APPLICATION OF A DISPERSION MODEL FOR SZEGED, A MEDIUM SIZED HUNGARIAN CITY: A CASE STUDY

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ABSTRACT

The aim of the study is the application of the CAR model to a medium-sized Hungarian city, Szeged. To study the sensitivity of the model, the concentration of pollutants as a function of distance from road axis, the effects of wind speed, road type and tree factor on the concentration as well as the concentration of the pollutants at different traffic speeds were analyzed and quantified. To summarize our results, main findings are as follows: the level of pollution increases with (i) increasing number of vehicles, (ii) decreasing speed in urban traffic (i.e., less than 50 $km \cdot h^{-1}$), (iii) larger fraction of heavy vehicles, (iv) increasing number of trees alongside the roads and (v) smaller mean annual wind speed. In addition, the model had been run on realistic input parameters, regional and city background concentration. Street geometry and traffic data for the period 1997-2007 at Szeged have been used. Model results have been compared to measurements showing good agreement with a slight overestimation of concentration due to the insufficient consideration of technical development of the vehicles; however, modelled data are showing smaller deviation than measurements.

KEYWORDS: traffic emission, air pollution, transport, statistical model, Szeged, Hungary.

INTRODUCTION

The majority (62.4%) of the population of Hungary lives in urban area. For this reason, both monitoring and modelling of urban air quality have great importance. The main source of pollution in cities – besides industry and households – is traffic. Though industrial and domestic emission is gradually decreasing year by year, road traffic is increasing continuously [1, 2]. Since it is virtually impossible to carry out fully comprehensive monitoring of pollution for all urban places, decision makers should use model results for the estimation of street air quality in many cases. There are three major approaches for street air quality models: (i) empirical approach; (ii) statistical approach and (iii) dynamical approach.

In Hungary, meteorological conditions for the development of poor air quality are most dominant from late autumn till spring time, in such cases when a well developed surface inversion fills the Carpathian Basin. Strong static stability usually occurs along with no significant wind conditions. This kind of situation occurs relatively frequently in the winter time during the development of a high pressure system after passing of a cold front over the Central European region. The stable layer inhibits pollutants to solute in the ambient atmosphere, so concentration of pollutants in urban area can rapidly increase.

Despite the progress made in controlling local air pollution, urban areas show ever increasing environmental stress. Safe comfortable urban environment and the risks of air pollution are of the major concerns. The importance of air quality problems depends on the size of the city, together with topographical, geographical and meteorological processes as well as with social factors [1].

The average annual variation of CO, NO, NO_2 and PM_{10} (with maxima in winter) are opposite to those of O_3 (with maxima in summer). The higher winter values are caused by atmospheric stability with frequent inversions. The lowest values in summer are due to dispersion caused by intensive vertical exchange in the atmosphere. The highest intensities of photochemical O_3 formation are observed during the early afternoon in summer. The very similar average weekly variations of CO, NO, NO_2 and PM_{10} show weekday maxima and weekend minima. Oppositely, those of O_3 show weekday minima and weekend maxima [1, 3, 4].

Study of the environmental impacts of any traffic management and control policies require not only analysis of average speeds but also other aspects of vehicle operation such as acceleration and deceleration [5]. Urban traffic is mainly characterised by stop-and-go driving cycles for vehicles joining the queue at traffic lamp junctions. The length of each cycle depends on the expected queue length at the traffic lamp and the frequency of each cycle directly affects the level of vehicle emissions. The greatest percentage of emissions for a vehicle that stops at a traffic lamp is due to its final acceleration back to cruise speed after leaving the traffic lamp [6]. Another paper [7] deals with speed limits imposed by speed control traffic signals and the consequent emissions increase.

Furthermore, the shape of a city and the land use distribution determine the location of emission sources and the pattern of urban traffic. These factors together are affecting urban air quality. Accordingly, more compact cities with mixed land use provide better urban air quality compared to disperse and network cities [8].

Regulatory air pollution modelling has been carried out in Hungary since the early 1960s. Firstly Gaussian puff models were used, in which instability and boundary layer depths were calculated [9]. For the uniform application of transmission schemes the standardization of air quality models is crucial. This work ended in the early 1980s [10], when pollution of point, line and areal sources were modelled. The next step was the development of the Hungarian Standardized Model (HNS-TRANSMISSION) in the 1990s. This Gaussian transmission model can consider contribution of up to 50 sources. It is suitable to describe transmission processes from local to regional scales including the effect of orography [11]. The EPA AERMOD system has been implemented at the Hungarian Meteorological Service as a powerful tool for case study calculations [12, 13]. The development of a meteorological pre-processor for the model has also been performed.

For experimental and comparison purposes, numerical studies have been made with the Dutch CAR model [14], which has been applied in our experiments as well. The model is now used as a regulatory model for cities in the Netherlands and, as an international version, the CAR International [15] is also available. A parallel workstation version of the Finnish Meteorological Institute (the CAR-FMI) is a descendant of the Dutch model, which is able to calculate hourly concentrations and statistics (daily, monthly and annual means, percentiles, etc.) of inert (CO and NO_x) and reactive (NO, NO_2 and ozone) pollutants emitted by a network of sources (CAR-FMI web). CAR model has also been used by [16] in their estimation of pollution from traffic in Xian, China.

The aim of the study is to apply the CAR model to a medium-sized Hungarian city, Szeged. The measured concentrations of CO and NO_x are dominantly originated from traffic-related emissions [17]. In the CAR model, concentration data of CO and NO_2 are used. In order to convert NO_x to NO_2, an NO_2 submodel is also introduced.

Since our intention is mainly to determine annual means and percentiles of some pollutants (CO, NO and NO_2), and we want to analyze the effect of traffic on pollution on an annual basis, it is sufficient to use the original Dutch model, which requires much less computational resources than its descendants.

DESCRIPTION OF THE CAR MODEL

The Dutch **CAR** model (**C**alculation of **A**ir pollution from **R**oad Traffic) [14] uses an empirical approach for the estimation of mean annual concentrations of NO_2 and non-reactive pollutants (carbon-monoxide and benzene) in urban and rural areas. The relationship between street types, wind speed and concentrations of the pollutants considered was based on wind tunnel experiments [18]. The experiments considered 49 configurations of street dimensions (street width vs. height of obstacles aside, distances and shapes, etc.). Effect of trees along streets was also considered. Results were combined in the TNO Traffic model [19]. From TNO some distinct configurations were categorised and some modifications were performed. A source receptor function is specified for each street category as a function of distance from road axis (from 5 to 30 m). Annual averages and 1-, 8- and 24-hour 98 percentiles are the outputs of the model for each pollutant (Figure 1).

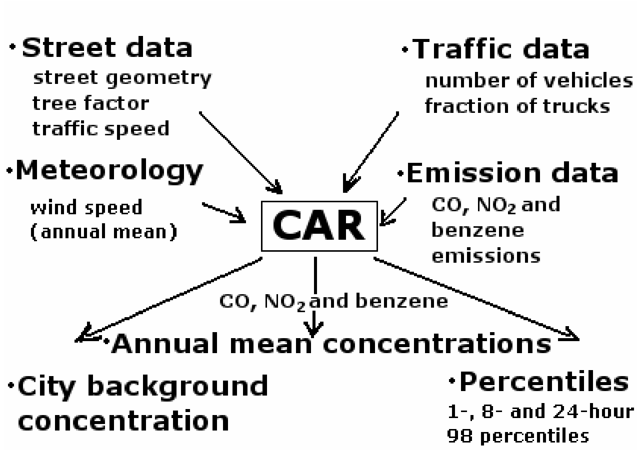

FIGURE 1 - Schematic diagram of the system parameter, input and output data of the CAR model [14].

The options of the model

One can choose from several street types for the calculations, as follows:

1. Road in open terrain, a few buildings or trees.

2. Base type, all roads different from type **1**, $\mathbf{3_a}$, $\mathbf{3_b}$ or **4**.

$\mathbf{3_a}$. Broad street canyon: building exceeding 3 m height on both sides of the road. Ratio of the height of the building vs. distance from road axis (*hb*) is between 1.5 and 3 on one side of the road and less than 3 on the other.

$\mathbf{3_b}$. Moderately narrow street canyon, *hb* ratio is less than 1.5 on both sides.

4. Building only on one side of the road, *hb* is less than 3.

The speed of road traffic can be categorised in four classes:

$\mathbf{V_a}$: Highway. Average speed is 100 km·h^{-1}.

$\mathbf{V_b}$: Road with maximum speed of 70 km·h^{-1}. Average speed is 44 km·h^{-1}.

$\mathbf{V_c}$: Regular city traffic. Average speed is 22 km·h^{-1}.

$\mathbf{V_d}$: Stagnating traffic. Flow of vehicles is not continuous. Average speed is 11 km·h^{-1}.

Emission factors can be adjusted to measurements in the model setup. The effect of trees along streets is considered for three types of vegetation:

1.00: Very few or no trees on either side of the street.

1.25: Trees on one side of the street, distance between trees is less than 15 m in the direction parallel to the road axis.

1.50: Trees on both sides of the street and tree tops touch each other over the street. More than one-third of the length of the street is covered by vegetation.

Calculation

Calculation is performed in the following steps:

1. Calculation of the city background concentration (C_b),

2. Assessment of the emission of the road traffic (E_t),

3. Calculation of the contribution by the configuration of the street (C_t),

Average concentrations are calculated at 1.5 m above surface from 5 up to 30 m away from the axis of the road.

The city background concentration ($C_b = C_r + C_c$) is obtained as a sum of the regional background concentration (C_r) and the size-dependent city contribution (C_c). The latter term ($C_c = \alpha \cdot R_c$) is a linear function of the radius of the city (R_c). The α coefficient has been determined by measurements. Diameter of the city equals to the diameter of the built-up area.

Two classes of traffic are considered: automobiles and trucks. Trucks are heavy vehicles (exceeding 3500 kg weight) and buses. Road traffic emission (E_t) is calculated as follows:

$$E_t = (1 - F_V) \cdot N \cdot E_p + F_V \cdot N \cdot E_V\,, \quad (1)$$

where F_V is the fraction of trucks in the traffic, N is the number of vehicles per day at the given location, furthermore E_p and E_V are the speed dependent emission factors of automobiles and trucks, respectively. It should be noted that emission factors used by the model have the dimension $\mu g \cdot m^{-1} \cdot s^{-1} \cdot vehicle^{-1}$, while the usual dimension of such parameters used by the official emission inventory is different ($g \cdot km^{-1}$). For this reason the emission parameters should be recalculated in the proper dimension (see Table 4 for the details and values used in the present calculation).

The contribution by the street configuration (C_t) is calculated using E_t road traffic emission factor and the street specific dispersion coefficient, which represents the effect of (i) wind speed, (ii) vegetation along the street and (iii) dilution during dispersion:

$$C_t = E_t \cdot \Phi_s \cdot F_r \cdot F_0\,, \quad (2)$$

where Φ_s is an empirical extinction (dilution) polynomial, a function of the distance from road axis. The dependent variable (x) of the polynomial is the distance from road axis. We use different Φ_s for different street types. F_r represents the ratio of the actual local annual mean wind speed to the national average. F_0 is the tree factor, which represents the effect of the trees on wind speed.

The 98 percentiles of the annual mean concentration for each pollutant (C_{pol}) is the sum of the city background concentration (C_b) and the street contribution (C_t) of CO, NO_2 and benzene:

$$C_{pol} = P_x \cdot C_t + C_b\,, \quad (3)$$

where P_x represents the ratio of the annual mean concentrations and the 98 percentiles of CO, NO_2 and benzene. P_x is a function of street type and can be adjusted to measurements in the model setup.

The above calculation is applicable only to inert gases. Since conversion of NO_x to NO_2 in streets can not be modelled in wind tunnel experiments, an NO_2 submodel – based on theoretical and empirical considerations – is introduced. The non-linear relation between NO_x and NO_2 is taken into account besides the direct emission of NO_2. The street contribution of NO_2 (C_{tNO2}) is calculated with the following correction factor:

$$C_{tNO2} = F_{NO2} \cdot C_{tNOx} + \frac{\beta \cdot C_{bO3} \cdot C_{tNOx}}{K + C_{tNOx}}\,, \quad (4)$$

where F_{NO2} is the fraction of emitted NO_2 of the total NO_x emission (that is a function of the traffic category and speed). So the first term represents the directly emitted NO_2 from traffic. The second term of the expression represents the ratio of NO_2 and NO_x at a certain ozone level (C_{bO3}). The β factor represents the fraction of background ozone concentration, which reacts with NO. K is a constant, based on measurements. C_{tNO2} , C_{tNOx} and C_{bO3} are the street contribution of NO_2, NO_x and background ozone concentrations, respectively [14].

SENSITIVITY STUDIES OF THE CAR MODEL

To study the effect of the input and system parameters on the calculated concentration, we performed model runs with arbitrary input data. The values of these parameters have been set to be close to their respective average or representative values for Szeged (Table 3 and 6). A city with a diameter of 4 km was considered. At an arbitrary site the fraction of trucks was put equal to 5 %, traffic was set to 20 000 vehicles per day with an average speed of 22 $km \cdot h^{-1}$ (**V_c** category) and tree factor was 1.25 in the standard run. Annual average wind speed was set to 2.5 $m \cdot s^{-1}$. Concentrations were calculated at 5 m from road axis. To assess the sensitivity, one parameter considered was modified, while the others remained constant.

In this chapter the effect of different input model parameters was studied to mean annual pollutants concentrations. Since for CO and benzene the results were identical (with different numerical values but same relative effects, of course), we only present the results for CO. As NO_2 has a different behaviour, results for NO_2 are presented separately. However, if the type of pollutant is not mentioned, concentration in this chapter refers to annual mean concentration of CO.

We compared the concentrations calculated for both CO and NO_2 to their WHO and Hungarian Standard air quality limit values [20-22]. Limit values are given in three categories: Highly Protected (HP), Protected I. and Protected II. categories.

The effect of wind speed

To study the sensitivity of the model, the effect of wind speed was analysed. Calculations for different tentative annual mean wind speed were performed for all road types. Dependence of the pollutants concentrations on mean annual wind speed resulted in similar functions for all the pollutants considered (Figure 2). An obvious finding is that increasing wind speeds involve the decrease of pollutants levels.

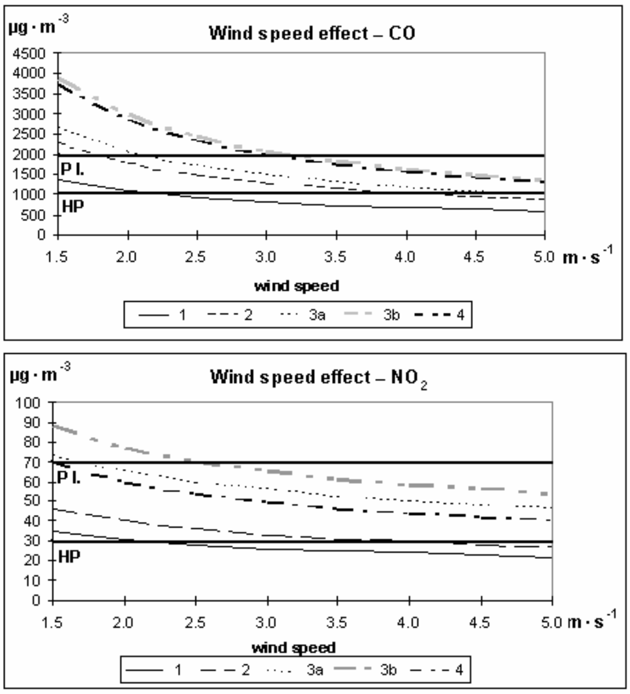

FIGURE 2 - The effect of mean annual wind speed on CO (upper panel) and NO_2 (lower panel) concentrations (μg·m^{-3}) 5 m away from road axis for different road types keeping other parameters constant: traffic 20 000 vehicles (5% trucks) per day, speed of vehicles 22 km·h^{-1} (V_c category), tree factor 1.25. Concentration limits: HP: Highly Protected; P I.: Protected I.

The highest CO concentrations (from 1 800 to 3 900 μg·m^{-3}, depending on road type) occurred at weak winds (at 1.5 m·s^{-1} mean annual wind speed), while strong winds (5 m·s^{-1}) resulted in the lowest concentrations (from 1 000 to 1 700 μg·m^{-3}). Wind effect, however, was more pronounced on CO than on NO_2. The ratio of maximum (at 1.5 m·s^{-1} mean annual wind speed) and minimum concentrations (at 5 m·s^{-1} annual mean) was 76 % for CO and 57 % for NO_2. The lowest concentration of CO for road type **3_b** is almost equal to its highest concentration for road type **1** (well below its limit value of Protected I. category: 2000 μg·m^{-3}). Its reason is that the effect of wind speed is less pronounced in a narrow street canyon, than in a broad street. It can be seen that the most significant decrease in mean annual pollutants levels with respect to the distance from the road axis appears at type **3_b**. For road type **1** only small changes can be detected in the distance related concentrations; however, they do not exceed the limit value.

Pollutants concentration as a function of distance from road axis

Away from the axis of the road, lower concentrations are shown due to the dilution of the pollutants (Figure 3). In the standard run, CO levels close to the axis of the road were higher than the limit value for two of the five road types. However, concentrations of CO were below the limit at a distance exceeding 14 m for all the road types. According to other studies, the roadside concentrations of gaseous and $PM_{2.5}$ pollutants decrease with the distance from the road and the exposure to both gaseous and particle pollutants in the vicinity of the selected urban road sites is interrelated to on-road vehicle emissions [23].

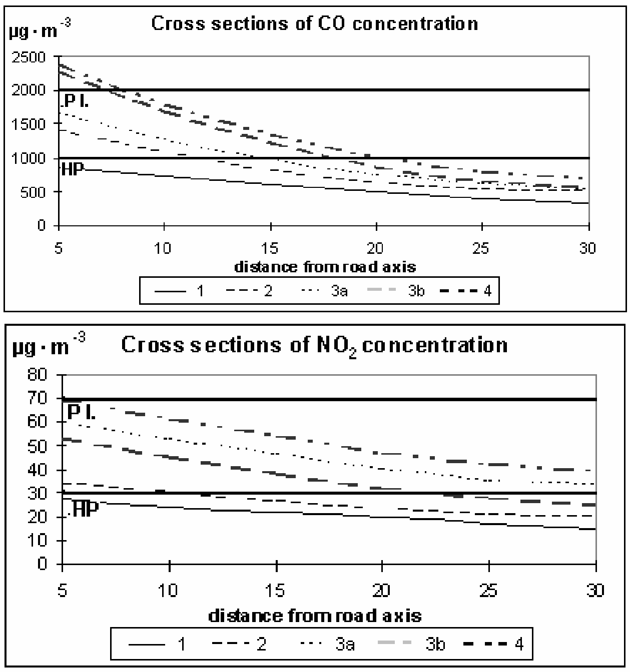

FIGURE 3 - Cross sections of CO (upper panel) and NO_2 (lower panel) concentrations (μg m^{-3}) for different road types. Annual mean wind speed: 2.5 m·s^{-1}, speed of vehicles: 22 km·h^{-1}, tree factor: 1.25. Concentration limits: HP: Highly Protected; P I.: Protected I. Distance from road axis is given in meters.

The effect of the road type and tree factor on the pollutants concentrations

The concentrations are the highest for road type **3_b**, while those for road type **4** are only slightly lower. On the other hand, the lowest levels are detected for type **1**. Different circulation patterns in each road type canyon result in different mean annual concentrations by constant tree factors (Table 1). More trees aside result in higher concentrations, since trees near the road reduce wind speed and, hence, dilution of the pollutants is also reduced. Furthermore, it is obvious that the tree effect on pollutants levels is as large as the effect of buildings close to the street: by tree factor **1.50** at road type **3$_a$** concentration is equal to that at road type **3$_b$** by a tree factor value of **1.00**. Tree effect indicates the highest impact on concentrations for road types **3$_b$** and **4** (Table 1).

TABLE 1 - Concentrations of CO (µg·m^{-3}) for different road types and tree factors (F_0) 5 m away from road axis. Regional wind speed, traffic and speed of vehicles were put equal to 2.5 m·s^{-1}, 20 000 vehicles per day and category V$_c$, respectively. Relative contribution of trees is given in brackets (%).

Road type	F_0 = 1.00	F_0 = 1.25	F_0 = 1.50
1	790	924 (17%)	1 058 (34%)
2	1 220	1 461 (20%)	1 703 (40%)
3$_a$	1 411	1 701 (21%)	1 990 (41%)
3$_b$	1 990	2 424 (22%)	2 858 (44%)
4	1 916	2 331 (22%)	2 747 (43%)

Pollutants concentrations at different traffic speeds

The CAR model can handle 4 different traffic speeds. Results for the most important speed categories are presented for calculation, assuming a tree factor of F_0 = 1.00 (Table 2).

TABLE 2 - Concentrations of CO and NO$_2$ at 5 m away from road axis for different traffic speeds. An annual mean wind speed of 2.5 m·s^{-1} was considered. (V$_b$: Road with maximum speed of 70 km·h^{-1}, average speed is 44 km·h^{-1}. V$_c$: Regular city traffic, average speed is 22 km·h^{-1}. V$_d$: Stagnating traffic, flow of vehicles is not continuous, average speed is 11 km·h^{-1}).

Road type	V$_b$	V$_c$	V$_d$	V$_b$	V$_c$	V$_d$
	[CO; µg·m^{-3}]			[NO$_2$; µg·m^{-3}]		
1	534	924	1 228	28	28	30
2	759	1 461	2 010	36	36	39
3$_a$	859	1 701	2 358	59	59	63
3$_b$	1 161	2 424	3 410	70	70	75
4	1 122	2 331	3 276	54	54	59

At all speeds the highest concentrations were taken for road types **3$_b$** and **4**. For CO, the mean annual concentration increases significantly with decreasing average traffic speed, since at lower average speed vehicles perform more speed change cycles especially in the lowest speed category, when vehicles perform several stop and go cycles. However, for NO$_2$ it is not the case. This is because vehicles are not the only sources of NO$_2$ generation. Nitrogen-dioxide can be formed due to chemical interaction of gases that are present in the urban air. Annual mean CO levels vary from 27 % to 171 % of the *Protected I.* limit value (2000 µg·m^{-3}) (Table 2). Concentrations of NO$_2$ occur within a much closer interval than those of CO. Its concentrations vary from 40 % to 107 % of the *Protected I.* limit value (70 µg·m^{-3}) (Table 2). As traffic speed decreases, pollution reaches the unhealthy level for several road types. At speed **V$_b$,** levels of both CO and NO$_2$ are under (or equal) the *Protected I.* limit values in all cases. At speed **V$_c$** for type **3$_b$** and **4,** concentration of CO is over the *Protected I.* limit value, while at **V$_d$** traffic speed, pollution is moderate only on streets with open area. For NO$_2$ different results were obtained: on road type **3$_b$** concentration of NO$_2$ is at the limit and for roads **3$_a$** and **4** it is close to the limit for all categories. Further calculations showed that a doubling in the traffic (i.e. double number of vehicles) results in 71 % increase in the CO concentration. Neither the effect of trees nor the increasing traffic speed can compensate the effect of a double truck fraction. The fraction of trucks has a great impact on the NO$_2$ concentration. Heavy duty vehicles may contribute to about 60 % of the total NO$_x$-emissions [24].

THE CASE STUDY

The CAR model has been applied to input data collected in a medium size Hungarian city, Szeged. The results have been compared to the measurements and to the air quality limit values of the pollutants considered. In this section – after a short site description – the input data are introduced and the results of the model calculations are discussed.

Site description

Szeged is a medium sized city with a population of about 155 000 inhabitants in the south-eastern part of Hungary (20º06'E; 46º15'N). The built-up area of the city is 46 km^2. This is the largest town in the southern part of the Great Plain, at the confluence of rivers Tisza and Maros. The annual mean temperature is 11 ºC, while the annual mean precipitation total is about 570 mm. The prevailing wind direction is westerly to north-westerly and the annual mean wind speed is 3.2 m·s^{-1}. As the major industrial area is found north-west to the city, air currents transport polluted air downtown [25, 26].

The traffic of Szeged is overcrowded. Though the order of magnitude of road traffic did not change in the period 1995-2000 but a slight increase in the daily number of vehicles can be experienced. On the other hand, structure of the traffic changed considerably. Majority of the vehicles have already been equipped with exhaust catalysers, so emission has significantly decreased despite the stagnating traffic: levels of road traffic emissions of CO in year 2000 were 35-40 % of those in year 1990 [27].

As a comparison, despite the rapid increase of the vehicles in Beijing, China by 60 % between 1998 and 2003, total vehicular emissions have not increased. Improvement of fuel quality (banning lead, reducing sulphur), introduction of CNG and LPG in buses and taxis, as well as fiscal incentives such as tax deductions for new vehicles meeting enhanced emission standards to encourage their sales, significantly improved the environmental quality of the Chinese capital [28]. Traffic regulations introduced by policymakers in Delhi, India, resulted in similar conclusions [29].

Due to highways M5 (Budapest – Szeged – Röszke, Hungarian-Serbian border; completed in 2005) and M43 (Szeged – Nagylak, Hungarian-Romanian border; construction started in 2009 and its completion is planned in 2012), which will drive transit vehicles outside the inhabited area of Szeged, will result in a significant drop in the traffic and hence, traffic related air pollution. This study is going to be a reference to the effects of the here-mentioned highways, as well.

The input data

Traffic census has been processed at 9 different sites in the city (Figure 4; sites 1 to 9 are from top left to right centre and left bottom). Both the average daily number of motor vehicles passing through each location and the air pollution data were considered for the 11-year period 1997-2007. Mean daily number of vehicles for the period considered is indicated for each location (Figure 4), furthermore, temporal course of mean daily number of vehicles at two different sites (Site 4 and 9) is also presented (Figure 4, bottom right). An increasing trend is present for the urban average traffic for the annual means taking into account all sites (~970 vehicles per day per year growth rate for the urban average during the 8 years period). Model results from two different type of urban sites are analysed: An air quality monitoring station is located at site 4 which is a typical dense urban area not so far from the city centre (with an average of 18 181 vehicles per day for the 8-year period 1997-2004), while site 9 is an open suburban site with an average of 4 676 vehicles per day.

Vegetation type and traffic speed categories for each site were estimated at a field trip experiment performed by the authors. According to this survey, vegetation types are **3a** (i.e. 'broad street canyon') and **2** ('base type'), furthermore, traffic speed categories are $\mathbf{V_c}$ (average traffic speed is 22 km·h^{-1}) and $\mathbf{V_b}$ (average traffic speed is 40 km·h^{-1}) for site 4 and 9, respectively. Tree factors of these locations were **1.25** (trees on one side of the street) and **1.00** (very few or no any trees), respectively (Table 3).

City diameter (4 km) was calculated for the area of Szeged using a circular model for the city. Concentrations were calculated at 5 m away from the road axis. This is the closest location to the source where concentrations can be obtained with the CAR model. Calculated concentrations are the highest here so the effects of the input parameters and the difference between each site are not attenuated by dilution.

The emission factors were changed from their default values according to the inventory of the Automotive Engineering Environmental and Energy Division at the Institute of Transport Sciences (web of the Ministry of Environment and Water, Hungary). Note that the dimension used in the CAR model (μg·m^{-1}·s^{-1}·vehicle^{-1}) differs from the one used in other sources (g·km^{-1}). In Table 4 the parameters are shown in both dimensions.

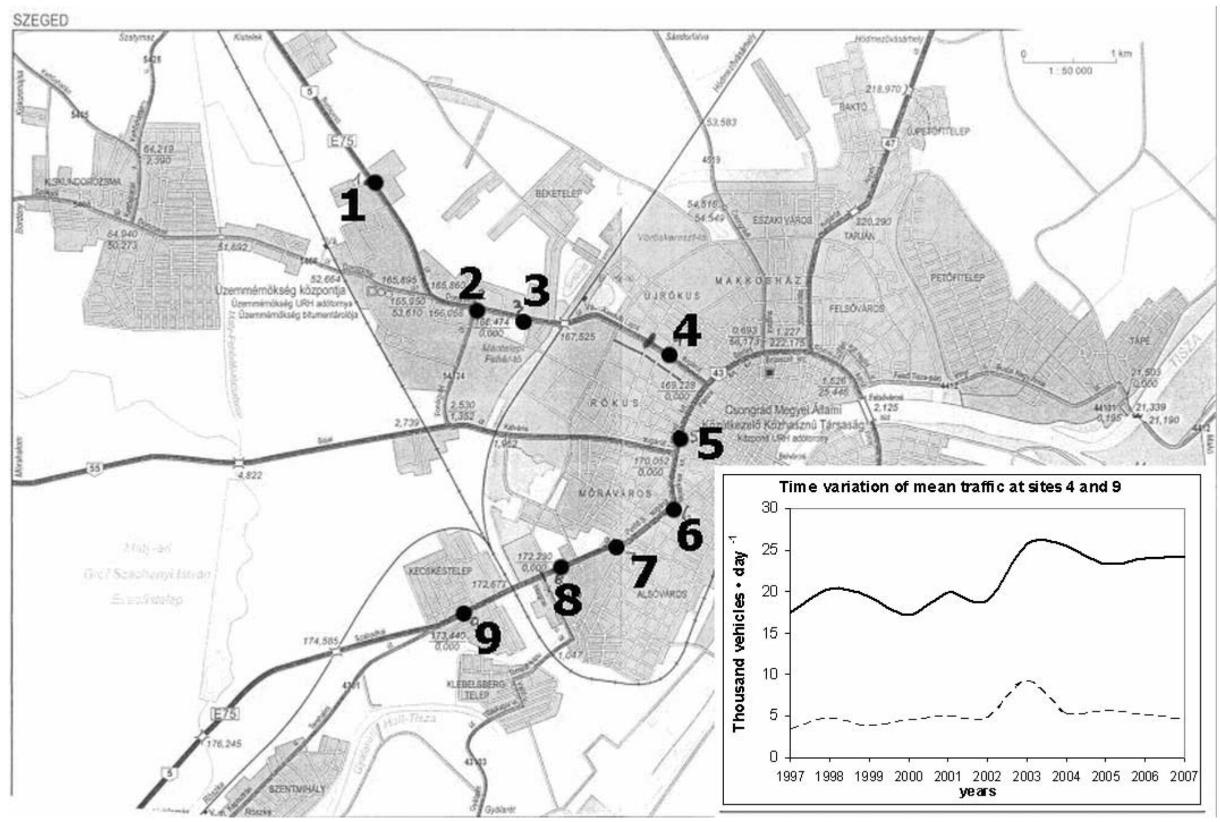

FIGURE 4 - Map of Szeged with the location of the measurement sites. Bottom right panel: time variation of daily number of vehicles at two locations (sites 4 and 9) for each year (1997–2007).

TABLE 3 - Road types, traffic speed and tree factor data at each site. V_b: Road with maximum speed of 70 km·h^{-1}, average speed is 44 km·h^{-1}. V_c: Regular city traffic, average speed is 22 km·h^{-1}. V_d: Stagnating traffic, flow of vehicles is not continuous, average speed is 11 km·h^{-1}.

Site	Road type	Traffic speed type	Tree factor
1	**2**	V_b	**1.00**
2	**4**	V_b	**1.00**
3	**4**	V_b	**1.00**
4	**3_a**	V_c	**1.25**
5	**3_a**	V_c	**1.25**
6	**3_a**	V_c	**1.25**
7	**3_a**	V_b	**1.25**
8	**4**	V_b	**1.25**
9	**2**	V_b	**1.00**

TABLE 4 - Emission factors for cars and trucks at different speed categories in different units. Parameters were taken from the official emission inventory of the Automotive Engineering Environmental and Energy Division at the Institute of Transport Sciences (KTI). (source: web of the Ministry of Environment and Water, Hungary).

Speed type	Speed (km·h^{-1})	CO g·km^{-1}	CO μg·m^{-1}·s^{-1}·vehicle^{-1}	NO_2 g·km^{-1}	NO_2 μg·m^{-1}·s^{-1}·vehicle^{-1}
		Cars			
V_a	13	30.57	0.354	1.38	0.016
V_b	22	21.00	0.243	1.33	0.015
V_c	44	11.72	0.136	1.40	0.016
V_d	100	6.40	0.074	2.45	0.028
		Trucks			
V_a	13	21.26	0.246	8.01	0.093
V_b	22	15.75	0.182	6.75	0.078
V_c	44	10.74	0.124	6.06	0.070
V_d	100	8.86	0.103	11.28	0.131

The background concentration data

In lack of onsite measurements background values can be determined by regional and urban scale air quality modelling. EMEP model activity includes transboundary air pollution modelling of main pollutants like (S, N, O_3 and PM) using actual emissions and meteorological condition to get spatial distribution of them over Europe [30]. In the area of Szeged the regional background intervals according to the EMEP calculation are shown in Table 5. Furthermore, the background concentrations of ozone are also published because of its important role in NO_x chemistry using by road models.

TABLE 5 - Summary of different measured and calculated background concentration values at Szeged.

2006 annual averages (μg·m^{-3})	Urban background measured at Kossuth str	Regional background measured at K-puszta	Regional background calculated by EMEP
NO_2	34.2	1.78	3.3 - 6.6
CO	687.0	-999.9*	-999.9*
Benzene	2.2	-999.9*	-999.9*
O_3	31.9	48.00	60 - 70

* -999.9: values are not available

Regional background concentrations have been measured at three stations in Hungary. Sites are located in areas of low population density, which are as far as possible from major roads, populated and industrial areas. The closest station to Szeged called K-puszta has a central location in the country and its measurements have been taken into consideration during EMEP model simulations and verifications. Measured annual averages of NO_2 and O_3 at K-puszta in 2006 are also shown in Table 5.

In the same way, local and actual urban background values can be examined by using an urban scale dispersion model (e.g.: ADMS-Urban). If this kind of evaluation for Szeged is not available, annual average values of an urban site would be accepted as background concentration in the measuring site, which is far away from sources and, which is, therefore broadly representative of city-wide background conditions, e.g. elevated locations, parks and urban residential areas. Only one monitoring site is operating at Szeged (Kossuth Lajos Avenue 89), annual averages of which are given in Table 5.

RESULTS AND CONCLUSIONS

Model integrations for all 9 locations (Figure 4) were performed using traffic data for each year in the period considered. The statistics (11-year averages, standard and relative deviations) of the input traffic data and output CO concentrations (Table 6), as well as temporal course of CO and NO_2, annual mean and 1 h 98 percentile concentrations are presented for site 4 (large traffic) and site 9 (small traffic) (Figure 5), respectively.

TABLE 6 - Model results of 11-year integration at 9 sites in Szeged for CO. 11-year averages, standard deviations and relative deviations are given for traffic and CO concentrations, respectively. Average fraction of trucks and city background concentrations (C_b) are also given. (Input sets of road type, traffic speed and tree factor data at each site are presented in Table 3.)

Site	Fraction of trucks, %	traffic (number of vehicles per day) 11-year average	Standard deviation	Relative deviation (%)	CO concentration (μg·m^{-3}); C_b = 254 μg·m^{-3} 11-year average	Standard deviation	Relative deviation (%)
Site 1	0.13	28 219	8 652	31	976	225	23
Site 2	0.08	26 011	6 471	25	1 398	273	20
Site 3	0.06	22 887	4 109	18	1 253	176	14
Site 4	0.04	21 408	3 188	15	740	92	12
Site 5	0.05	17 419	2 672	15	1 829	380	21
Site 6	0.04	10 849	3 280	30	1 234	340	27
Site 7	0.07	11 741	1 649	14	701	253	36
Site 8	0.05	8 851	1 156	13	735	58	8
Site 9	0.08	5 063	1 520	30	383	38	10

Major findings of the study are as follows.

Traffic increased with time at all locations during the period 1997-2007 (Figure 4).

[i] The pattern of traffic (spatial distribution) did not change during the period of time considered. Annual mean daily number of vehicles was the largest at site 1 and the smallest at site 9 in all year (Table 6).

[ii] 1 h 98 percentile concentration values of CO at a site with high traffic (e.g. site 5) are approximately 4 times higher than values at a site with low traffic (e.g. site 9).

[iii] Mean annual concentration of CO is less then 40% of the limit for *Highly Protected* category (1 000 $\mu g \cdot m^{-3}$) at site 9 and around 74% at site 4, while 1 h 98 percentile values are around the limit for *Protected I.* category (2 000 $\mu g \cdot m^{-3}$) at site 9 and above it at site 4.

[iv] Results obtained for NO_2 are similar to those for CO (Figure 5).

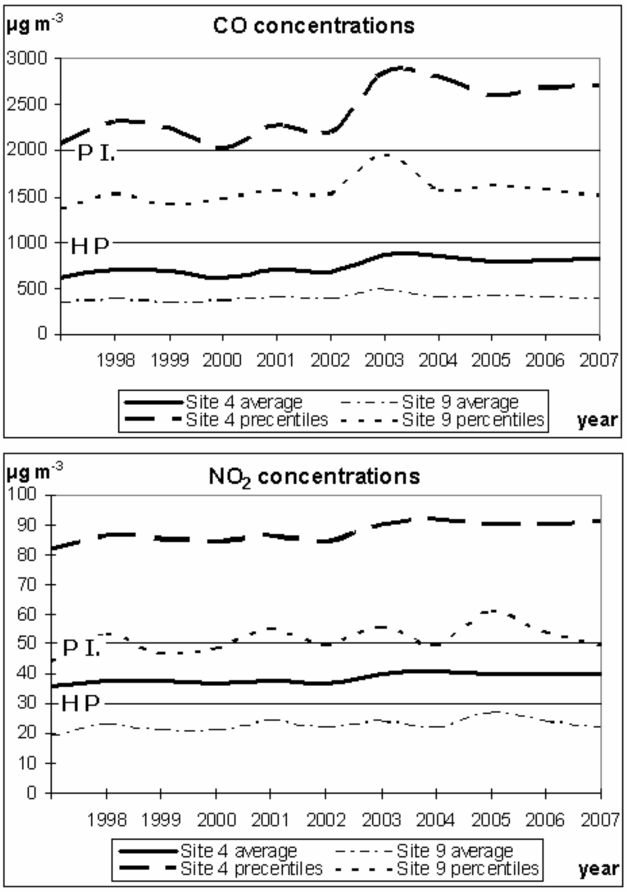

FIGURE 5 - Calculated annual mean and 1h 98 percentile CO (upper panel) and NO_2 (lower panel) concentrations ($\mu g \cdot m^{-3}$) at sites 4 and 9. Concentration limits: HP: Highly Protected; P I.: Protected I.

For the year 2001 a test calculation of concentration cross section at Site 4 on a monthly basis was performed (Figure 6). Seasonal variation of the tree factor and monthly mean wind speeds were taken into account. There was a significant variation in the output concentrations, although a seasonal variation in the traffic itself was not considered. According to the results, much higher concentrations occur in the summer than in the winter. This is due to the fact that wind speed is the least from late summer till early autumn (2.7-2.9 $m \cdot s^{-1}$, from July till November) and vegetation has more effect on the wind speed in summer and autumn than in the winter (Figure 6).

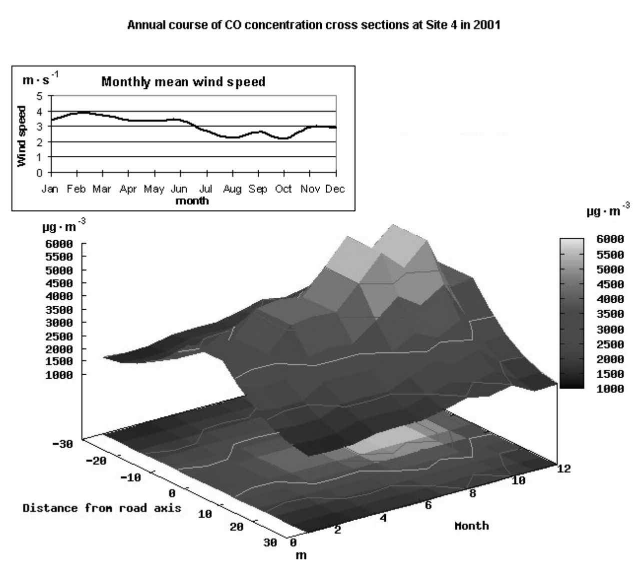

FIGURE 6 - Cross sections of CO 1 h 98 percentile concentrations for each month in 2001. (Monthly mean wind speed (top left) and seasonal variation of tree factor are considered.)

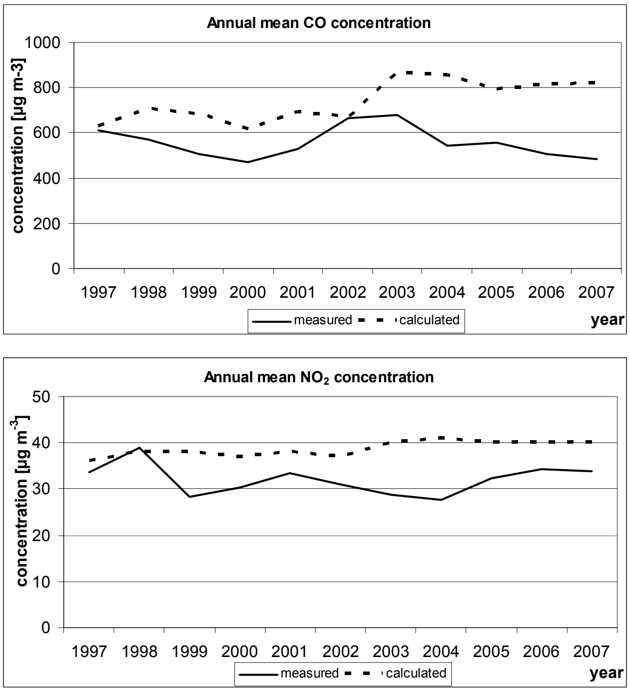

FIGURE 7 - CO (upper panel) and NO_2 (lower panel) annual mean concentrations ($\mu g \cdot m^{-3}$) measured near site 4 (solid line) and calculated (dotted line) for site 4, respectively.

Furthermore, it was detected that a doubling in the traffic (i.e. double number of vehicles) results in 71 % increase in the CO concentration. Neither the effect of trees nor the increasing traffic speed can compensate the effect of a double truck fraction. The fraction of trucks has a great impact on the NO_2 concentration.

Concentration data collected at the air quality monitoring station (near site 4) were compared to the above model output. Concentration data showed slight growth for CO and a gradual decrease for NO_2 (6.88 $\mu g \cdot m^{-3} \cdot year^{-1}$ and –0.62 $\mu g \cdot m^{-3} \cdot year^{-1}$, respectively) in the period considered (1997-2004) (Figure 7).

Measured data were slightly lower than the modelled ones. In the model results a smaller deviation is present from the average than in the measurements. These discrepancies arise from the fact that emission parameters have been taken constant, although the structure and technical quality of the transportation system in Szeged is improving considerably.

It should be noted that in the present work we only wanted to demonstrate the behaviour of the CAR model, and did not want to fit them to measurements, although we did not get good agreement between the modelled and measured concentrations. In order to use the model by decision makers for environmental prediction, the emission parameters used for the calculations should be updated on a regular basis.

To summarize the results, main findings are as follows: concentrations of the pollutants increase with the (i) increasing number of vehicles, (ii) decreasing speed of road traffic, (iii) larger fraction of heavy vehicles, (iv) increasing number of trees alongside the roads and (v) smaller mean annual wind speed.

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