THE EFFECT OF POLLUTANT EMISSION FROM DISTRICT HEATING SYSTEMS ON THE CORRELATION BETWEEN AIR QUALITY AND HEALTH RISK

by

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The monitoring and the control of air pollution which is a consequence of the activities of district heating plants in the area of Niš have indicated that there is a cause and effect relationship between the emitted pollutants and air quality on one hand, and health risk on the other hand. The aim of this paper is to determine the correlation between district heating plants, air quality and health risk. The evidence of this connection is the hazardous health quotient and the level of total carcinogenic risk in comparison to measured immission concentration and expected immission concentrations of pollutants from district heating plants in the city.

Key words: *heat sources, concentration, air pollutant, health risk, hazardous health quotient*

Introduction

The aim of this study is to determine the influence of pollutant emission from district heating system on air quality and health risk assessments, on the territory of the city of Niš. The assessment of air quality in the area of Niš has been carried out in accordance with the legislation of the Republic of Serbia, as well as according to the procedures and recommendations of U. S. EPA. Health risk assessment has also been carried out in accordance with the methodology and recommendations made by U. S. EPA. There is qualitative and quantitative correlation and dependency between the emission of pollutants produced by fuel combustion in district heating plants and the air quality in the city. The result of the increasing activities of district heating plants is an increased emission concentration and degradation of air quality, which has been confirmed by the research conducted on the territory of Niš [1]. Immission concentrations of pollutants are regularly measured and monitored in Niš. These features are variable and the differences are noticeable during the change of seasons, which is connected to the activities of the district heating plants and industrial power plants (stationary sources of air pollution). Fossil fuels are the main energy sources in the area of Niš. The most

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common energy-generating products are solid fossil fuels, such as: all types of coals (lignite, semibituminous and bituminous coal, as well as anthracite) and firewood. Liquid fossil fuels and natural gas are also used as fuels on the territory of Niš.

Methodological approach to making qualitative and quantitative assessment of air quality and health risk

In order to perform qualitative and quantitative assessments of air quality, the original method for making the correlation between the concentration of pollutants and air quality index scale (according to the standard U. S. EPA, 451/K-94-001) has been used in this paper [2]. The correlation of pollutant concentrations and air quality index has been determined by the following methods: statistical method, the method of analysis and the synthesis of the effects of mid-annual concentrations on the health of the exposed population. According to the world experience, measured and estimated immission concentrations of pollutants are used to assess the potential territorial health risk. The correlation between the air quality index, the air quality and its effects on human health provides an opportunity for comparative analysis of the impact of pollutants on air quality and air pollution health risk. Table 1 gives an overview of the correlation between the short-term immission concentrations of pollutants and air quality index [3]. Table 2 provides an overview of the original connection of immission concentration of pollutants and air quality index, while tab. 3 shows the relationship between the health quotient and the health risk category.

Table 1. The correlation between immission concentrations of pollutants and air quality index

Conc. level	Pollutant concentration							Index range
	O_3 [ppm] 1 hour	O_3 [ppm] 8 hour	Particulate matter, $PM_{2,5}$ [μmm^{-3}] 24 hour	Particulate matter, PM_{10} [μmm^{-3}] 24 hour	CO [ppm] 24 hour	SO_2 [ppm] 24 hour	NO_2 [ppm] 24 hour	
I	–	0-0.064	0.0-15.4	0-54	0.0-4.4	0-0.034	**	0-50
II	–	0.065-0.084	15.5-40.4	55-154	4.5-9.4	0.035-0.144	**	51-100
III	0.125-0.164	0.085-0.104	40.5-65.4	155-254	9.5-12.4	0.145-0.224	**	101-150
IV	0.165-0.204	0.105-0.124	65.5-150.4	255-354	12.5-15.4	0.225-0.304	**	151-200
V	0.205-0.404	0.125-0.374	150.5-250.4	355-424	15.5-30.4	0.305-0.604	0.65-1.24	201-300
VI	0.405-0.504		250.5-350.4	425-504	30.5-40.4	0.605-0.804	1.25-1.64	301-400
VII	0.505-0.604		350.5-500.4	505-604	40.5-50.4	0.805-1.004	1.65-2.04	401-500

** The above mentioned levels do not have negative effects of human health

Table 2. The correlation between annual immission concentrations of pollutants and air quality index

Conc.level	Pollutant concentration					Index range
	Soot [μgm^{-3}]	CO [mgm^{-3}]	SO_2 [μgm^{-3}]	NO_2 [μgm^{-3}]	HCHO [μgm^{-3}]	
I	0.0-11.80	0.0-1.43	0.0-11.80	0.0-24.00	0-0.05	0-50
II	11.81-50.00	1.44-3	11.81-50.00	24.01-60	0.06-0.10	51-100
III	50.01-77.77	3.01-3.95	50.01-77.77	60.01-84.00	0.11-0.14	101-150
IV	77.78-105.00	3.96-4.91	77.78-105.00	84.01-120.00	0.15-0.20	151-200
V	105.56-209.72	4.92-9.70	105.56-209.72	120.00-150.00	0.21-0.24	201-300
VI	209.73-279.17	9.71-12.89	209.73-279.17	150.01-180.00	0.25-0.29	301-400
VII	279.18-348.61	12.90-16.86	279.17-348.61	180.01-210.00	0.30-0.35	401-500

Non-cancer disease risk assessment can be regarded as the correlation between the exposure and the appropriate reference dose (RfD) of pollutants. The increased probability of health risk among the individual y, exposed to the cancerous pollutant x, in a particular subgroup in the environment i can be obtained by calculating the hazardous health quotient HQ [4, 5]:

Table 3. The correlation between hazardous health quotient and health risk categories

Hazardous health quotient (HQ)	Health risk category
$1 < HQ \leq 1.6$	Moderate
$1.7 < HQ \leq 2.3$	Significant
$2.4 < HQ \leq 4$	High
$4 < HQ$	Extremely high

$$HQ_{\mathrm{i,x,y}} = \frac{E_{\mathrm{i,x,y}}}{RfD} \tag{1}$$

where $HQ_{\mathrm{I,x,y}}$ is the hazardous health quotient of non-cancerous substances (dimensionless size), $E_{\mathrm{i,x,y}}$ [mg/kg per day] – the exposure or an average intake of pollutant x in a function of time, for an individual y, observed in the environment i:

$$E_{\mathrm{i,x,y}} = 0.001\, C_{\mathrm{i,x}} \frac{IR_{\mathrm{y}}}{BW_{\mathrm{y}}} \frac{ED_{\mathrm{i}} ET_{\mathrm{i}} EF_{\mathrm{i}}}{AT_{\mathrm{x}}} \tag{2}$$

where $C_{\mathrm{i,x}}$ [mgm^{-3}] is the concentration of pollutant x in the environment i, IR_{y} [m^3 per day] – is a breathing rate at rest per unit of time for an individual in a subgroup y, in the environment i, ET_{i} [days/years] – the exposure time in the environment i, BW_{y} [kg] – the body weight of an individual in a subgroup y, ED_{i} [years] – the exposure duration of an individual in the environment y AT_{x} [days] – the time of the pollutant x activity, and EF_{i} [days/year] – the exposure frequency for the typical resident in neighborhood *i*.

For the evaluation of carcinogenic effects caused by long-term exposure to pollutants, potentially increased risk of cancerous diseases can be identified as a combination of exposure and coefficient of carcinogenic potential for each individual [6]. Potentially increased risk of getting cancer has been determined in the example of an individual y exposed to the pollutant x:

$$ICR_{\mathrm{i,x,y}} = E_{\mathrm{i,x,y}} SF_{\mathrm{x}} \tag{3}$$

where $ICR_{\mathrm{i,x,y}}$ is the cancer risk for an individual y, under the influence of pollutant x in an environment i, and SF_{x} [mg/kg per day] – the slope factor or increased cancer risk from a lifetime exposure to a pollutant x.

Emission and immission concentrations of pollutants from district heating plants in Niš

District heating system has been used in Niš since 1973. The system of district heating is characterized by 13 heat source generators, with a capacity of 237.15 MW. Since 1977, district heating plants have been using crude-oil, heating oil, coal, and natural gas.

The facilities of the city plants provide district heating to more than 1.5 million m^2 of heating surface. The mass of the emitted pollutants through emission factors has been calculated according to the data about the quantity of fuel used for district heating system in Niš. The correlation between the amount of emitted pollutants and the amount of burned natural fuel has been determined according to the common level of emission factors.

The measured mass of emitted pollutants developed by burning fuels used in district heating operators in Niš (tab. 4) is given in tabs. 5, 6, 7, and 8. The actual mass of emitted pollutants caused by burning fossil fuels depends on many factors such as: height and diameter of the emitter, velocity of flue gases, gases retaining in the furnace flue pipes, flue gas temperatures, fuel combustion procedure, *etc*. [7-9]. However, the results of the calculation of mass emission of pollutants emitted by burning fuels using emission factors are relevant and are they used for certain analysis. Fuel oil, coal, oil, and gas have been used as fuels for district heating in Niš for the last 27 years. In the observed period, high concentrations of SO_2, NO_x and formaldehyde and lower concentrations of SO_3 and CO were emitted

Table 4. Quantity of emitted pollutants measured by emission factor during heavy fuel oil consumption in district heating plants in Niš

Year	kg of emitted pollutants per m^3 of heavy fuel oil					
	HCHO	CH_4	NO_X	SO_2	SO_3	CO
1977/78	452.3	2,455.343	80,638.62	267,813.26	4,122.39	31.015
1978/79	579.871	3,147.871	103,38273	343,349.96	5,285.11	39.763
1979/80	741.471	4,025.13	132,193.73	439,035.743	6,757.981	50.843
1980/81	794.598	4,313.536	141,665.621	470,493.324	7,242.200	54.486
1981/82	868.291	4,713.584	154,804.054	514,128.079	7,913.861	59.540
1982/83	719.259	3,904.550	128,233.672	425,883.754	6,555.535	49.320
1983/84	955.454	5,186.755	170,343.975	565,738.548	8,708.289	65.516
1984/85	1,162.577	6,311132	207,270.872	688,378.455	10,596.059	79.719
1985/86	1,158.947	6,291.430	206,623.809	686,229.459	10,562.980	79.470
1986/87	1,319.215	7,161.454	235,197.258	781,126.279	12,023.706	90.460
1987/88	1,142.75	6,203.818	203,746.445	676,673.291	10,415.884	78.364
1988/89	1,292.479	7,016.314	230,430.545	765,295.291	11,780.023	88.627
1989/90	1,337.584	7,261.174	238,472.257	792,003.056	12,191.129	91.720
1990/91	1,414.930	7,681.050	252,261.884	837,800.526	12,896.080	97.023
1991/92	1550,937	8,419.376	276,510.037	918,332.374	14,135.689	106.350
1992/93	1,122.271	6,092.331	200,085.000	664,513.070	10,228.704	76.955
1993/94	702.434	3,813.216	125,234.041	415,921.519	6,402.189	48.166
1994/95	947.483	5,143481	168,922.752	561,018.450	8,635.634	64.970
1995/96	1,233.389	6,694.781	219,895.678	730,307.377	11,241.461	84.575
1996/97	1,262.846	6,855.454	225,147.574	747,749.731	11,509.948	81.795
1997/98	1,092.697	5,931.785	194,812.313	647,001.663	9,959.155	74.927
1998/99	1,105.134	5,999.300	197,029.647	654,365.770	10,072.509	75.780
1999/00	1,046.547	5,681.254	186,584.322	619,675.232	9,538.523	71.764
2000/01	1,106.577	6,007.132	197,286.836	655,219.942	10,085.655	75.879
2001/02	1,445.499	7,846.997	257,711.844	855,900.672	1,317.951	99.120
2002/03	1,727.682	9,378.844	308,020.937	102,2984.91	15,746.579	118.470
2003/04	648.715	3,521.598	115,656.679	384,113.62	5,912.576	44.480
2004/05	419.605	2,277.858	74,809.625	248,454.272	3,824.40	28.773

to the air (tabs. 4, 5, 6, and 7). In the period between 2005 and 2009, there was no significant increase in the number of users connected to district heating system and no significant change in the amount and type of energy generating products used in district heating plants in Niš. The immission concentrations for the most adverse meteorological conditions have been calculated by the analysis of all 13 heat generating sources in Niš. The software package Screening air dispersion model (SCREEN) has determined that in 5 heat sources, there has been an exceeding limit values of emissions and in district heating plants, "Krivi Vir," "Sombor", "Pantelej", "Car Uroš", and "Čair". The results of the measured immission concentrations show that the maximum immission concentrations are mostly in the area of urban residential areas.

Table 5. Quantity of emitted pollutants measured by emission factor during coal consumption in district heating plants in Niš

Year	kg of emitted pollutant per 1000 kg of coal				
	HCHO	CH_4	NO_x	SO_X	CO
1994/95	0.480	1,097.5	878.0	10,234.485	5,487.4
1995/96	0.539	122.18	977.8	12,666.312	6,110.9
1996/97	–	–	–	–	–
1997/98	0.056	1,264.09	1,011.3	11,788.164	6,320.5
1998/99	0.526	1,192.7	954.2	11,121.939	5,963.3

Table 6. Quantity of emitted pollutants measured by emission factor during natural gas consumption in district heating plants in Niš

Year	kg of emitted pollutant per m^3 of gas					
	HCHO	CH_4	NO_x	SO_2	SO_3	CO
2003/04	984.336	5,343.54	175,493.1	582,839.589	8,971.521	43.659
2004/05	1,124.545	6,104.677	200,490.407	665,859.49	10,249.42	49.878

Table 7. Quantity of emitted pollutants measured by emission factor during heating oil consumption in district heating plants in Niš

Year	kg of emitted pollutant per m^3 of heating oil				
	HCHO	NO_x	SO_2	SO_3	CO
1994/95	53.955	1,939.687	6,767.77	86.326	53.955
1995/96	82.27	2,957.868	9,778.44	131.64	82.27
1996/97	–	–	–	–	–
1997/98	88.42	3,178.736	11,090.945	141.474	88.42
1998/99	82.62	2,970.206	10,363.362	132.193	82.62
1999/00	73.126	2,628.891	9,172.478	9,172.478	73.126
2000/01	91.405	326.025	11,465.29	11,465.289	91.405
2001/02	135.27	4,862.97	16,967.43	16,965.79	135.27
2002/03	148.03	5,321.733	18,568.08	18,568.087	148.03
2003/04	67.173	2,414.908	8,425.87	8,425.056	67.173
2004/05	53.091	1,908.626	6,659.396	6,659.396	53.091

District heating in the area of Niš with limit-exceeding emission values

The largest urban district heating plant "Krivi Vir" is located in one of the most densely populated residential areas. It has three sources of emissions and boiler capacity of 127.8 MW. For heat generation, this plant uses natural gas. The position of this district heating system and energy sources is shown in fig. 1.

Immission concentration has been calculated according to the data about the current emission concentrations from heat sources of the district heating plant "Krivi Vir" in January 2009 (tab. 8). The immission concentrations have been calculated by the screening air dispersion model (SCREEN), and their distribution are represented in figs. 2 to 10.

Figure 1. District heating plant "Krivi vir" (full white boundary), its heat source and the surrounding residential area (dashed white boundary)

Therefore, it can be concluded that the maximum immission concentrations at the ground level in the most adverse weather conditions are formed at a distance of 100 m to 200 m from the emitting source of the district heating plant "Krivi Vir". The heat sources of the plant can have a significant impact air quality in the residential area near the plant. Measured emission concentrations, particularly nitrogen oxides, and the calculated maximum immission concentrations (tab. 9) from another energy source in the plant can be considered high (tab.

8). According to the applicable legislation of the Republic of Serbia, the limit value for immission concentration of nitrogen dioxide during one hour is 150 μg/m^3. Therefore, it can be concluded that the maximum immission concentration of nitrogen dioxide from the second source (223.6 μg/m^3, fig. 6) may affect both the health of the exposed population and the air quality field. The air quality category in this area is "unsatisfactory". The *HQ* at four hour exposure during the day is 1.70 for the population over 18, and 4.76 for children under 10. According to the obtained health quotient index, an area under the influence of maximum nitrogen dioxide concentrations is the area of health risk. Part of the population over 18 has significant health risk, while children under 10 have extremely high health risk.

Table 8. Emission concentrations of pollutants emitted by district heating plant "Krivi Vir" in Niš

Measured emission concentartion [mgm^{-3}]			
Sulphur dioxide (SO_2)	Carbon monoxide (CO)	Nitrogen oxides (NO_x)	Methane (CH_4)
The first energy source			
1.0	–	181.5	10.67
The second energy source			
–	2	456	2
The third energy source			
–	9	3	2

Table 9. Maximum one hour immission concentrations at the ground level [μgm^{-3}]

Distancefrom the source [m]	Sulphur dioxide (SO_2)	Carbon monoxide (CO)	Nitrogen oxides (NO_x)	Methane (CH_4)
The first energy source				
100	0.5523	–	78.53	4.660
The second energy source				
100	–	3.587	223.6	2.916
The third energy source				
258	–	0.4310	0.1418	$0.9301 \cdot 10^{-1}$

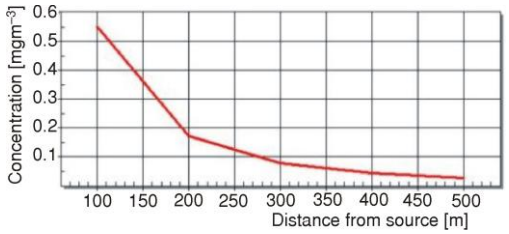

Figure 2. One-hour immission concentrations of SO_2 from the first energy source

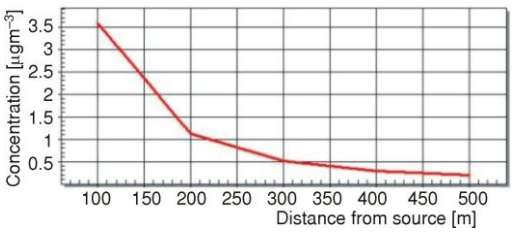

Figure 3. One-hour immission concentrations of CO from the second energy source

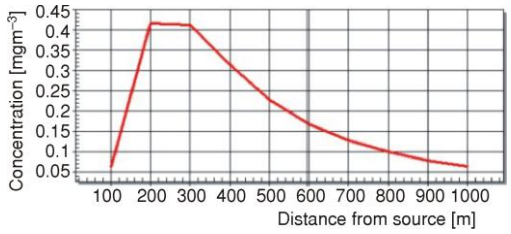

Figure 4. One-hour immission concentrations of CO from the third energy source

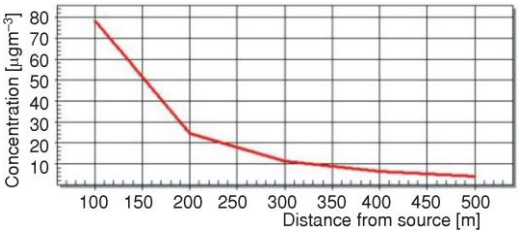

Figure 5. One-hour immission concentrations of NO_x from the first energy source

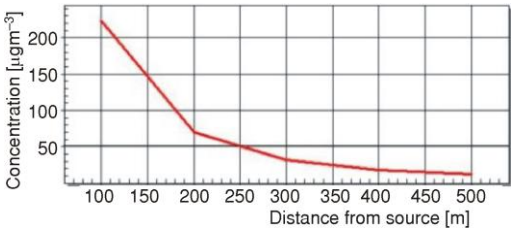

Figure 6. One-hour immission concentrations of NO_x from the second energy source

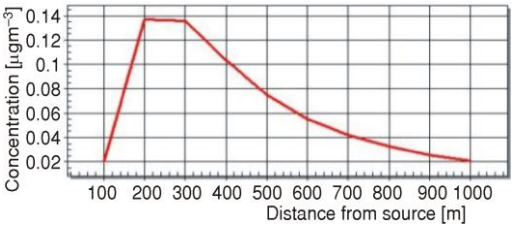

Figure 7. One-hour immission concentrations of NO_x from the third energy source

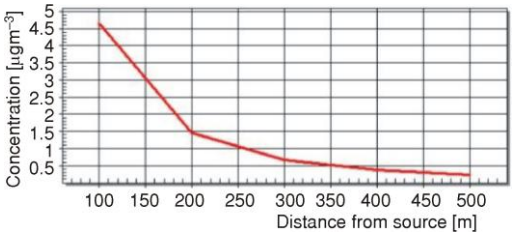

Figure 8. One-hour immission concentrations of CH_4 from the first energy source

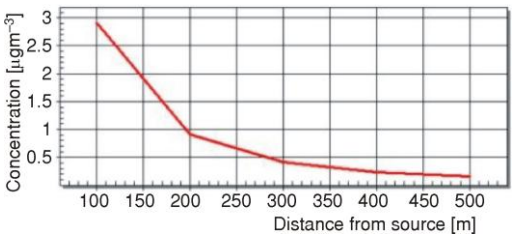

Figure 9. One-hour immission concentrations of CH_4 from the second energy source

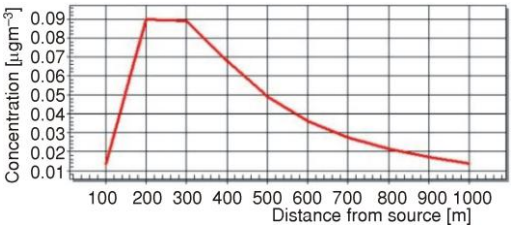

Figure 10. One-hour immission concentrations of CH_4 from the third energy source

The district heating plant "Somborska" is located northeast of the city center, in a densely populated residential area. The heat source of this plant is 25 m high. The source is located on the north wall of a residential building (fig. 11). This heat source is connected to the boiler with installed capacity of 5.4 MW, which uses heating oil. The position of the district heating plant and its energy-generating source is presented in fig. 11. Table 10 provides an overview of the measured emission concentration of pollutants.

Calculated, maximum ground concentrations that occur 100 meters from the source of transmission (tab. 11). The concentrations are rapidly declining, if the distance from the emitting source is bigger, as shown in the diagrams (figs. 12 to 15).

Figure 11. District heating plant "Somborska", its heat source, and the surrounding residential area (dashed white boundary)

Table 10. Emission concentrations of pollutants emitted by the district heating plant "Somborska" in Niš

Measured emission concentrations from two boilers [mg/m^3]			
Sulphur dioxide (SO_2)	Carbon monoxide (CO)	Nitrogen oxides (NO_x)	Methane (CH_4)
3200	20	754.33	14

Table 11. Maximum one hour immission concentration at the ground level [μgm^{-3}]

Distance from the source [m]	Sulphur dioxide (SO_2)	Carbon monoxide (CO)	Nitrogen oxides (NO_x)	Methane (CH_4)
100	388.4	23.96	183.6	23.96

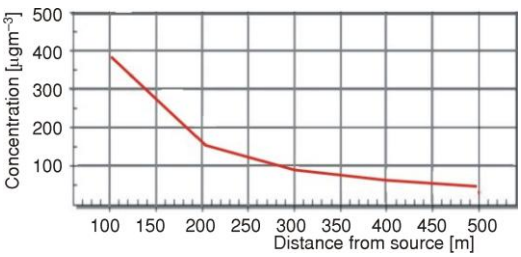

Figure 12. One hour immission concentrations of SO_2 from the heat source "Somborska".

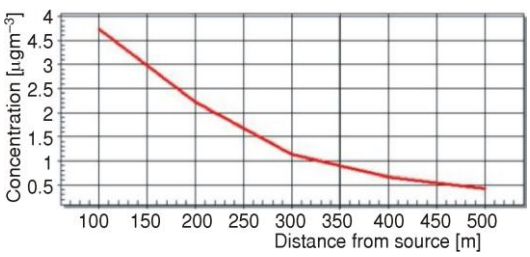

Figure 13. One hour immission concentrations of CO from the heat source "Somborska".

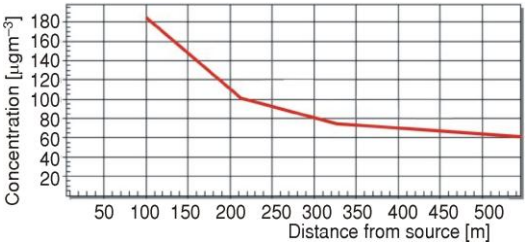

Figure 14. One hour immission concentrations of NO_x from the heat source "Somborska"

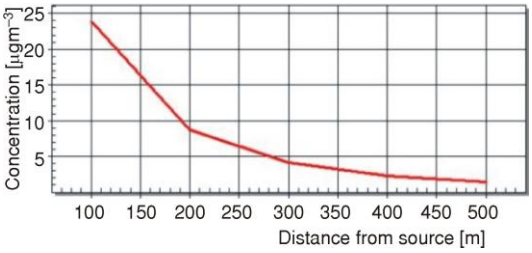

Figure 15. One hour immission concentrations of CH_4 from the heat source "Somborska"

Taking into account that the eastern wind with the annual frequency of 89.75% is the second most common wind in Niš, the emitted concentration of pollutants can have significant influence on the health of the exposed population west of the emitter. According to the Serbian legislation, the limit immission value SO_2 concentration is 350 μg/m^3, while calculated maximum SO_2 immission concentration at 100 m distance from the emitter is 388.4 μg/m^3.

Comparing the above-mentioned value of immission concentrations with immission limit values, it can be concluded that the calculated immission concentration of SO_2 and NO_x during one-hour period is above the immission limit values. The air quality is in the category of "unsatisfactory" which raises the need for continuous monitoring of concentrations of these substances. The health quotient index for maximum one-hour immission concentration of SO_2 and NO_x for children under 10 is 3.54. The area in which the group of the population is exposed to maximum immission concentration of SO_2 and NO_x is in the zone of high health risk.

The health quotient index for people over 18 is 1.27. This value indicates that people who are over 18 are exposed to a moderate health risk.

City district heating plant "Pantelej" with its 25 m high heat source is connected to two active boilers of installed capacity 0.58 MW. This plant is using fuel oil (S) and it supplies heat to small residential blocks. The position of this district heating unit and its heat source is shown in fig. 16.

Table 12 provides an overview of emission concentrations for January 2009, while the results of the calculated immission concentrations of pollutants are presented in the diagrams (fig. 17 to 20), and in tab. 13.

Table 12. Calculated emmission concentrations of pollutants emitted from district heating plant "Pantelej" in Niš

Average emmission concentrations from two boilers [mgm^{-3}]			
Sulphur dioxide (SO_2)	Carbon monoxide (CO)	Nitrogen oxides (NO_x)	Methane (CH_4)
3452.33	47.67	766.83	57.5

Table 13. Calculated maximum immission concentrations at the ground level during one hour [μgm^{-3}]

Distance from the source [m]	Sulphur dioxide (SO_2)	Carbon monoxide (CO)	Nitrogen oxides	Methane
89	312.5	5.208	182.3	6.511

Figure 16. Public district heating utility company "Pantelej" and its heating source

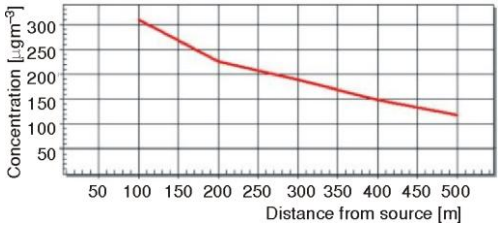

Figure 17. One-hour immission concentrations of SO_2 from the district heating plant "Pantelej"

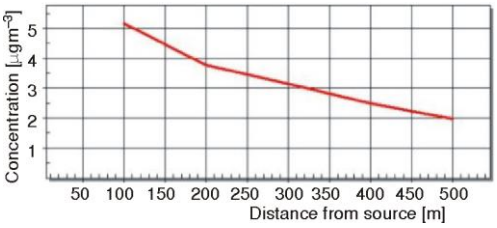

Figure 18. One-hour immission concentrations of CO from the district heating plant "Pantelej"

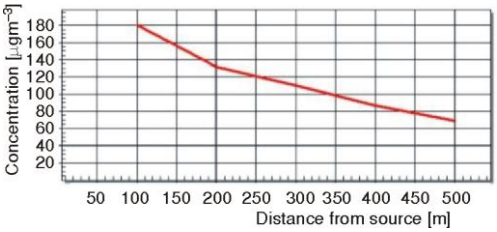

Figure 19. One-hour immission concentrations of NO_x from the district heating plant "Pantelej"

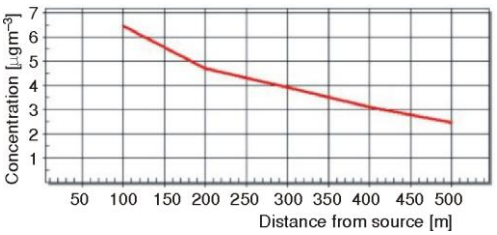

Figure 20. One-hour immission concentrations of CH_4 from the district heating plant "Pantelej"

Taking into consideration that the measured immission concentrations of SO_2 and NO_x are high as well as their immission concentrations (tab. 12), the category of air quality in the immediate vicinity of the district heating unit "Pantelej" is in the category of "unsatisfactory" and it affects the health of the exposed population. Children under 10 are exposed to high health risk, which has been confirmed by the fact that the hazardous health quotient is 3.88. Part of the population over 18 is exposed to moderate health risk. The hazardous health quotient is 1.38.

One of the urban district heating units "Car Uroš" is located in the southwest of the city, its energy source is 20 m high and it has two boilers with installed capacity of 0.75 MW and 0.90 MW (fig. 21).

Figure 21. District heating plants "Car Uroš" and "Obilićev Venac" and the position of the elementary school "Dositej Obradović" (dashed white boundary)

For generating heat, this plant uses fuel oil (S). Combustion of fuel emits pollutants, whose emission concentrations were measured in March 2009, are given in tab. 14. Ground immission concentrations whose values are shown in the diagrams (figs. 22 to 25) have been calculated in the most adverse weather conditions. The maximum immission concentrations are given in tab. 15.

Table 14. Emission concentrations of pollutants emitted by the district heating plant "Car Uroš" in Niš

Average emmission concentrations from two boilers [mgm^{-3}]			
Sulphur dioxide (SO_2)	Carbon monoxide (CO)	Nitrogen oxides (NO_x)	Methane (CH_4)
3,433.33	33.33	661	69.33

Table 15. Maximum one hour immission concentrations at the ground level [μgm^{-3}]

Distance form the heat source [m]	Sulphur dioxide (SO_2)	Carbon monoxide (CO)	Nitrogen oxides (NO_x)	Methane (CH_4)
88	351.4	3.799	185.1	7.425

Maximum ground concentrations of pollutants appear at a distance of 88 m from the heat source. Sulfur-(IV)-oxide and nitrogen oxides immission concentrations during the period of one hour are above the immission limit value (ILV), and the air quality is in the category "unsatisfactory". For this reason, the measurement site for monitoring immission concentrations of pollutants has been placed near the school. According to the monitored immission concentrations at the measurement site Dositej Obradović, hazardous health quotient for maximum one-hour concentration of SO_2 is 1.16 for the population over 18, and 3.21 for children under 10. Likewise, the hazardous health quotient for maximum NO_x immission concentrations is 1.40 among the population over 18, and 3.93 for children under 10. The exposed population over 18 is faced with moderate health risk, while younger population is faced with high health risk. The distribution of pollutants emitted from the heat source of the heating plant "Car Uroš" is represented by the diagrams in figs. 22 to 25.

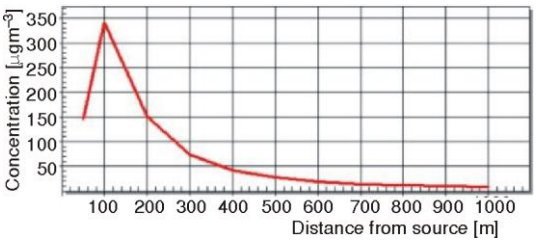

Figure 22. One-hour immission concentrations of SO_2 from the district heating plant "Car Uroš"

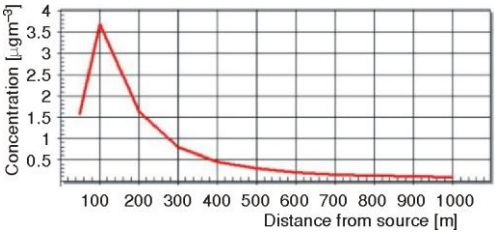

Figure 23. One-hour immission concentrations CO from the district heating plant "Car Uroš"

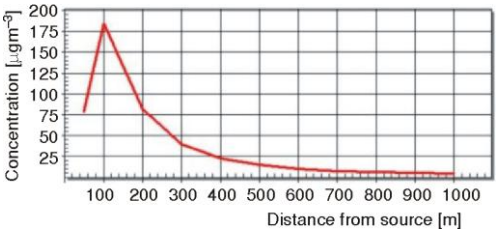

Figure 24. One-hour immission concentrations of NO_x from the district heating plant "Car Uroš"

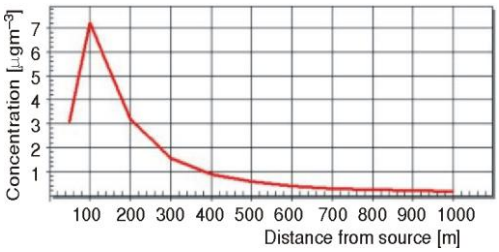

Figure 25. One-hour immission concentrations CH_4 from the district heating plant "Car Uroš"

The sports and recreation complex "Čair", south of the city stadium has a 32-meter high district heating unit, with two boilers with total installed capacity of 2.5 MW. About 100 m southeast of the city heating plant, there are single-storey residential houses and a children's play area (fig. 26).

Figure 26. Public utility company – district heating plant "Čair"

According to the calculated immission concentrations at the ground level, as shown in figs. 27 to 30, it can be concluded that the heat source of the district heating unit "Čair" can significantly affect the air quality in the immediate surrounding. Calculated immission concentrations of pollutants given in the table are based on the middle emission levels of pollutants from both boilers. Maximum immission concentrations occur at a distance of 127 m from the heat source and NO_x concentrations are the highest. On the basis of the measured emission concentration (tabs. 16 and 17) in March 2009, immission concentrations of pollutants from the heat source of the district heating plant "Čair" is shown in figs. 27 to 30.

Table 16. Emission concentrations of pollutants emitted by the district heating plant "Čair" in Niš

Average emission concentrations from two boilers [mgm^{-3}]			
Sulphur dioxide (SO_2)	Carbon monoxide (CO)	Nitrogen oxides (NO_x)	Methane (CH_4)
2932	15.6	541.33	51.33

Table 17. Measured maximum one hour immission concentrations at the ground level [μgm^{-3}]

Distance form the heat source [m]	Sulphur dioxide (SO_2)	Carbon monoxide (CO)	Nitrogen oxides (NO_x)	Methane (CH_4)
127	158.1	0.8342	158.1	1.147

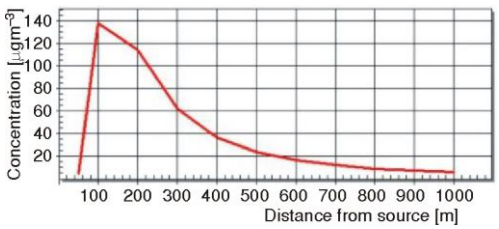

Figure 27. One-hour immission concentrations of SO_2 from the district heating plant "Čair"

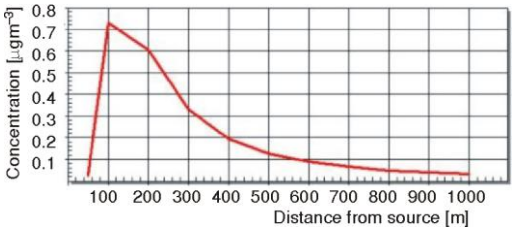

Figure 28. One-hour immission concentrations of CO from the district heating plant "Čair"

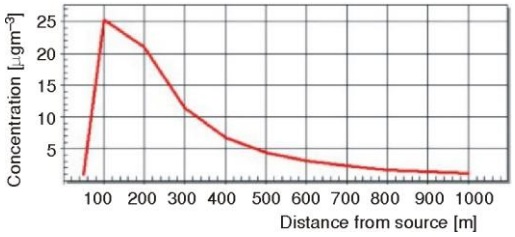

Figure 29. One-hour immission concentrations of NO_x from the district heating plant "Čair"

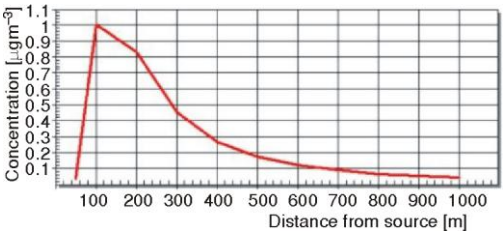

Figure 30. One-hour immission concentrations of CH_4 from the district heating plant "Čair"

Emission concentrations of NO_x generated from one of the boilers exceed the emission limit values, and it can be concluded that the air quality in that area is "unsatisfactory". Also, there is a possibility for higher emission concentrations due to incomplete combustion of fuel oil in adverse weather conditions. Hazardous health quotient for NO_x immission concentration during one hour is 1.20 for people over 18 and 3.36 for children under 10. According to the hazardous health quotient, it can be concluded that there is a moderate health risk among the population over 18 and a high health risk among the population under 10. In the immediate vicinity of the heating source "Čair", there is one of the measurement sites for air quality monitoring in the city of Niš.

Soot immission and health risk assessment

The method of radial basis function (RBF) has been used for the assessment of air quality and territorial health risk, in the areas where measurement of pollutant concentrations had not been carried out. The method of RBF was used to predict the immission concentration and determine the air quality field in relation to the calculated values of the air quality index.

Determination of the air quality field has been carried out according to the data about the emission concentration of certain pollutants and transmission of these pollutants into the atmosphere. In this paper, predicting immission concentrations has been carried out by means of RBF network. The process of pollutant transmission in the atmosphere is complex (it includes transportation, transformation, and deposition), and prediction of the immission concentrations according to emission concentration requires certain meteorological data, topography of the territory, physical and chemical transformation of pollutants, as well as, their diffusion and deposition. The researchers Stevanović, *et al.* [10] have investigated these issues in detail.

Predicting the immission concentration by means of RBF network is simpler, and the results obtained by such analysis are satisfactory. Application of the RBF network in predicting the immission concentration is based on the statistically processed immission concentrations that are being monitored on the analyzed territory of the city. The maximum absolute error that can occur while determining the air quality field, and making air quality maps in the city of Niš for the period 1995-2008 is 10^{-4} or less. The model used for mapping air quality by means of RBF network was defined by the number of inputs and hidden neurons, and it proved to be suitable for the subject analysis [11-14].

The legislation of the Republic of Serbia has not defined the rules for monitoring particulate matter that are below 5 μm in diameter. In order to determine the relationship between the particles from the above mentioned district heating plants, air quality and the

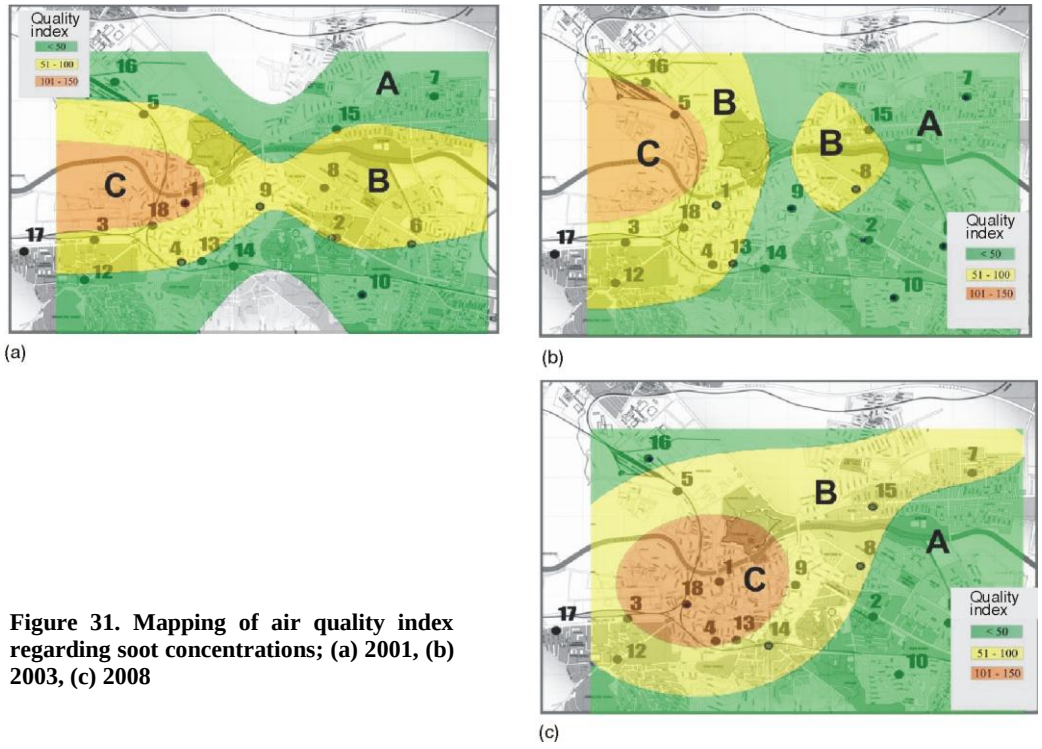

Figure 31. Mapping of air quality index regarding soot concentrations; (a) 2001, (b) 2003, (c) 2008

health risk, mapping the air quality influenced by measured immission concentrations of soot particles has been carried out by means of RBF network. The air quality index and the probability of carcinogenic risk have also been determined. Between 2001 and 2009, there was an increase of soot concentration in the area of Niš. The field of air quality was determined by the method of radial network basis function. Maps of the air quality fields are given in fig. 31. Since soot is considered to be a cancerous substance, there is the probability of cancer risk among the population exposed to it four hours a day. Air quality field is in the category "good", if the air quality is less than 50. This field is represented in fig. 31 as field A, and is characterized by immission concentrations below the immission limit values. Therefore, the population exposed to these concentrations does not suffer from health risk. Air quality field in the category "moderately good" (field B) is presented in fig. 31, and includes

the surrounding of the plants that have been analyzed. Air quality index within this air quality field ranges from 51 to 100, while the probability of total carcinogenic risk ranges from $3.56 \cdot 10^{-6}$ to $1.5 \cdot 10^{-5}$. Air quality field in the category "unsatisfactory" (field C) is presented in fig. 31, and it includes the area of the analyzed plants. Air quality index within this air quality field ranges from 101 to 150, and the probability of total carcinogenic risk is from $1.51 \cdot 10^{-5}$ to $2.35 \cdot 10^{-5}$.

Conclusions

According to the results of the research, the following conclusions can be made.

- Qualitative and quantitative assessment of air quality has been carried out by the appropriate scientific methods: the method of causal analysis, statistical method and radial basis function method.
- The immission concentrations for the most adverse weather conditions have been calculated by the analysis of 13 district heating units in Niš, using the software package Screening air dispersion model (SCREEN). The results of the calculated immission concentrations show that the maximum concentrations at the ground level are mostly in the urban residential areas. In cases where the calculated one-hour concentrations are above the immission limit values (ILV), hazardous health quotient ranges from 1.27 to 1.70 for the population over 18, whereas it ranges from 3.54 to 4.76 for the population under 10.
- A linear relationship between emission and immission concentrations cannot be established by the analysis of emission and immission concentrations which are the consequence of fuel oil combustion in the district heating plants in Niš. The level of immission concentrations is not only influenced by emission concentration, but also by a set of different parameters (air temperature, air velocity, built areas, *etc*.).
- Prediction of immission concentrations of soot particles by means of radial basis function (RBF) network has proven to be simpler and more convenient than the application of the methods based on emission concentrations. Therefore, the results obtained are at a high level of reliability. The application of RBF network for predicting emission concentrations is based on statistical analysis of the measured immission concentrations of soot particles on the analyzed territory, with a maximum absolute error up to 10^{-4}. Concentrations of soot particles are higher in the areas near the major district heating plants, in comparison to the areas unaffected by heat sources. The analysis of the maps of air quality fields indicates that the air quality fields which are considered to be health risk areas are usually formed under the influence of dominant northwest and east winds.
- According to the measured emission concentrations of pollutants from urban heating plants in Niš (involving a 27-year period), it can be concluded that large amounts of SO_2 and NO_x are emitted to the air during the heating season.

Nomenclature

C – concentration [mgm^{-3}]
$E_{i,x,y}$ – exposure [$mgkg^{-1}$ per day]
IR_y – breathing rate at rest per unit of time for an individual in a subgroup y in the environment i [m^{-3} per day]
SF_x – slope factor or increased cancer risk from a lifetime exposure to a pollutant x, [$mgkg^{-1}$ per day]

Acronyms

BRF – radial basis function
HQ – hazardous healt quotient
ILV – immision limit value
PM – particulate matter
US EPA – U. S. A. Environmental Protection Agency

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