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DETERMINATION OF HEALTH RISK ZONES FROM AIR POLLUTION IN THE CITY OF NIŠ CAUSED BY THE PRESENCE OF SOOT WITH THE USE OF THE RBF NEURAL NETWORK

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Abstract. *This paper determines and presents the health risk zones in relation to the concentration of soot particles present in the ambient air of the city of Niš for the analyzed period from 1995 to 2011. The originality of the method applied in this paper for assessing territorial health risks lies in predicting the concentration of soot particles in the ambient air of Niš. The prediction of the concentration of soot particles was conducted using the RBF (Radial Basis Function) neural network. So far, prediction of the concentration of pollutants in the ambient air was based on the knowledge of emission concentrations of pollutants by certain polluters, as well as on the knowledge of transmission of pollutants in the atmosphere. Given that the transmission of pollutants in the atmosphere is a complex process, prediction of concentrations in the ambient air based on emission concentrations requires knowledge of meteorological data, terrain topography, physical and chemical transformations of pollutants, and their diffusion and deposition. For these reasons, application of the RBF neural network is simpler, while the results are satisfactory. The maximum absolute error when determining health risk zones on the territory of Niš using the RBF neural network is 10-4 or less. For the analyzed period of time between 1995 and 2011, health risk zones in the city of Niš with values of soot concentrations exceeding the allowed limits were found in 2001, 2002, 2003, 2008, 2009, 2010 and 2011. The value of the total carcinogenic risk in these years, in the health risk zones, ranged from 3.57·10-6 to 3.30·10-5. The values of the total carcinogenic risk were determined as the product of the population's exposure to concentrations of soot particles and the coefficient of carcinogenicity.*

Key words: *health risk, health risk zone, soot, radial basis functions, total cancer risk*

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1. Introduction

Numerous epidemiological and toxicological studies have shown that certain effects of air pollutants individually or collectively affect the occurrence of acute or chronic diseases in the exposed human population.

Figure 1 shows schematically the causal connection between exposure, health effects, and health risks. For a full understanding and assessment of health risks, it is necessary to monitor air pollutants from their point of origin, through chemical transformations in the atmosphere, exposure, and biological effects, to the occurrence of adverse health effects (Figure 1).

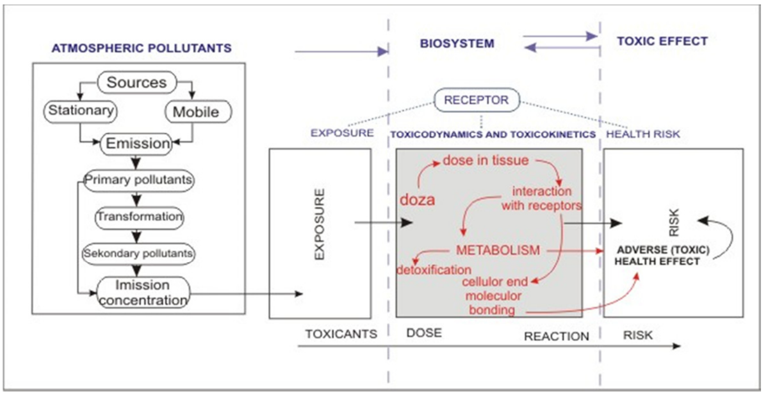

Fig. 1 The causal relationship between exposure, health effects, and health risks

The subject of this paper is the monitoring of the presence of soot particles in the city of Niš, and their impact on the probability of health risk or occurrence of cancerous diseases.

Soot represents carbon particles impregnated with tar that originate in the process of incomplete combustion of carbon-based fuel substances. The chemical composition of soot particles includes organic and inorganic substances. Organic substances such as benz-pyrene, benzanthracene, pyrene, fluoranthene, chrysene, et al. have a carcinogenic effect. In addition to organic substances (tar), soot particles contain inorganic acids, of which sulphuric acid is the most prominent.

The diameter of a soot particle can be around 0.1 μm. Because of their size, soot particles have a low rate of sedimentation. In certain conditions, small particles can combine and usually form particle ca. 5 μm in size.

2. The Method

Health risk is defined as the likelihood of adverse effects to human health, depending on exposure, concentrations, and the activity interval of a particular agent from an environmental medium (air, water, soil) under real conditions.

To assess long-term carcinogenic effects due to exposure to air pollutants, a potentially increased risk of cancerous disease occurrence can be determined as the product of exposure and the carcinogenicity coefficient, which is established for every carcinogenic pollutant. Potentially increased risk of getting cancer for an individual subgroup *y* (healthy adults, sick individuals, children, senior citizens) from exposure to pollutants *x* is:

$$ICR_{i,x,y} = E_{i,x,y} \cdot SF_x \tag{1}$$

where: ICR$_{i,x,y}$ – is the probability of risk from carcinogenic diseases for an individual *y* under the influence of pollutant *x* in an environment; SF$_x$ – the carcinogenicity coefficient for pollutant *x* [mg/kg/day]; E$_{i,x,y}$ – exposure, or average intake of pollutant *x* over time, for a representative individual *y* in the studied subgroup in an environment *i* [mg/kg/day].

Exposure is calculated by the equation:

$$E_{\mathrm{i,x,y}} = 0{,}001 \cdot \mathrm{C}_{\mathrm{i,x}} \left(\frac{IR_y}{BW_y} \right) \left(\frac{ED_i \cdot ET_i \cdot EF_i}{AT_x} \right), \tag{2}$$

where: C$_{i,x}$ – is the concentration of pollutant *x* in an environment *i* [mg/m^3], IR$_y$ – breathing rate at rest per unit of time for the representative individual in subgroup *y* in an environment *i* [m^3/day]; ET$_i$ – exposure time of a representative individual in environment *i* [days/year]; BW$_y$ – weight of a representative individual in the corresponding subgroup shown as *y* [kg]; ED$_i$ – time of exposure of a representative individual in an environment *i* [years]; and AT$_x$ – the average time of impact by pollutant *x* [days].

The concentration of pollutants in the air affects air quality, which is directly related to the occurrence of health risk in the exposed population. Table 1 shows the relation between soot particle concentration and the air quality category.

Table 1 Relation of mean annual concentrations of soot particles and air quality categories.

Soot concentration [μg/m^3]	Air quality category
0.0-11.80	Good
11.81-50.00	Moderately good
50.01-77.77	Unfavorable
77.78-105.00	Highly unfavorable
105.56-209.72	Bad
Above 209.73	Very bad

We mapped the air quality for the city of Niš by using the radial basis function (RBF) neural network. The radial basis function (RBF) neural network is a multi-character neural network, a universal functionally approximated value that is widely used for various applications, such as form recognition or control, identification, and prediction of nonlinear dynamic systems. It is a structurally flexible network for determining embedded dimensions and realizing the desired mapping between given and predicted values.

The originality of the method used in this study for the assessment of air quality and territorial health risk lies in the prediction of pollutant concentrations over the whole analyzed area, based on statistically analyzed and measured concentrations in individual points in space by using the RBF neural network, which represents a mapping of air quality.

3. Results and Discussion

The annual mean concentrations of soot observed in Niš between 1995 and 2000 did not exceed 50 [$\mu g/m^3$] and the fields of air quality predicted by the RBF neural network did not represent significant health risk zones.

Between 2001 and 2011, there was an increasing trend of soot concentration in Niš. By using the RBF neural network method, we determined fields of air quality. This paper particularly analyzes fields of air quality that were also health risk zones in 2001, 2002, and 2008. Since soot falls into the category of confirmed carcinogenic chemicals, we calculated the probability of a carcinogenic risk by applying equations 1 and 2, based on the assumption that the population in certain zones is exposed for 4 hours a day. At the six measuring points: 1, 2, 4, 6, 9, and 10 (Figure 2), which were part of a monitoring network for air quality, the measured concentrations in 2001 were not high, but the distribution of sampling locations enabled us, by using the RBF neural network, to determine the fields of air quality, which represent potential health risk zones. The field of air quality in the category "extremely unfavorable" with concentrations ranging from $77.78\mu g/m^3$ to $79.84\mu g/m^3$ is designated for the western part of the city of Niš (part of the map highlighted red, Figure 2). As this field includes a small area and is not inhabited, the calculation of the probability of carcinogenic risk was not done.

The second predicted field of air quality is in the quality category "unfavorable" (part of the map highlighted orange, Figure 2). The calculated value of the air quality index that characterizes the field in the "unfavorable" category contains soot concentrations ranging from $50.01\mu g/m^3$ to $77.77\mu g/m^3$. For the field of air quality in the "unfavorable" category, we calculated the probability of the total carcinogenic risk, which is in the range from $1.51 \cdot 10^{-5}$ to $2.35 \cdot 10^{-5}$, meaning that 1-2 in every 100.000 exposed people could fall ill.

By applying the RBF neural network method, we predicted the field of air quality in the category "moderately good" (part of the map highlighted yellow, Figure 2) and the calculated value of the total carcinogenic risk ranges from $3.56 \cdot 10^{-6}$ to $1.5 \cdot 10^{-5}$. The field of air quality predicted in the "good" category (part of the map highlighted green, Figure 2) is not a potential carcinogenic risk zone. This field spreads symmetrically to the north and south of the city around the field of air quality in the "moderately good" category.

To assess air quality in 2002, we used information about the annual mean soot concentrations, monitored at eight measuring points: 1, 2, 6, 7, 8, 9, 10, and 13. For an area in the western part of the city, where there were no measuring points, we predicted a field of air quality in the category "unfavorable" by using the RBF neural network (part of the map highlighted orange, Figure 3). Concentrations of soot in this field ranged from $50.01\mu g/m^3$ to $58.43\mu g/m^3$ and the calculated total carcinogenic risk as a probability ranged from $1.57 \cdot 10^{-5}$ to $1.84 \cdot 10^{-5}$. Another designated field of air quality in the "moderately good" category in the 2002 season is similar in form and occupied an area next to the field of air quality designated in the 2001 heating season (part of the map highlighted yellow, Figure 3). Concentrations of soot within this field ranged from $11.81\mu g/m^3$ to $50\mu g/m^3$. The total calculated carcinogenic risk for the exposed population in the territory thus defined ranged from $3.71 \cdot 10^{-6}$ to $1.57 \cdot 10^{-5}$.

The third predicted field of air quality is in the "good" category.

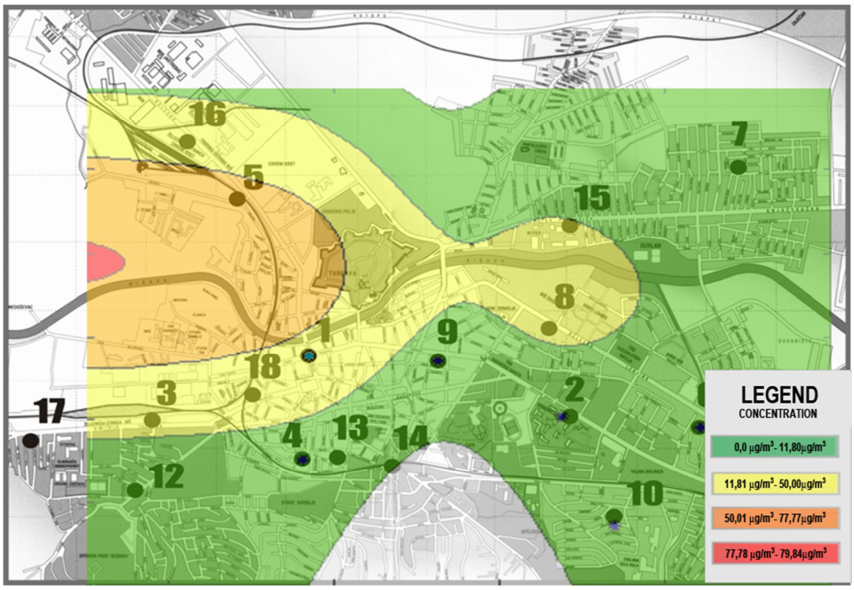

Fig. 2 Map of air quality on an annual basis in relation to soot in 2001

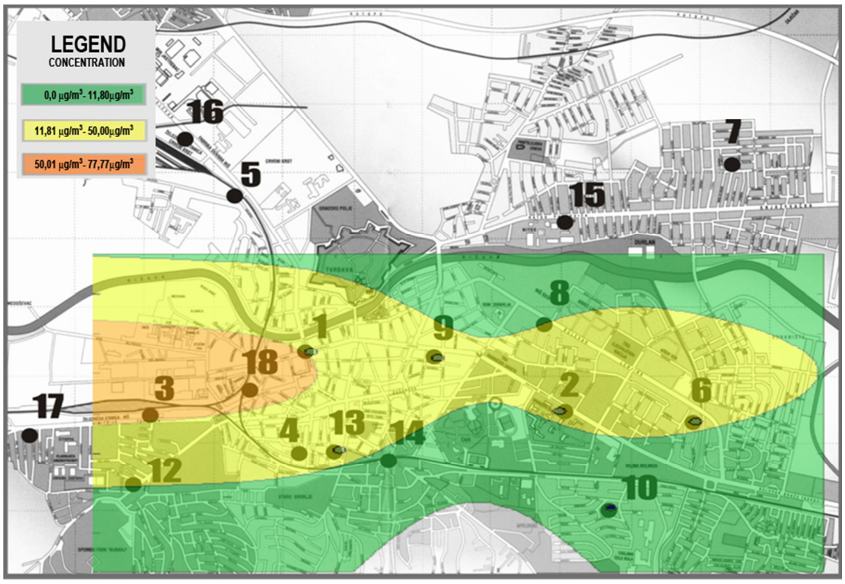

Fig. 3 Map of air quality in relation to soot in 2002

Analyzing the annual mean concentrations of soot in 2003, monitored at the same measuring points as in 2002, we predicted an air quality field in the western part of the city in the category "unfavorable" (part of the map highlighted orange, Figure 4). Concentrations of soot within this field from 50.01μg/m^3 to 58.92μg/m^3 cause the probability of total annual carcinogenic risk in the range from $1.51 \cdot 10^{-5}$ to $1.78 \cdot 10^{-5}$. We predicted two independent fields of air quality in the category "moderately good" (part of the map highlighted yellow, Figure 4). The value of the air quality index, which is in the "moderately good" category for both fields, ranged from 11.81μg/m^3 to 50.00μg/m^3, and the total probability of carcinogenic risk ranged from $3.71 \cdot 10^{-6}$ to $1.56 \cdot 10^{-5}$.

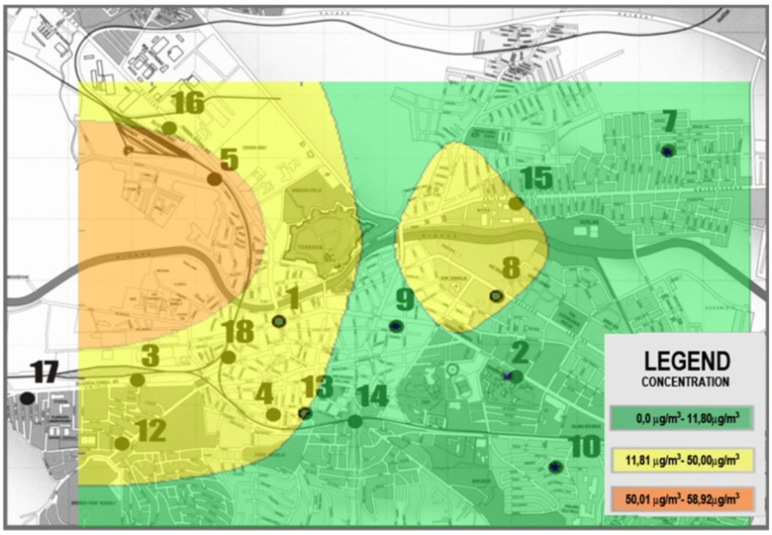

Fig. 4 Map of air quality in relation to soot in 2003

Fields of air quality designated in 2008 by use of the RBF network and based on monitored concentrations at measuring points 8, 14, 15, 16, 17, and 18 show a potential carcinogenic risk. An analysis of the map of air quality fields in relation to the annual concentrations of soot leads to the conclusion that a broader central part of the city represents a potential health risk zone. This zone includes the field of air quality that is in the "unfavorable" category, with concentrations ranging from 50.01μg/m^3 to 66.84μg/m^3 (part of the map highlighted orange, Figure 5). The exposed population within this field is subject to the probability of total carcinogenic risks with values ranging from $1.51 \cdot 10^{-5}$ to $2.02 \cdot 10^{-5}$. The predicted field of air quality in 2008 is in the "moderately good" category compared to the annual mean concentrations (part of the map highlighted yellow, Figure 5) and the probability of total carcinogenic risk ranges from $3.56 \cdot 10^{-6}$ to $1.5 \cdot 10^{-5}$. The eastern part of the city, the southernmost part of the city, and a small area in the north-western part of the city (north-western part of the industrial zone) fall in the "good" category of air quality and do not constitute health risk zones.

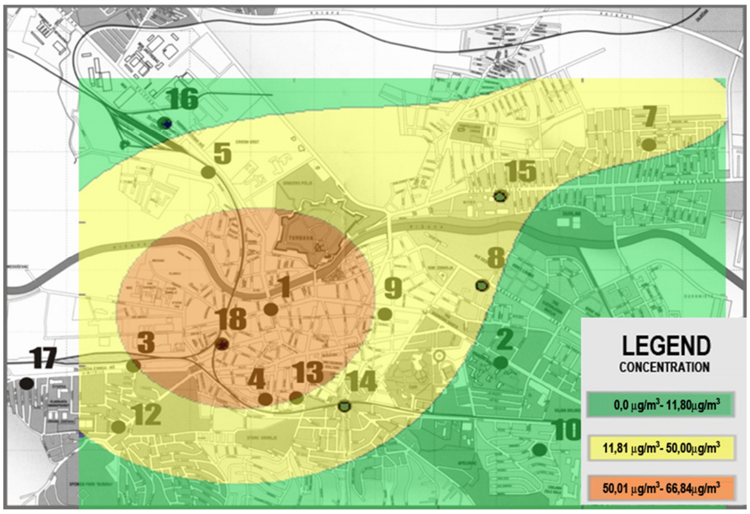

Fig. 5 Map of air quality in relation to soot in 2008

In 2009 and 2010, there was an increase in the concentration of soot in Niš. By using the RBF network, the mapping of air quality for the entire area of city of Niš was carried out, based on the measured concentration at the measuring points 1 2 8 14. 15. 16. 17 and 18. In the city there are 4 fields of air quality which are in the "good", "moderately good", "unfavorable" and "very unfavorable" categories (Figure 6 and 7), with concentrations in the range given in the table 1. Based on air quality field analysis, it can be concluded that in the southwestern part of the city, two zones of health risk can be found. One zone has a probability of total carcinogenic risk in the range from 2.36 to 3.17 10^{-5} (part of the map colored red, Figure 6 and 7) and another zone has a probability of total carcinogenic risk from 1.52 to 2.35 10^{-5} (part of the map colored orange, Figure 6 and 7). The central part of the city, as the northern and eastern part of the city is in the area of health risks in which the probability of total carcinogenic risk is lower, ranges from 3.56 to 1.51 10^{-5}.

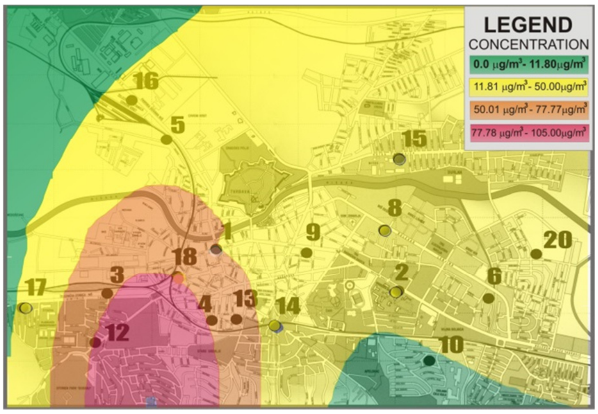

Fig. 6 Map of air quality in relation to soot in 2009.

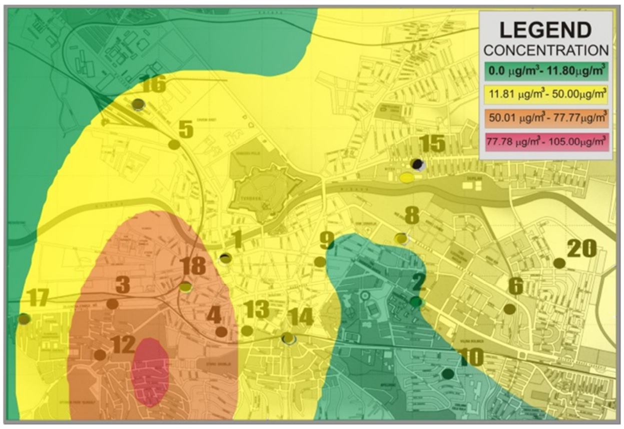

Fig. 7 Map of air quality in relation to soot in 2010.

In 2011 (Fig. 8), there was a slight decrease in the concentration of soot and the formation of two health risk zones with values of total carcinogenic risk from 3.57 10^{-6} to 1.51 10^{-5} (colored yellow) and from 1.52 10^{-5} to 2.19 10^{-5} (colored orange). Air quality in 2011 was very similar to the air quality which is designated for the analyzed area of the city of Nis in 2002, 2003 and 2008.

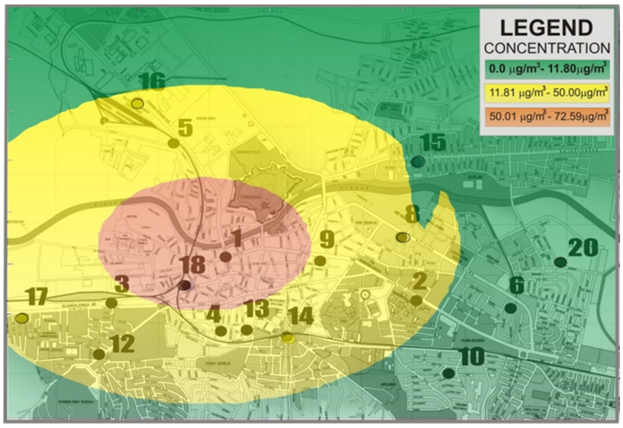

Fig. 8 Map of air quality in relation to soot in 2011.

CONCLUSION

On the basis of obtained research results, we can draw the following conclusions:

The prediction of soot concentrations by using the RBF neural network has proved to be a simpler and more practical application than the methods used up to now, and the results are highly reliable. The application of the RBF neural network method in determining air quality fields in the analyzed area and in determining health risk zones is an original methodological approach and the scientific contribution of this paper.

The designated fields of air quality and health risk zones in relation to soot concentration between 1995 and 2011 indicate that the soot presented in the ambient air of Niš did not have a significant impact on the air quality and the health of the exposed population. The value of total carcinogenic risk for the identified fields of health risk ranged from $3.57 \cdot 10^{-6}$ to $3.30 \cdot 10^{-5}$, which means that it is possible that from the 100 000 ill persons, three exposed persons are in the analyzed periods.

In the network of air quality monitoring on the territory of Niš for the period between 1994 and 2009, there is an inconsistency in the number and locations of measuring points. This profoundly affects the representativeness of assessing air quality in specific areas of the city of Niš and identifying health risk zones.

REFERENCES

1. A. Đorđević: Qualitative and Quantitative Air Quality Evaluation in the city of Nis, Endowment Andrejevic, ISSN 1450-801X, ISBN 978-86-7244-706-4, Belgrade 2008.
2. Guideline for reporting of daily air quality-air quality index (AQI), U.S. Environmental Protection Agency Office of Air Quality Planning and standards Research Triangle Park, North Carolina 27711, July 1999.
3. Richard W. Baldauf, DeNiš D. Lane and Glen A. Marote: Ambient air quality monitoring network design for assessing human health impacts from exposures to airborne contaminants, University of Kansas, Department of Civil and Environmental Engineering, Lawrence, Kansas, *U.S.A.,* March 1999.
4. Andrew G. Salmon, M.A., D.Phil.: *Determination of Noncancer Chronic Reference Exposure Levels* - Air Toxicology and Epidemiology Section, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, February 2000.
5. Fraser,A.M., Swinney, H., Independent coordinates for strange attractors form mutual information, *Physical Review A*, Vol.33, pp.1134-1140, 1986.
6. Katayama, R., Kuwata, K., Kajitani, Y., Watanabe, M.: Embedding dimension estimation of chaotic time series using self-generating radial basis function network, *Fuzzy Sets and Systems*, Vol. 71, pp. 311-327, 1995.
7. Riedmiller, M. and Braun, H. A.: Direct Adaptive Method for Faster Back-propagation Learning: The RPROP Algorithm", *Proc. of the IEEE Int. Conf. on Neural Networks*, pp. 586-591, 1993.

ODREĐIVANJE ZONA ZDRAVSTVENOG RIZIKA AMBIJENTALNOG VAZDUHA U GRADU NIŠU UZROKOVANOG PRISUSTVOM ČAĐI KORIŠĆENJEM RBF NEURONSKE MREŽE

U radu se određuje prisustvo zona zdravstvenog rizika u odnosu na koncentraciju čestica čađi prisutnih u ambijentalnom vazduhu grada Niša za analizirani period od 1995. do 2011. godine. Originalnost primenjene metode u ovom radu, za procenu prostornog zdravstvenog rizika je u predviđanju koncentracije čestica čađi u ambijentalnom vazduhu grada Niša. Predviđanje koncentracije čestica čađi urađeno je primenom RBF (Radijalne Basisne Funkcije) neuronske mreže. Predviđanje koncentracije zagađujućih supstanci u ambijentalnom vazduhu bazirano je na poznavanju imisionih koncentracija zagađujućih supstanci koje se prate u okviru postojeće mreže monitoringa, kao i na poznavanju transmisije polutanata u atmosferi. Kako je proces transmisije polutanata u atmosferi veoma složen, predviđanje koncentracija u ambijentalnom vazduhu, baziran na emisionim koncentracijama, zahteva poznavanje meteoroloških podataka, topografiju terena, fizičke i hemijske transformacije polutanata i njihovu difuziju i depoziciju. Iz tih razloga, primena RBF neuronskih mreža je jednostavnija, a rezultati zadovoljavajući. Maksimalna apsolutna greška pri određivanju zona zdravstvenog rizika na teritoriji grada Niša su reda veličine 10-4 ili manje. Za *analizirani vremenski period između 1995. i 2011. godine, zone zdravstvenog rizika u gradu Nišu sa vrednostima koncentracijama čađi iznad dozvoljene granice prisutne su u 2001., 2002., 2003., 2008., 2009., 2010. i 2011. godini. Vrednost totalnog kancerogenog rizika u ovim godinama u odnosu na zone zdravstvenog rizika nalaze se u opsegu od 3.57□10-6 do 3.30□10-5. Vredosti ukupnog kancerogenog rizika određene su kao proizvod ekspozicije čestica čađi na određenu populaciju i kancerogenog koeficijenta.*

Ključne reči: *zdravstveni rizik, zona zdravstvenog rizika, čađ, RBF neuronske mreže, ukupni kancerogeni rizik*