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MOTOR VEHICLE EXHAUST EMISSIONS IN THE CITY OF NIŠ

Abstract: *Clean air is the foundation of a healthy life and survival on Earth. With the development and advances of human society an increasing number of pollutants in the atmosphere is present. In the 1950s, air pollution was recognized as a global issue whose solution would demand the use of existing and new scientific achievements as well as large financial funds. Firstly, the creation of national law regulations, which were later implemented into the international and European directives, started. As motor vehicles are one of the most prominent air pollutants, an estimation of pollutant emission at the busiest crossroads within the center of Niš has been analyzed in this paper, taking into account the frequency of vehicles on these crossroads. The values of emitted pollutants from the exhaust fumes of motor vehicle at the busiest crossroads in Nis are presented here, both with tables and graphs. Furthermore, the concentration of the calculated pollutants- carbon(II)–oxide and particles of the size of PM is also given. The paper indicates the influence of pollutants emitted through motor vehicles exhaust fumes on the health of the exposed population.*

Key words: air pollution, pollutants, COPERT 4 model, exposure.

INTRODUCTION

According to the report submitted by the European Environment Agency (EEA), the emission and exposure to pollutants such as SO_2, CO, C_6H_6 and Pb has been significantly reduced. Despite recent improvements, air pollution is still a threat to general human health and environment.

Bad air quality affects two following domains the most:

- Urban spaces, where the majority of European population is settled;
- Ecosystems.

According to the report of the Republic of Serbia ("Official Gazette RS", no., 11/2010, 75/2010 and 63/2013), the conditions regarding monitoring and requirements of air quality were regulated.

Air pollutant emission comes from almost every economic and public activity.

Motor vehicles whose number increases daily, represent mobile sources of pollutants, and have as such become a rising urban and non-urban area threat. Gasoline and other oil derivative burnings coming from motor vehicles pollute the air with a number of toxic compounds (oil ash, nitric oxides, sulfuric oxides, carbon oxide, organic peroxides, lead compounds, cadmium compounds etc.), which create residue along the sides of the road and have an overall negative effect.

Quantification of the emission coming from motor vehicles is a key factor in assessing its effects on the quality of the ambiental air and population exposure. Although the most important emission specifications of separate vehicles are regulated by technological standards, the quality of gasoline is rule-regulated, as well as other factors, referring to the use of vehicle and distance travelled, all of which can have a specific effect.

The model used in this paper to calculate motor vehicle pollutant emission is COPERT 4. It represents a model and a software tool which determines the amount of emitted pollutants coming from road traffic. It is also a consisting part of EMEP/EEA Emission Inventory Guidebook, the UNFCC, UNECE TFEIP methodology, as well as UNECE CLRTAP, and is also a part of the European Union regulation regarding the maximum allowed amount of emission per nation. COPERT 4 model, which supports a specialized software, meets the assessment demands in all of the afore mentioned documents and methodologies fully.

A problem that we have encountered in the paper is related to the fact that no valid data base formed that meets the criteria and instructions given by COPERT 4 model has been formed yet.

COPERT 4 MODEL

COPERT 4 software tool assesses the emition of the most important pollutants (carbon dioxide, nitric oxides, rapidly vaporizable organic compounds, PM 2.5 particles, amonia, sulfur dioxide, heavy metals), as well the emition of gases that can create greenhouse effects (carbon dioxide, nitric oxide, methane), all of which are emitted by different types of vehicles (passenger vehicles, light and heavy duty vehicles, mopeds and motorcycles). The programme also enables the speciation of NO/NO_2, pure carbon, organic particles and organic, non-methanic, vaporizable compounds (NMVOC) while the engine is running on a stable temperature (hot emission), the emission caused by the starting of the engine (the so-called cold start), as well as the emission of organic, non-methanic, vaporizable compounds causing the vaporing of fuel. The overall emission is calculated based on data that needs to be collected, and the factors of emission.

COPERT 4 model application offers the possibility to chose one of three methods (Tier 1, Tier 2, Tier 3) in order to assess pollutant emission coming from road traffic:

Tier 1 method

Tier 1 method uses fuel as the main indicator of the road traffic activity alongside the average specific fuel emission factors. It provides data that is classified based on four NFR codes regarding exhaust gases.

Taking into account that road traffic is the biggest source of pollution in every country, Tier 1 method needs to be applied only if there is no fuel data more specific than the national sources. If road traffic proves to be the biggest source of pollution, the country should collect precise data which is needed for a more complex Tier method (desirably Tier 3 method).

The following formula is applied in Tier 1 method:

$$E_i = \sum_j (\sum_m (FC_{j,m} \cdot EF_{i,j,m})) \quad (1)$$

where the following stand for:

E_i - pollutant emission i [g]

$FC_{j,m}$ - the amount burned m of a specific fuel by a specific vehicle j [kg]

$EF_{i,j,m}$ - the amount of fuel burned - specific pollutant factor of emission i for a specific category j and type of fuel m [kg/g].

Categories taken into account are the following: passenger cars, light duty vehicles, heavy duty vehicles, motorcycles and mopeds. Types of fuel taken into account are the following: gasoline, diesel, TNG and natural gas.

Tier 2

This method is related to fuel according to different categories and the level of pollutant emission. Algorithm

$$E_{i,j} = \sum_k (N_{j,k} \cdot M_{j,k} \cdot EF_{i,j,k}) \quad (2)$$

where the following stand for:

$M_{j,k}$ - annual distance travelled by all vehicles of a specific category j and technology k [voz·km],

$EF_{i,j,k}$ - technological specific pollutant emission factors i for a vehicle of a specific category j and technology k [g/voz·km]

Tier 3 method

This method assesses the overall amount of pollutant emission coming from road traffic and is calculated as a sum of both hot emissions and cold start emissions. The whole emission can be summed up by using the following formula:

$$E_{sum} = E_{hot} + E_{cold} \quad (3)$$

where the following stand for :

E_{sum} - the whole emission [g] of a pollutant,

E_{hot} - the emission[g] coming from a period of stable (hot) engine run,

E_{cold} - the emission[g] coming from a period until the engine warms up (cold start).

The formula that is applied in order to calculate the pollutant hot emission is the following:

$$E_{hot;i,k,r} = N_k \cdot M_{k,r} \cdot e_{hot;i,k,r} \quad (4)$$

where the following stand for:

$E_{hot\ i,k,r}$ - hot emission of pollutant exhaust gases i [g], for a vehicle of a specific technology k in a period of time on a specific road r,

Nk - the number of vehicles [voz] of a specific technology k which have been registered in a period of time,

$M_{k,r}$ - distance travelled per vehicle [km/voz] for vehicles of a specific technology k on a specific road r,

$e_{hot\ i,k,r}$ - emission factor [g/km] of a pollutant i, for a vehicle of a specific technology $_k$ on a specific road r.

Cold start emission has been taken into account as an extra emission per km, by applying the following formula:

$$E_{cold,i,j} = \beta_{i,k} \cdot N_k \cdot M_K \cdot e_{hot,i,k} \cdot (e^{cold} / e^{hot}_{i,k} - 1) \quad (5)$$

where the following stand for :

$E_{cold\ i,j}$ - pollutant emission i for vehicles of a specific technology k at cold start,

$ß_{i,k}$ - a part of distance travelled with a cold engine or with a working catalyst

N_k - the number of vehicles registered [voz] of a specific technology k,

M_k - the overall distance travelled per vehicle [km/voz] for a vehicle of a specific technology k,

$e^{cold}/e^{hot}_{i,k}$ - cold start and hot pollutant emission ratio i for a vehicle of a specific technology k.

RESULTS AND DISCUSSION

Air pollutant emission assessment coming from motor vehicles in Nis area has been conducted via modified Tier 1 method which uses the amount of propellent fuel burned and factors of emission for a specific type of motor vehicle depending on the type of propellent fuel. As Tier 1 method demands relevant statistical data regarding fuel, as well as the volume and the size of fuel burned during road traffic, and the data of the Republic Data Institute have not been divided into four categories, there was a need to assess every vehicle fuel burn on the analized travelled distances separately based on a specific fuel burn per km.

The largest number of registered vehicles in Nis is represented by passenger cars based on the data received from the Ministry of Internal Affairs, Niš Police Department, regarding the number of registered vehicles in Niš area.

The role of motor vehicles in air pollution in urban areas can be traced by registering the amount of motor vehicales present in traffic by the amount of time. The study of traffic activity in Niš, related to the basic traffic grids, indicates a high vehicle activity on the main city traffic grids.

Table 1. *The number of registered vehicles in Nis*

Category	Fuel	The number of registered vehicles
PC	Gasoline	28946
	Diesel	16518
	TNG	15549
LDV	Gasoline	562
	Diesel	1970
HDV	Diesel	1544
Buses	Diesel	450
Mopeds and motorcycles	Gasoline	1522

Of all registered vehicles in Niš area, 91% are passenger cars, 6% are trucks, 2% are mopeds and motorcycles and 1% are buses. The data received from the Niš Police Department indicates that vehicles are not divided into categories or technologies, which are needed for Tier 2 and Tier 3 methods respectively, and in result Tier 1 method was applied, which is also generally used in situations where important data is lacking in order to apply the first two methods.

Statistical average of data received from the Niš Police Department, Ministry of Internal Affairs of the Republic of Serbia, was used as entry level data for COPERT 4 model (table 1).

Vehicle frequency analysis was conducted during November 2009, at six intersections in the city. Public and commercial vehicles (trucks and buses) were separately observed. The data was imported every 5 minutes, starting from 5 AM on one day up until 1 AM on the following day. Analysis was conducted at the following intersections (table 2, figure 1) [3]:

- Nikola Tesla Boulevard - Pantelej Street
- Dr Zoran Đinđić Boulevard - Zetska Street
- Nemanjić Boulevard - Sremska Street
- Cara Dušana Street - Obrenovićeva Street
- Vožd Karađorđe Street - Kralj Stefan Prvovenčani Street
- 7. Juli Street - Kralj Stefan Prvovenčani Street.

Table 2 the number of vehicles covered in November 2009.

Table 2. *The number of motor vehicles at the most active intersections in Nis* [3]

	Passenger cars	Trucks	Public buses
Nikola Tesla Boulevard - Pantelej Street	38721	2273	566
Dr Zoran Đinđić Boulevard - Zetska Street	31726	1320	676
Nemanjić Boulevard - Sremska Street	35282	1465	356
Cara Dušana Street - Obrenovićeva Street	20584	1355	288
Vožd Karađorđe Street - Kralj Stefan Prvovenčani Street	33025	1494	1406
7. Juli street. - Kralj Stefan Prvovenčani Street	30195	1669	826

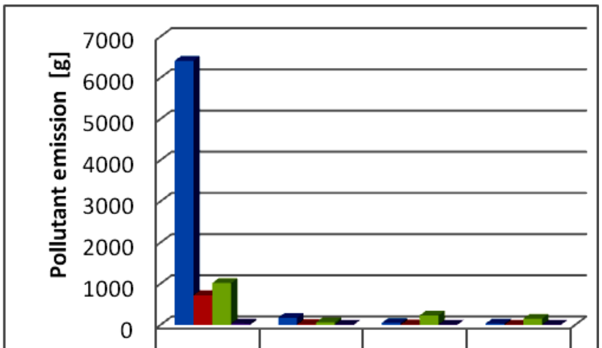
Figure 1 *City plan with marked intersections where traffic was observed* [3]

The following chart (Table 3) shows the received daily values of pollutants emitted per type of vehicle and propellant fuel, at the most active intersections in the city. Motor vehicles frequency analysis was conducted from 05^{00h} to 01^{00h} after midnight, and the results were imported every 5 minutes.

Table 3. *The amount of calculated emitted pollutants*

The intersections where traffic analysis was conducted	Type of vehicle	Type of propellant	Pollutant emission			
			CO	NMVOC	NO_x	$PM_{2.5}$
Nikola Tesla Boulevard - Pantelej Street	Passenger cars	Gasoline	5139	532	550	1,47
		Diesel	88	21	210	31,5
		TNG	1185	168	257	0
	Light duty vehicles	Gasoline	144	13	22	0,03
		Diesel	29	4	40	8
	Heavy duty vehicles	Diesel	50	9	229	8
	Public buses	Diesel	33	6	150	5
Dr Zoran Đinđić Boulevard - Zetska Street	Passenger cars	Gasoline	4211	436	451	1,2
		Diesel	72	17	172	26
		TNG	971	137	210	0
	Light duty vehicles	Gasoline	84	8	13	0,02
		Diesel	17	2	23	4
	Heavy duty vehicles	Diesel	29	5	133	4,5
	Public buses	Diesel	39	7	180	6
Nemanjić Boulevard - Sremska Street	Passenger cars	Gasoline	4683	485	502	1,3
		Diesel	80	19	191	29
		TNG	1080	153	234	0
	Light duty vehicles	Gasoline	93	8	14	0,02
		Diesel	18	3	25	5
	Heavy duty vehicles	Diesel	32	6	148	5
	Public buses	Diesel	21	4	97	3
Car Dušan Street - Obrenovićeva Street	Passenger cars	Gasoline	2732	283	293	0,78
		Diesel	47	11	112	17
		TNG	630	89	136	0
	Light duty vehicles	Gasoline	86	8	13	0,02
		Diesel	17	3	24	4,6
	Heavy duty vehicles	Diesel	30	6	136	5
	Public buses	Diesel	17	3	76	2,6
Vožd Karađorđe Street - Kralj Stefan Prvovenčani Street	Passenger cars	Gasoline	4383	454	470	1,25
		Diesel	752	18	179	27
		TNG	1011	143	219	0
	Light duty vehicles	Gasoline	95	9	15	0,02
		Diesel	19	3	26	5
	Heavy duty vehicles	Diesel	33	6	150	5
	Public buses	Diesel	81	15	374	13
7. Juli Street. - Kralj Stefan Prvovenčani Street	Passenger cars	Gasoline	4007	415	429	1,1
		Diesel	69	16	164	24
		TNG	924	131	200	0
	Light duty vehicles	Gasoline	106	10	17	0,02
		Diesel	21	3	29	5,6
	Heavy duty vehicles	Diesel	37	7	168	5,7
	Public buses	Diesel	48	9	220	7,4

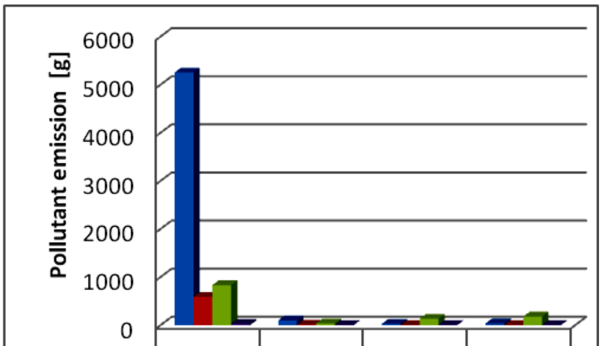
Table 4. *Charted and graphic presentation of emitted pollutants at the Nikola Tesla Boulevard - Pantelej Street intersection*



	PC	LDV	HDV	BUSES
CO	6412	173	50	33
NMVOC	721	17	9	6
NOx	1017	62	229	150
PM2.5	32,97	8,03	8	5

Based on the conducted assessment of the emitted pollutants from $05^{00}$to 01^{00} hours (table 4) it can be concluded that the overall emitted amount is as follows: CO 6668 g; NMVOC 753 g, NO_x 1458 g; $PM_{2.5}$ 54 g. It can also be concluded that the amount of CO in the emitted exhaust gases of motor vehicles is the highest when compared to the amount of other analyzed emitted substances.

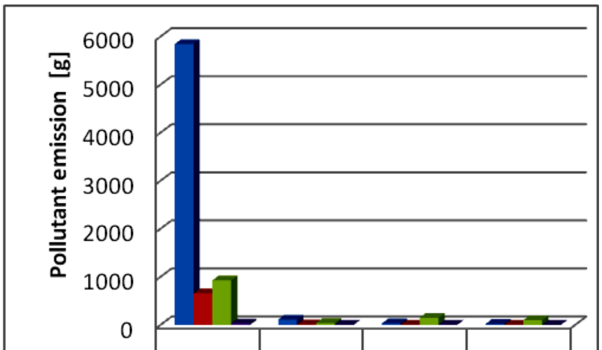
Table 5. *Charted and graphic presentation of emitted pollutants at the Dr Zoran Đinđić Boulevard and Zetska Street intersection*



	PC	LDV	HDV	BUSES
CO	5254	101	29	39
NMVOC	590	10	5	7
NOx	833	36	133	180
PM2.5	27,2	4,02	4,5	6

Based on the conducted assessment of the emitted pollutants from 05^{00} do 01^{00} hours (table 5) at the Dr Zorana Đinđića Boulevard and Zetska Street intersection it can be concluded that the overall emitted amount is as follows: CO 5423 g; NMVOC 612 g; NO_x 1182 g; $PM_{2.5}$ 41,72 g. The amount of CO in the emitted exhaust gases of motor vehicles is the highsest with gasoline propellent passenger cars (table 5).

Table 6. *Charted and graphic representation of emitted pollutants at the Nemanjić Boulevard - Sremska Street intersection*

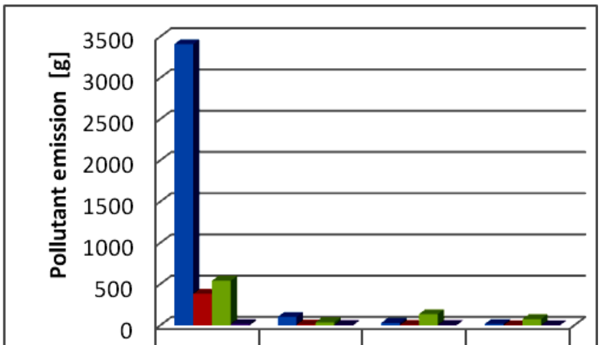


	PC	LDV	HDV	BUSES
CO	5843	111	32	21
NMVOC	657	11	6	4
NOx	927	39	148	97
PM2.5	30,3	5,02	5	3

Based on the conducted assessment of the emitted pollutants from 05^{00} do 01^{00} hours, table 6 shows the overall emitted amount at the Nemanjić Boulevard and Sremska Street intersection as follows: CO 6007 g; NMVOC 678 g; NO_x 1211 g; $PM_{2.5}$ 43,32 g.

It can be seen that of the overall emitted pollutant amount, the highest is CO with 65,2% (table 6).

Table 7. *Charted and graphic representation of emitted pollutants at the Car Dušan Street - Obrenovićeva Street intersection*

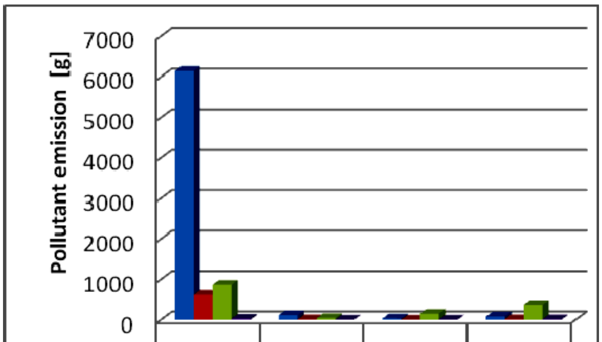


	PC	LDV	HDV	BUSES
CO	3409	103	30	17
NMVOC	383	11	6	3
NOx	541	37	136	76
PM2.5	17,78	4,62	5	2,6

Based on the conducted assessment of the emitted pollutants for the according timeframe (table 7) at the Cara Dušana Street and Obrenovićeva Street intersection it can be said that the overall emitted pollutant amount is as follows: CO 3559 g; NMVOC 403 g; NO_x 790 g ; PM 30g.

This intersection also shows the amount of CO as the highest emitted pollutant with 74% of the overall emitted amount (table 7).

Table 8. *Charted and graphic representation of emitted pollutants at the Voždova Street - Kralja Stefana Prvovenčanog Street intersection*

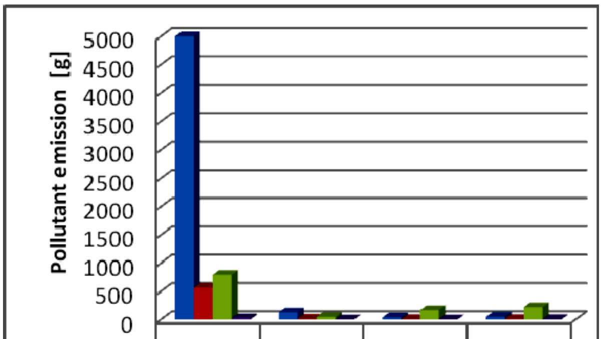


	PC	LDV	HDV	BUSES
CO	6146	114	33	81
NMVOC	615	12	6	15
NOx	868	41	150	374
PM2.5	28,25	5,02	5	13

Based on the conducted assessment of the emitted pollutants (table 8) at the intersection at The National Theatre the following emission values can be observed: CO 6374 g; NMVOC 648 g; NO_x 1433 g; $PM_{2.5}$ 51,27g.

At this point of analysis, the amount of PM 2.5 is much higher in the emitted exhaust gases of motor vehicles in relation to the number of vehicles that pass the intersection daily because of the significantly larger number of public buses driving there (table 8).

Table 9. *Chart and graphic representation of emitted pollutants at the 7. Juli Street and Kralja Stefana Prvovenčanog Street intersection*



	PC	LDV	HDV	BUSES
CO	5000	127	37	48
NMVOC	562	13	7	9
NOx	793	46	168	220
PM2.5	25,1	5,62	5,7	7,4

Based on the conducted assessment of the emitted pollutants for the appropriate timeframe, chart 9 shows the overall emitted amount at the 7. Juli Street and Kralj Stefan Prvovenčani Street intersection as follows: CO 5212 g; NMVOC 591 g; NO_x 1227 g ; $PM_{2.5}$ 43,82g.

This intersection also shows the amount of CO as the highest emitted pollutant with 73,5% of the overall emitted amount (table 9).

The result indicates a high level of CO emission. Adding to this statement, there is a paper on air analysis in Nis from 1994 to 2012 which clearly shows that the allowed values of emission are exceeded (GVI CO 3mg/m^3 anually). The allowed values of emission were exceeded in 1997, 1998, 2002, 2003 and 2008, and in 2000, 2001, 2004, 2005, 2006 and 2007 there was no statistical observation regarding the emission of CO. Based on that fact and the increasing amount of emission concentrations by 48,18% it can be said that there are high concentrations of CO in the near proximity of active intersections in Nis (figure 2). [1]

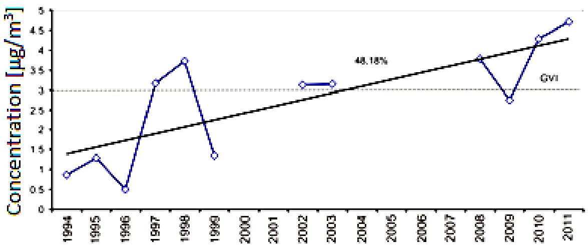


Figure 2. *Average annual CO concentration in ambiental air of Nis regarding the analysed period.* [1]

The expected amount of emitted particles the size of 2,5 µm ($PM_{2,5}$) does not indicate that GVI has been exceeded. However, a paper called "The influence of ambient particulate matter on health of pre-school children in the city center of Nis, Serbia" was written because there was a substantial lack of measuring of concentration of suspended particles in the near proximity of active intersections in Nis. The paper offered the results of studies conducted in 2012 and 2013 which tackled the subject of the concentration of particles the size of 2,5 µm ($PM_{2,5}$) in ambiental air by using automatic measuring device in "Pčelica" and "Bambi" kindergarten establishments. The measuring of particles $PM_{2,5}$ was conducted from April 20th to May 25th 2012 with children being observed for sub chronic exposition. „Bambi" kindergarten school is located in a densely populated area of the city with frequenting traffic. During May and April the concentration of $PM_{2.5}$ was noticeably exceeding the allowed emission concentrations ranging from 43,11% to 107,4%. [1]

Of all the exposed pre-school children 30,67% had one of the accompanying respiratory diseases in April while the percentage in May was 38,33 „Analysis of the Nis region population's health conditions" paper published by the Nis Public Health Institute shows the increasing number of people with respiratory diseases. Public Health Services show that the most frequent diseases are those of respiratory tract with 28,1%, Labor Health

Services show the 21,7% and Pre-school Health Services show an alarmingly large percentage of 71,1%, whilst Youth Health Services show a 60,0% result. [2]

Tier 1 method does not always offer relevant data regarding the emittion of pollutants coming from motor vehicles, and in that regard the data regarding the number of registered vehicles needs to be systematized according to COPERT 4 model.

CONCLUSION

The effects of the environmental pollution are felt even today even though they were most severe in the twentieth century with air pollution being only one of its mediums. The encompassing battle to preserve healthy environmental conditions demands regular control of all pollutant emission sources, in order to establish adequate measures of prevention, protection and management of processes that affect its degradation. In accordance with general environmental protection principles established in the paper, the goal was to analyze the effects of pollutant emission from the exhaust gases of motor vehicles in urban spaces. Nis was chosen to be the analyzed area. Vehicles were observed at the most frequented intersections in the city via COPERT 4 and Tier 1 models. The results in ambient air showed a carbon oxide interval ranging from 3559 [g] at the Cara Dušana Street and Obrenovićeva Street intersection up to 6668 [g] carbon oxide interval at the Nikola Tesla Boulevard and Pantelej Street intersection. This result is in accordance with the measured concentrations on the city level. The paper shows the flow of CO concentration from 1994 to 2011 based on which it can be concluded that in 2003 the concentration level of CO exceeded the allowed borderline values. The increase in the CO concentration level is related to the increasing number of registered vehicles in the city.

At the Vožd Karađorđe Street and Kralj Stefan Prvovenčani Street intersection a larger number of $PM_{2.5}$ particles that amounted to 51, 27 [g] was emitted due to higher frequency of buses. However, systematization of data collected from the Ministry of Internal Affairs, Nis Police Department, is needed in order to make these results more precise and accurate.

Statistical data related to the number of diseases in Nis area indicate increasing number of respiratory diseases primarily with children as well as cardiovascular and cancerous diseases.

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BIOGRAPHY

Marija Rašić was born in Lebane, Serbia, in 1981. She graduated from Faculty of Occupational Safety in Niš, University of Niš. She is currently working toward the Ph.D. degree at the Faculty of Occupational Safety in Niš, University of Niš. Her main areas of research include the impact of traffic on air pollution etc.

EMISIJA IZDUVNIH GASOVA MOTORNIH VOZILA NA PODRUČJU GRADA NIŠA

Marija Rašić, Amelija Đorđević, Ivan Krstić, Vladica Stevanović

Rezime: *Čist vazduh predstavlja osnovu zdravog života i opstanka na Zemlji. Razvojem i napredkom ljudskog društva došlo je do sve većeg prisustva zagađujućih supstanci u atmosferi. Sredinom prošlog veka aerozagađenje je prepoznato kao globalni problem za čije rešavanje bi trebalo koristiti postojeća i nova naučna dostignuća kao i velika finansijska sredstva. Počelo se najpre sa izradom nacionalnih zakonskih regulativa kaoje su kasnije implementirane u međunarodne, evropske direktive. Kako motorna vozila predstavljaju jedan od najvećih zagađivača vazduha u radu je na osnovu COPERT 4 modela, primenom Tier 1 metode izvršen proračun emisije zagađujućih supstanci na najprometnijim raskrsnicama, unutar gradskog jezgra Niša, uzimajući u obzir frekvenciju vozila na ovim raskrsnicama. Dobijene vrednosti emitovanih masa zagađujućih supstanci sa izduvnim gasovima motornih vozila na najprometnijim raskrsnicama u Nišu, u radu, prezentovane su grafički i/ili tabelarno. Takođe prezentovane su i koncentracije izmerenih zagađujućih supstanci: ugljenik(II)-oksida i čestica reda veličine* $PM_{2,5}$. *Rad ukazuje i na uticaj zagađujućih supstanci emitovanih sa izduvnim gasovima motornih vozila na zdravlje eksponirane populacije.*

Ključne reči: *aerozagađenje, zagađujuće supstance, model COPERT 4, ekspozicija.*