calendar year. Suspended particulate concentrations at the kindergarten "Bambi" during the 29 monitored days exceeded 50 μg/m^3 on 23 days. The tolerable limit value of 75 μg/m^3 was exceeded on 16 days during the monitored period. Such high PM_{10} values can cause serious health risk in the exposed population, to an even greater extent. The calculated percentage of individual risk applies only to a 2-hour exposure to high concentrations twice a month.

Based on the results of earlier studies it is estimated that approximately 3% of cardiopulmonary and 5% of lung cancer deaths are attributable to PM globally. In the European Region, this proportion is 1–3% and 2–5%, respectively, in various subregions [20].

Results emerging from a recent study indicate that the burden of disease related to ambient air pollution may be even higher. This study estimates that in 2010, ambient air pollution, as annual $PM_{2.5}$, accounted for 3.1 million deaths and around 3.1% of global disability-adjusted life years.

Exposure to $PM_{2.5}$ reduces the life expectancy of the population of the Region by about 8.6 months on the average. Results from the scientific project Improving Knowledge and Communication for Decision-Making on Air Pollution and Health in Europe, which uses traditional health impact assessment methods, indicate that the average life expectancy in the most polluted cities could be increased by approximately 20 months if the long-term $PM_{2.5}$ concentration was reduced to the WHO (AQG) annual level [21].

Adverse health effects from other gaseous pollutants, such as SO_2, nitrogen dioxide (NO_2), and carbon monoxide (CO), should not be underappreciated. Recent epidemiologic studies conducted throughout the world have provided valuable insight into the associations between SO_2, NO_2, and CO exposure and increases in cardiopulmonary mortality, respiratory and cardiovascular hospital admissions, emergency admissions caused by stroke (NO_2), and myocardial infarction (NO_2 and CO) [22].

The study "Air pollution and sudden infant death syndrom" [23] nevertheless have not been able to identify the specific components of particulate matter and carbon monoxide, nor elucidate the mechanism by which these pollutants affect health in children and infants, which may be different from adults.

Our study shows that mean annual CO concentrations in ambient air for the analyzed location of the kindergarten "Bambi" (7.769 mg/m^3) are 63.20% higher than the same concentrations at the kindergarten "Maslačak" (4.91 mg/m^3). By comparing the difference of the hazard quotient and health risk in exposed children from the two kindergartens, we concluded that the health risk for children at the kindergarten

"Bambi" is 63.18% higher for a 2-hour exposure and 63.26% higher for a 4-hour exposure. If we compare the values of the average respiratory disease incidence monitored in the kindergartens, we can conclude that the average incidence at the kindergarten "Bambi" is 57.15%, as opposed to 41.10% at the kindergarten "Maslačak", which is a 16.05% difference. It is also significant that there is 3% higher percentage of non-smoking family members of the children attending the kindergarten "Bambi". According to the presented results, there is a causality between pollutants emitted from mobile sources and the occurrence and development of respiratory diseases in preschool children. A direct link between the percentage of occurrence and development of a specific respiratory disease and the concentration of a specific pollutant in ambient air is still the subject of ongoing scientific research.

The mean annual incidence of respiratory diseases in the experimental group, with prominent effects of polluted air, was 57.17%, whereas the value was considerably lower in the control group – 41.10%. We also noticed significant differences (up to four times higher incidence) in certain respiratory diseases – for instance, *Bronchitis et Bronchiolitis acuta*, 12.50% in the control group and 20.00% in the experimental group or *Tracheitis* and other obstructive lung diseases, 0.96% in the control group and 3.88% in the experimental group. Some respiratory diseases, such as Other nose and paranasal sinus diseases, code J30-J31 and J33-J34, and Influenza, code J10-J11, were not even registered in the control group. Monthly monitoring indicates considerable seasonal fluctuations of respiratory disease incidence.

The probability of individual cancer risk, caused by PM_{10} concentrations in the experimental area, ranges from $5.060 \cdot 10^{-5}$ to $9.170 \cdot 10^{-5}$ (5–9 *per* million exposed preschool children).

Conclusion

Based on the presented results and the discussion, we unequivocally conclude that there is a directly proportional relationship between ambient air quality and respiratory diseases in preschool children.

Development of a network and system for monitoring ambient air quality in urban areas can significantly contribute to respiratory disease prevention, primarily for preschool and school children.

R E F E R E N C E S

1. SEPA. Annual Report on the Environment in the Republic of Serbia for 2010. Available from: www.sepa.gov.rs/download/Izvestaj_o_stanju_zivotne_sredine_za_2010_godinu.pdf
2. Regulation on Monitoring and Air Quality Requirements. Official Gazette RS; 11/2010, 75/2010 and 63/2013.
3. Institute of Public Health Niš. Annual reports on air quality in the city of Niš. Available from: www.izjz-nis.org.rs
4. *Đorđević A, Milošević L. Rašić M.* Analysis of gaseous substance toxicity assessment. J Sci Eng Safety Eng 2013; 3(1): 17−21.
5. *Longhurst* J. 1 to 100: Creating an Air Quality Index in Pittsburgh. Environ Monit Assess 2005;106(1−3): 27−42.
6. *Cairncross EK, John J, Zunckel M.* A novel air pollution index based on the relative risk of daily mortality associated with short-term exposure to common air pollutants. Atmos Environ 2007; 41: 8442−54.
7. *Đorđević A, Živković N, Milošević L, Mijailović I, Mihajlović E.* Health effects of ambient particulate matter on preschool children in the City Center of Niš, Serbia. Proceedings from the 4th WeBIOPATR workshop & conference; Belgrade, Serbia; 2013 October 2−4; Belgrade: WeBIOPATR2013, Particulate Matter Research and Management; 2013. p. 209−16.
8. *United States Environmental Protection Agency.* Chemicals under the Toxic Substances Control Act (TSCA). Available from: http://www.epa.gov.
9. *Baldauf RW, Lane DD, Marote GA.* Ambient air quality monitoring network design for assessing human health impacts from exposures to airborne contaminants. Environ Monit Assess 2001; 66(1): 63−76.
10. Integrated Risk Information System (IRIS). U.S. EPA. Available from: https://www.gov.com
11. *Papić V, Vidović M.* Determining the Quantity of Gaseous Pollutants Emitted from Road Traffic Using the COPERT 4 Model of the European Environment Agency. Belgrade: University of Belgrade, Faculty of Transport and Traffic Engineering, Institute of Faculty of Transport and Traffic Engineering. 2010. (Serbian)
12. *Đorđević A.* Causal Analysis of Air Quality and Health Risk from Air Pollution [dissertation]. Niš: Faculty of Occupational Safety; 2010. p. 299.
13. Federal contaminated site risk assessment: Guidance on human health preliminary quantitative risk assessment (PQRA), Environmental Health Assessment Services Safe Environments Programme. Cat. H46-2/04-367E ISBN 0-662-38244-7. Ottawa, Canada: Minister of Health; 2004.
14. *Sills R, Hultin ML, Depa M.* General Approach for the Screening-Level Risk Assessment of Air Toxics Mixtures and Cumulative Risk Assessment. Lansing: MDEQ AQD; 2008.
15. *Sills R, Sadoff M.* Risk Assessment for Lead Emissions of the Wolverine Clean Energy Venture (WCEV). Lansing: MDEQ AQD; 2008.
16. *Baldauf RW, Lane DD, Marote GA.* Ambient air quality monitoring network design for assessing human health impacts from exposures to airborne contaminants. Environ Monit Assess 2001; 66(1): 63−76.
17. *Đorđević A, Todorović B, Živković N, Raos M, Milošević L.* Determination of Health Risk Zones of Air Pollution in the City of Niš caused by Presence of Soot by Use of RBF Neural Network. Facta Universitatis 2013; 4(2): 119−28.
18. *Đorđević A, Živković N, Mihajlović E, Radosavljević J, Raos M, Živković L.* The effect of pollutant emission from district heating systems on the correlation between air quality and health risk. Thermal Science 2011; 15(2): 293−310.
19. *Đorđević A, Milošević L, Krstić I. Rašić M.* Exposure Assessment for Characterization of Health Risk From Air Pollution. Proceedings, III International Conference „Ekology of Urban Areas 2013"; Zrenjanin; 2011 December 7; Zrenjanin: University of Novi Sad, Technical Faculty „Mihailo Pupin"; 2013. p. 105−11.
20. *Cohen AJ, Anderson RH, Ostro B, Pandey KD, Krzyzanowski M, Künzli N*, et al. Urban air pollution. In: *Ezzati M A, Lopez DA, Rodgers A, Murray C,* editors. Comparative quantification of health risks. Global and regional burden of disease attributable to selected major factors.Geneva: World Health Organization; 2004; p. 1353–433.

21. *Lim SS, Vos T, Flaxman AD, Danaei G, Shibuya K, Adair-Rohani H*, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet 2012; 380(9859): 2224−60.
22. *Koken PJ, Piver WT, Ye F, Elixhauser A, Olsen LM, Portier CJ.* Temperature, air pollution, and hospitalization for cardiovascular diseases among elderly people in Denver. Environ Health Perspect 2003; 111(10): 1312−7.
23. *Tong S, Colditz P.* Air pollution and sudden infant death syndrome: a literature review. Paediatr Perinat Epidemiol 2004; 18(5): 327−35.

Received on September 10, 2014.
Revised on January 27, 2015.
Accepted on February 23, 2015.
Online First February, 2016.