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Short Communication

A Specific Approach for Estimating Traffic-Induced Urban Pollution

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Abstract

Most air pollution originates from combustion processes, so it is important to make quantitative as well as qualitative analysis, as the sources of pollution can be stochastic – especially for road traffic. The point of our study is to better determine road traffic as one of the largest pollution sources in the city of Niš, Serbia. The research was conducted at several locations in the city that represent all of the main roads across the city. Parameters considered in the study were traffic frequency, vehicle type, annual vehicle mileage in the city, and average vehicle velocity. Besides these parameters, roadside CO_2 concentration was measured for evaluation. These data were used as the input for the COPERT methodology of air pollutant emissions calculation from road transport. On the basis of these data, annual CO_2 emissions and major pollutants were calculated, as well as the specific average emissions on roads. According to this, a classification of roads in respect to their specific average emissivity is given at the end of this paper.

Keywords: COPERT, CO_2 emissions, pollutant emissions, air pollution, road traffic

Introduction

The impact of pollutants as a consequence of a traffic activity (CO, NO_X, CO_2, SO_X, VOC) has been well documented [1-3]. Recently, since recognizing the problem of global warming caused by GHG emissions, more attention has been focused on CO_2 emissions. Vehicles represent one of the greatest emitters of all pollutants, as well as carbon dioxide. As estimated, in the overall balance of CO_2 vehicles contribute 10%, and in Europe 20% of anthropogenic emissions [1]. Countries with rapid urbanization, such as India and China, are becoming increasingly dependent on automobile transport, which has become a major air pollutant in urban areas [4-6]. As has been presented by Živković et al., in the city of Niš this percentage is even higher [2]. Although measuring pollutant concentrations themselves is not difficult, a closer determination of traffic sources is very complicated considering their stochastic nature [5]. For this reason, different methods for modelling emissions from traffic were suggested. Such estimates are of great importance for more efficient management of air quality.

Emissions from traffic depend on many parameters: vehicle type, engine displacement, vehicle age, fuel type, cruising speed, etc. Examining the emissions of CO_2 and pollutants during the study, the authors have chosen a "macro" or "top-bottom" approach to determine emissions from a single vehicle, based on obtained emissions data. Such data, when they are sufficiently determined, can be used for building a national inventory of emissions [7-9]. In recent years there have been significant efforts to determine emissions in the function of engine type, engine size, and the speed at which the vehicle is moving [8-11].

For this purpose various models for prediction of gaseous emissions were developed [1, 7, 12, 13]. The COP-

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ERT computer program developed by Ntziachristos and Samaras was used for this study, which utilizes the macroscopic approach [14]. Emission assessment was done on the basis of data measured at all of the major intersections in the city, as well as from the data obtained from the Republic of Serbia Ministry of Interior Affairs (MUP) in Niš.

Methodology

Traffic monitoring was done on the main crossroads in the city. Select locations are main street intersections, or characteristic locations on main streets (Fig. 1).

Quantification of traffic intensity was done by counting vehicles that pass through the crossroads, where logging is performed every five min for a period from 5 a.m. to 1 a.m. the next day. This period was chosen as the period when public transport is active, and in the period between 1 a.m. and 5 a.m. traffic in negligible. During counting the vehicles were divided into two categories: passenger cars, and buses and trucks. The category of passenger cars implies scooters, motorcycles, cars, and pickups. As the measurements were done in late autumn, the number of scooters and motorcycles was negligible in comparison to other types of vehicles. During the traffic monitoring, CO_2 concentration measurements were performed in order to link the traffic emissions and measured CO_2 concentrations.

The vehicle fleet data were imported into the COPERT software package, from which overall traffic emissions were calculated. Average emission output of CO_2 and pollutants per vehicle and km was obtained. The results were used for determining traffic-induced emissions. In order to establish the accuracy of traffic frequency, the crossroads at Location I was monitored during workdays in order to determine measured data statistical stability.

Emission and Emission Factor Calculation

The fleet composition data used in this paper were obtained from MUP. Based on these data, it was noticed that passenger cars occupy by far the largest share of the fleet. Vehicles with petrol engines are the most common, making almost 2/3 of the fleet, and the average age of vehicles is about 14 years. The emmision values are calculated using the COPERT methodology [12, 14]. Basically, COPERT was used as a tool for assessing emissions from traffic at the national level. COPERT operation is based on the analysis of large amounts of data from several European vehicle testing facilities. This is a very reliable methodology, since the actual high-level agreement of data obtained [13]. As constant vehicle velocity was adopted, the emission factor for substance i in the specific vehicle category could be calculated as [13, 15]:

$$EF_i = bv^2 + av + k \quad (1)$$

Equation (1), from which one calculates the emission factor, is generally approximated by a second-degree polynomial function of average vehicle velocity, or a graph [1, 9, 10, 13, 14]. Nejadkoorki et al. suggest more complicated formulas for emission calculation as a function of average velocity [1]:

$$EF_i = k + av + bv^2 + cv^3 + \frac{d}{v} + \frac{e}{v^2} + \frac{f}{v^3} \quad (2)$$

In eqs. (1) and (2) k, a, b, c, d, e, and f are constants.

Some authors obtain the emission factor as a function of acceleration as well as velocity [9, 11, 16-18]. Although EF_i is not a constant, it is assumed that for an average vehicle velocity, it is approximately a constant [14].

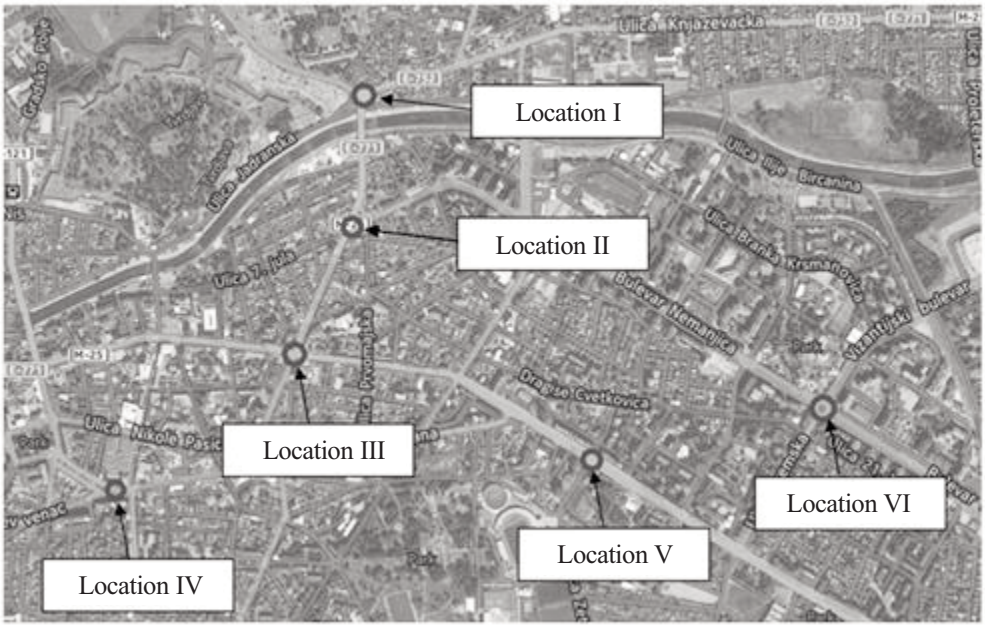

Fig. 1. Measuring locations in the city of Niš.

Table 1. Personal vehicle fleet composition.

		Gasoline			LPG	Diesel	
		<1.4	1.4-2	>2	-	<2	>2
PRE ECE	Conventional	0.55%	0.32%	0.03%	3.54%	6.30%	0.22%
ECE 15/00-01		1.55%	0.89%	0.08%			
ECE 15/02		0.90%	0.52%	0.05%			
ECE 15/03		2.92%	1.67%	0.16%			
ECE 15/04		8.17%	4.69%	0.45%			
PC Euro 1-91/441/EEC		2.72%	1.56%	0.15%	0.68%	1.22%	0.04%
PC Euro 2-94/12/EEC		2.14%	1.23%	0.12%	0.54%	0.96%	0.03%
PC Euro 3-98/69/EC Stage2000		3.18%	1.82%	0.17%	0.80%	1.42%	0.05%
PC Euro 4-98/69/EC Stage2005		5.86%	3.36%	0.32%	1.47%	2.62%	0.09%
PC Euro 5-EC 715/2007		7.49%	4.30%	0.41%	18.78%	3.35%	0.12%

The relationship between traffic intensity and partial CO_2 and CO_2 emissions is presented in Fig. 2. According to Fig. 2, the CO_2 concentration is over 300 ppm higher than normal concentration in the atmosphere. From this amount approximately 150 ppm originates from traffic. Thus it could be concluded that at the observed locations traffic contributes with almost 20% to the CO_2, which correspondes to other data [1].

The annual AM_i emissions of the i^{th} supstance by a vehicle in the j^{th} category is equal to:

$$AM_i = \sum_j EF_{i,j} num_j L_j \tag{3}$$

...where num_j is the number of vehicles in the j^{th} category, $EF_{i,j}$ is the emission factor for i^{th} supstance in the j^{th} category, and L_j is average annual mileage for the vehicle in the j^{th} category.

Simmilary, the annual roadside emission RM_i is equal to:

$$RM_i = 31.563 \cdot 10^6 \sum_j EF_{i,j} f_j S_j \tag{4}$$

...where f is the average daily frequency of vehicles [s^{-1}] in the jth category, S_j is the length of observed section, and $31.563 \cdot 10^6$ is the number of seconds in a year.

On the basis of eq. (3) it is possible to estimate error as:

$$\delta AM_i = \delta EF_{i,j} num_j L_j + EF_{i,j} \delta num_j L_j + \\ + EF_{i,j} num_j \delta L_j \tag{5}$$

...and, similary, on the basis of eq. (4) and error estimations:

$$\delta RM_i = \delta EF_{i,j} f_j S_j + EF_{i,j} \delta f_j S_j \tag{6}$$

Fleet Composition

As has been stated earlier, MUP data were used for analysis. Vehicles were divided into the following categories: personal vehicles, buses, trucks, and motorcycles.

Personal Vehicles

Passenger cars by far represent most of the fleet at 58,049, or 91.12% of the fleet. Before inputting the data into the COPERT, statistical averaging was carried out while processing the data obtained from MUP (Table 1), in order to adjust them for use in COPERT. For the average mileage per year in the city, an amount of 3,500 km annualy was adopted, assuming that the average urban drive amounts to 10 km daily [15] (the amount was adopted on the basis of the author's expirience and direct odometer reading). According to the Serbian Environmental Protection Agency data and data presented in Table 1, it could be calculated that the average personal vehicle in the city of Niš is driven approximately 13,400 km per year,

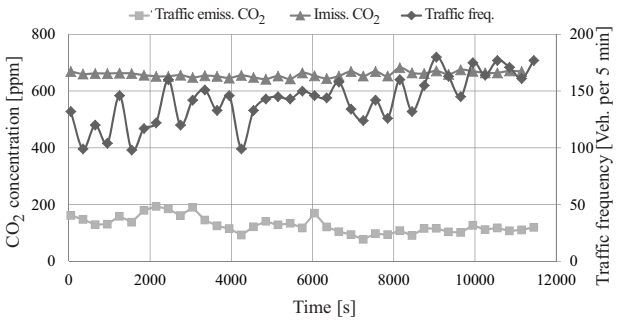

Fig. 2. Comparison of traffic frequency, measured CO_2 concentrations, and calculated CO_2 emissions.

Table 2. Emission factors for vehicle categories [g·km^{-1}].

Vehicle type	CO_2	CO	NO_x
Personal vehicles	330	9.7	0.763
Buses	2,410.8	4.7	1.433
Trucks	500	9.4	2.514

with a deviation of 7.5%, which was adopted as the value of data uncertainty [19]. The average vehicle velocity and annual mileage were adopted by monitoring the driving habits of Niš citizens.

Buses

Four-hundred and seventy-seven buses are registered in Niš. However, during the emissions calculation only buses from the public transport company were used in the account. According to the most recently available data, 124 buses were engaged in the city of Niš public transport, and they were driven 8,609,250 km annually [20]. This makes public transport buses far more influential in comparison with other busses that travel through the city.

Trucks

During traffic frequency counting, light trucks were counted among passenger cars. The authors have adopted as a boundary between light and heavy trucks an engine displacement of 2,000 cm^3. All transport vehicles with engines larger than 2,000 cm^3 were categorized as heavy trucks. According to this, there are 2,286 trucks in the city. For annual mileage 2,000 km was adopted for city territory, with an assumed uncertainty of 17%.

Motorcycles

During the considered period the number of motorcycles on the streets was negligible.

Emission Factors

COPERT analysis has shown that average personal vehicle emissions are consistent with other data presented in Table 2 [21-25]. Due to specific features of the fleet in Niš, compared with Western European and U.S. fleets (average age of the fleet), the advantage has been given to the locally defined emission coefficient.

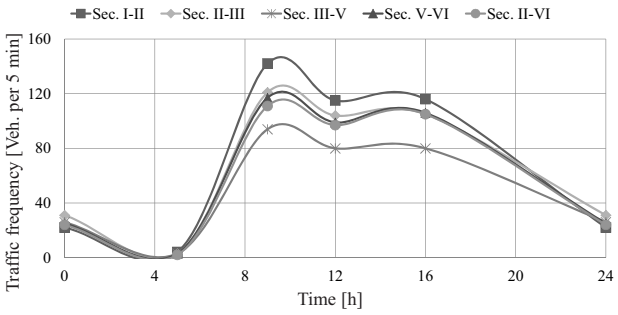

Fig. 3. Daily variation of personal vehicle traffic on street sections.

Model Validation

The results of traffic frequency monitoring at Location I are shown in Table 3 with daily variations. It could be concluded from the results in the table that the total number of passenger vehicles during a workday does not vary more than 3.46%, compared to the average. Also, in the graphics in Fig. 3 one can see the similarity of curves representing the frequency of traffic throughout the day. On the graph in Fig. 3 two peaks could be noted: in the period 8-9 a.m., and 3-4 p.m. Those periods correspond to the daily morning and evening rush-hours. For the buses and truck traffic, the biggest difference in total traffic frequency, in comparison with average traffic frequency, is higher and amounts to 8.13%, which is in the acceptable limits (Table 3).

On the basis of traffic deviation data, emission deviation data, and eq. (4), it is possible to calculate emission deviation. Deviations have been presented in the table for the observed sections, and for total annual emissions. The analysis of the method conducted by Sturm et al. has shown that, depending on the method, deviations can vary up to 36% [26]. The main reason for high values of uncertainty is the uncertainty of emissions data, but also the uncertainty of average mileage traveled through the city.

The error of the emission factors $\varepsilon_{i,j}$ have been estimated in respect to average results for emission factors:

$$\varepsilon_{i,j} = \left|\overline{EF}_{i,j} - EF_{i,j}\right| \tag{7}$$

...where $\overline{EF}_{i,j}$ represents the average emission factor (Table 2). The results are presented in Table 4.

Table 3. Traffic fluctuations at Location I.

Day	I	II	III	IV	Average	σ
No. personal vehicles	38,721	37,182	40,428	38,408	38,685	1,338 (3.45%)
No. buses and trucks	2,839	2,951	3,421	3,380	3,148	256 (8.13%)

Table 4. Error estimation for emission factors [g·km^{-1}].

Authors	CO_2	CO	NO_x
Current research	330	9.7	0.763
Joumard et al. [22]	225	2.5	-
Samaras [21]	300	5	-
EPA [24]	368	5.84	0.693
Boričić [23]	-	15.98	-
Leinert [25]	-	-	0.660
Average	306	7.80	0.705
ε_{max}	7.3%	24.3%	8.01%

Results and Discusion

Based on traffic frequency stability data at major intersections, it is possible to determine the approximate number of vehicles on the section between monitoring crossroads (Fig. 3). According to eqs. (3) and (4), it is possible to calculate overall annual emissions for Niš, and the annual emissions for the main roads in the city. The results are presented in Tables 5, 6, and 7.

Niš has 286.1 km of streets and local roads. The monitored street sections are 4.4 km long, which makes 1.5% of overall streets in the city [27]. The traffic in these street sections contributes 15.1% to the total annual emissions in the city. Results for each section are presented in Table 6 for personal vehicle subcategory, and in Table 7 for buses and trucks. Based on this fact, it is possible to divide streets in the city into two categories (Table 8). The first category occupies monitored street sections (which represents the main roads), and the second category represents side roads, whose specific average emission is at least 10 times lower than the emissions of the fist category.

Table 5. Overal annual emissions.

Vehicle	No. of vehicles	Annual mileage [km]	tCO_2/yr	tCO/yr	tNO_x/yr
Personal vehicles	58.049	3,500	67,047	1,970.8	155
Buses	124	69,500	20,778	40.5	12.4
Trucks	2,286	2,000	2,286	43	11.5
Sum	60,459	-	90,111	2,054.3	178.8
ε_{max}	-	-	22.0%	35.5%	20.0%

Table 6. Personal vehicle emissions estimation on observed street sections.

Section	Lenght [km]	tCO_2/yr	tCO/yr	tNO_x/yr
II-VI	1.63	3,681.0	108.2	8.5
II-III	0.38	858.2	25.2	2.0
V-VI	1	2,258.3	66.4	5.2
III-V	0.95	2,526.6	74.3	5.8
I-II	0.39	710.3	20.9	1.6
Sum	-	10,034.3	295.0	23.2
ε	-	10.7%	27.7%	11.5%

Table 7. Bus and truck emission estimations on observed street sections.

Section	Lenght [km]	tCO_2/yr	tCO/yr	tNO_x/yr
II-VI	1.63	1,461.2	9.7	2.7
II-III	0.38	393.2	2.6	0.7
V-VI	1	247.1	1.64	0.46
III-V	0.95	1,086.3	0.5	0.14
I-II	0.39	403.6	0.14	0.04
Sum	-	3,591.4	14.5	4.04
ε	-	15.4%	32.3%	16.1%

Table 8. Average emission factors for streets in Niš [g·km^{-1}·s^{-1}].

	CO_2	CO	NO_x
I category	98.2	2.2	0.2
II category	9.3	0.21	0.02

Conclusions

This paper presents a method for determining street emissions. During the study, six major crossroads in the city were monitored. Monitoring of the crossroads has enabled the determination of traffic intensity on straight sections between the crossroads. In order to calculate specific emissions of the city fleet, the fleet composition data were obtained from MUP. According to this data, specific vehicle emissions and total annual emissions were calculated using the COPERT methodology.

Analysis showed that on observed sections, the specific emissions are 11 times higher compared to the rest of the streets in the city. Based on this fact, streets were divided into two categories: main streets and side streets. At the end of the paper an error analysis was given. Although high, the error is still at reasonable value. There is still a need for further research, however, since there are still many gaps in the emissions data. Closer determination of input data would additionally increase the quality of results, and therefore output data.

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