APPLICATION OF CALINE4 FOR MODELING DISPERSION OF ROADSIDE CO AND NO_2 EMISSIONS IN SZEGED, HUNGARY

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REZUMAT. În această lucrare este prezentat un studiu al calităţii aerului din regiunea Szeged, pentru o perioadă cuprinsă între 1995 şi 2007. Parametrii utilizaţi sunt după cum urmează: cei meteorologici, caracteristicile drumului şi poziţii ale receptorilor. Efectele calităţii aerului de la emisiile de trafic au fost evaluate folosind un model de dispersie - CALINE4.

Cuvinte cheie: calitatea aerului, model de dispersie, CALINE4.

Abstract. In this paper is presented a study for air quality of Szeged area, for the period between 1995 and 2007. The parameters used are as follows: meteorological parameters, characteristics of the road, and positions of the receptors. The ambient air quality effects of the traffic emissions were evaluated using the CALINE4 dispersion model.

Keywords: air quality, dispersion model, CALINE4.

1. INTRODUCTION

EU urban areas host 80 % of the population and generate 75 to 85 % of gross national product. They play an essential role in the vitality and competitiveness of Europe. However, this vitality is today endangered by the impact of non-sustainable urban means of transport. Private car use generates pollution, high energy consumption, noise, congestion and accidents. Reducing emissions, improving air quality, reducing accidents and congestion, reducing social deprivation, and thus increasing the quality of life in urban areas, requires modal shift from private transport to public and sustainable transport.

Vehicular consumption of fossil fuel contributes over 90 % of air pollution in Hong Kong (Hung, 2006). Rate of this parameter is 72 % in Delhi (Yedla and Dhakal, 2007) and 75 % in Mexico City (Stevens et al., 2005). In Hungary, traffic is responsible for the following ratios of the total emissions: 70 % for CO, 55 % for NO_x and 14 % for PM (Ministry for Environment, Hungary, 1995-2004).

The aim of the study is to analyse how air pollution of vehicular traffic changed on the main roads of the Szeged regions between 1995-2007.

2. TOPOGRAPHY AND AIR QUALITY OF SZEGED AREA

2.1. Topography

The city of Szeged being the largest town in SE Hungary (20°06'E; 46°15'N) is located at the confluence of the Tisza and Maros Rivers characterized by an extensive flat landscape with an elevation of 79 m a.s.l.. The built-up area covers a region of about 46 km^2 with about 155,000 inhabitants.

Szeged and its surroundings are not only characterized by extensive lowlands but also they have the lowest elevation in Hungary but the Carpathian Basin as well. This result to a “double basin” situation. Due to the position of the city in a basin (a smaller one within a larger one), temperature inversions form more easily in the area (e.g. due to cool air flow from the basin slopes) and prevail longer than in flat terrain, leading to an enrichment of air pollutants within the inversion layer.

2.2. Air quality

Air quality is modified and influenced by the prevailing atmospheric conditions, which are controlled by the prevailing meteorological parameters, mainly temperature profile close to ground level. The recorded averages of these for the city of Szeged are the following: annual mean temperature: 11.2°C; mean January and July temperatures: –1.2 °C and 22.4 °C, respectively; mean annual relative humidity: 71 %; mean annual precipitation total: 573 mm; mean annual sunshine duration: 2102 hours; mean annual wind speed: 3.2 m s^{-1}.

The city structure is a very simple one characterized by an intertwined network of boulevards, avenues and streets sectioned by the River Tisza. However, this simplicity also largely contributes to the concentration of traffic as well as air pollution within the urban areas.

The industrial area is mainly restricted to the north-western part of the city. Thus, the prevailing westerly and northerly winds tend to carry the pollutants from this area towards the city centre.

The total urban spread extends well beyond the city limits and includes the largest oil field in Hungary with several oil torches located just north of the town. This oil field is also a significant source of such air pollutants as NO_x and sulphur dioxide. The power station, located in the western part of the city, is also a major source of pollution. Exhaust fumes have also largely contributed to the steady increase of nitrogen oxide and carbon monoxide in the air of Szeged. Besides, as a result of the heavy traffic, deposited dust is often suspended in the air.

In a detailed analysis, Szeged was ranked to the 32nd position of 88 Hungarian cities, according to the quality of the environment and the level of environmental awareness. [The city ranked to the 1st position was considered to have the best environmental conditions (Makra et al., 2002)].

On the basis of the frequency of pollutant concentrations exceeding the air quality limits, measured at the Regional Immission Examining (RIE) network of stations for Hungary in 2001, the air quality of Szeged, according to a three-category classifying system (satisfactory, moderately polluted, polluted), can be listed into the "polluted" category (Mohl et al, 2002).

The traffic system of Szeged is highly overcrowded. Among vehicles participating in the traffic, the ratio of passenger cars is the highest: 84 %. In the year 2000, after modernization of vehicles, CO concentration of the air in the city was reduced to 36-40 % of that measured in 1990. On the other hand, the traffic in the main roads increased to 3-70 % during the same period. During a regular day (a 24-hour period) about 70-90 thousand vehicles, on an average, pass through the city (Mohl et al., 2002).

3. DATA

Meteorological parameters (direct and derivative), road characteristics and receptor positions were used in the study for the period between 1995-2007 (Table 1). The parameters considered are as follows: I: meteorological parameters: air temperature (°C), wind speed ($m{\cdot}s^{-1}$), wind direction (degree), standard deviation of the wind direction (degree), atmospheric stability (A-G), height of the mixing layer (m), aerodynamic roughness (cm); II. Characteristics of the road: traffic density (vehicle / hour), emission factor (g / vehicle mile), height of the road (m), width of the road (m); III. Positions of the receptors: X coordinate, Y coordinate, Z coordinate (m).

4. METHOD

Pollutants outcome from the exhaust pipe take part in primary process, on the one hand the thermal turbulence caused by the different surface heating and by the buoyant exhausted plume create eddy movements and, on the other hand, mechanical turbulence is induced from the wind flow and the traffic wake. Thermal influences interact with mechanical effects.

Behind a vehicle due to the thermal and mechanical turbulence a well-mixed zone can be occurred.

The ambient air quality effects of the traffic emissions were evaluated using the CALINE4 dispersion model (Benson, 1984). CALINE4 is a Gaussian dispersion model specifically designed to evaluate air quality impacts of roadway projects. Each roadway link is treated as a separate emission source producing a plume of pollutants, which disperses downwind. Pollutant concentrations at any specific location are calculated using the total contribution from the overlapping pollution plumes originating from the sequence of roadway links.

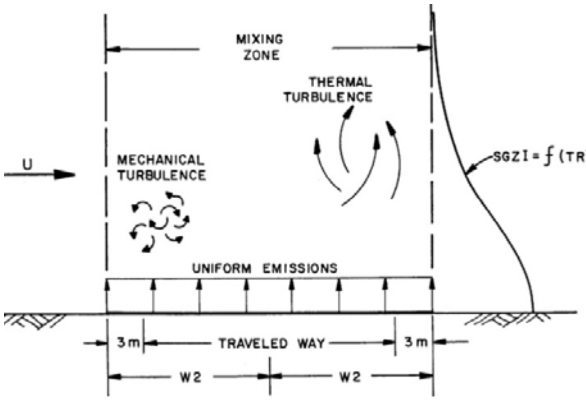


Fig. 1. The Mixing Zone Model.

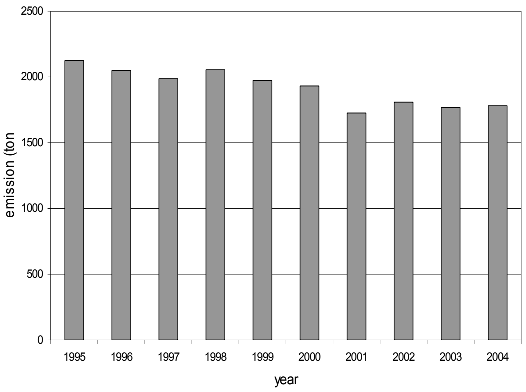


Fig. 2. CO emission of vehicular traffic, Szeged, 1995-2004, t/year (Ministry of Environment, Hungary, 2007).

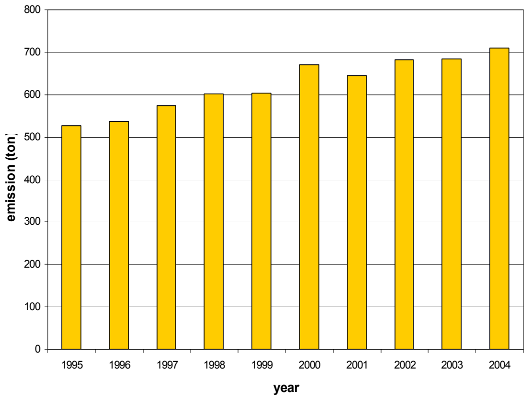


Fig. 3. NO$_2$ emission of vehicular traffic, Szeged, 1995-2004, t/year (Ministry of Environment, Hungary, 2007)

Mixing Zone Model: CALINE4 treats the region directly over the highway as a zone of uniform emissions and turbulence. This is designated as the mixing zone, and is defined as the region over the travelled way (traffic lanes excluding shoulders) plus three meters on either side. The additional width accounts for the initial horizontal dispersion imparted to the pollutants by the vehicle wake.

Pollutants emitted along a highway link are treated as being well mixed within the mixing cell volume due to mechanical turbulence from the moving vehicles and the convective mixing due to the temperature of the vehicle exhaust gases, which are assumed to be the dominant dispersive mechanisms.

The initial vertical dispersion parameter (SGZI) is modelled as a function of the pollutant residence time (TR) within the mixing zone.

Pollutant concentrations downwind from the mixing cell are calculated using horizontal and vertical dispersion rates, which are a function of different meteorological and ground surface conditions (Fig. 1).

In CALINE4, a specific computational scheme called the Discrete Parcel Method is used to model NO$_2$ concentrations. A simplified set of controlling reactions is assumed (Hanrahan, 1999).

5. RESULTS

Vehicular emissions of CO and NO$_2$ for the period 1995-2004 show slight temporal change. CO indicates decreasing, while NO$_2$ increasing trends, however neither are significant (Figs. 2-3).

Annual mean concentrations, as means of all the receptors, for both CO and NO$_2$, on the major roads of the Szeged region, modelled in one meter height, show clear increasing trends (Figs. 4a-b).

Annual mean CO concentrations on some major roads of the Szeged region, considered in the function of the receptors, indicate higher values in the downtown and lower ones towards the outskirts. Furthermore, they show slight increasing trend (Fig. 5).

Annual mean NO$_2$ concentrations on some major roads of the Szeged region, considered in the function of the receptors, also indicate higher values in the downtown and lower ones towards the outskirts. They show more definite increasing trend as CO concentrations (Fig. 6).

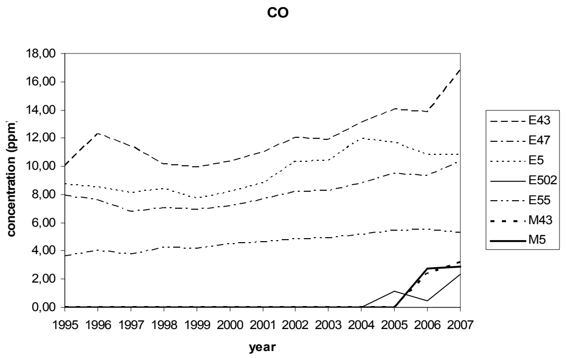


Fig. 4*a*. Annual mean CO concentrations, as means of all the receptors, on the major roads of the Szeged region, ppm (h = 1 m).

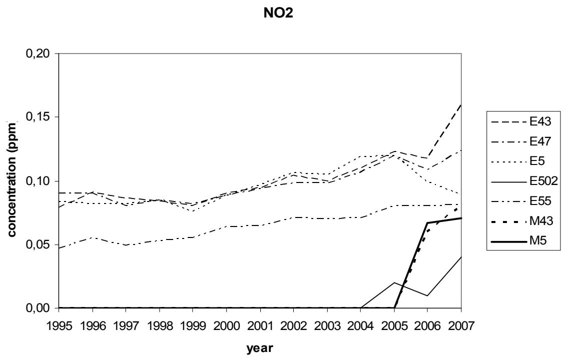
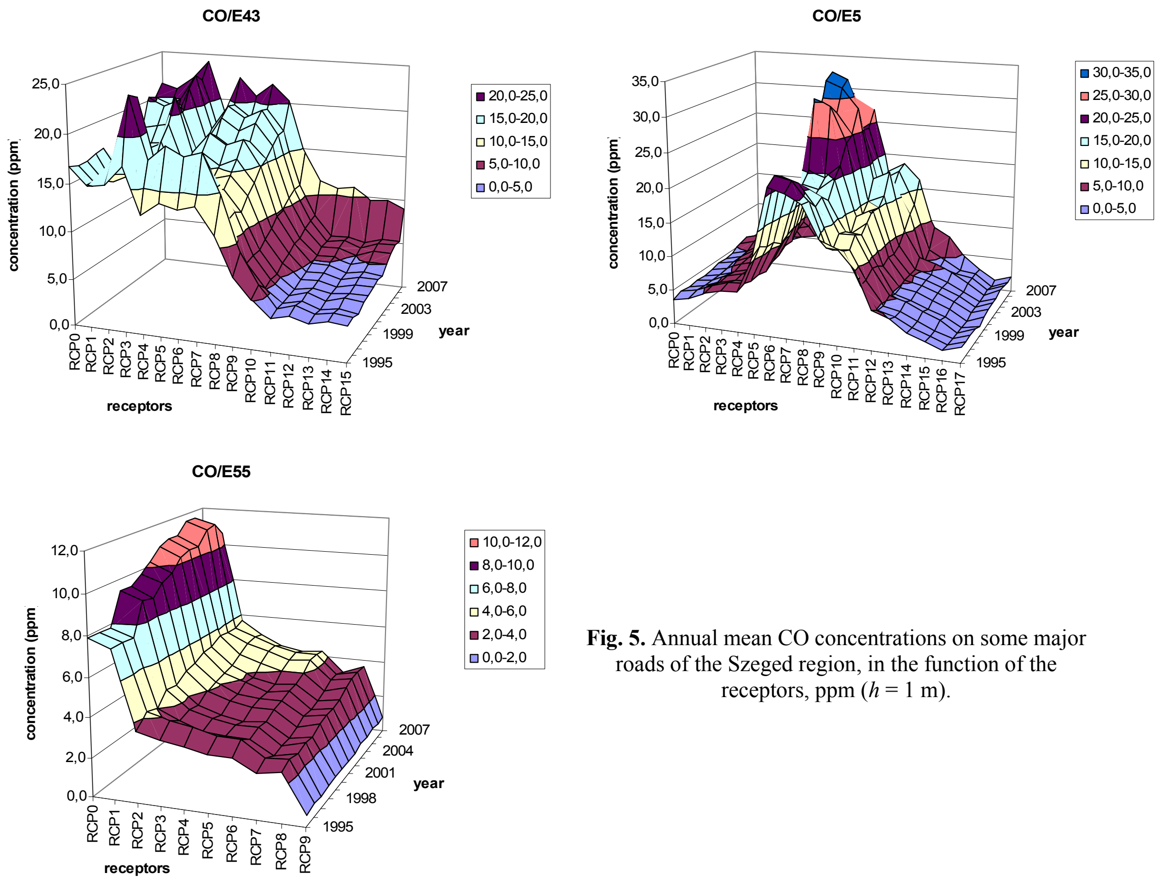


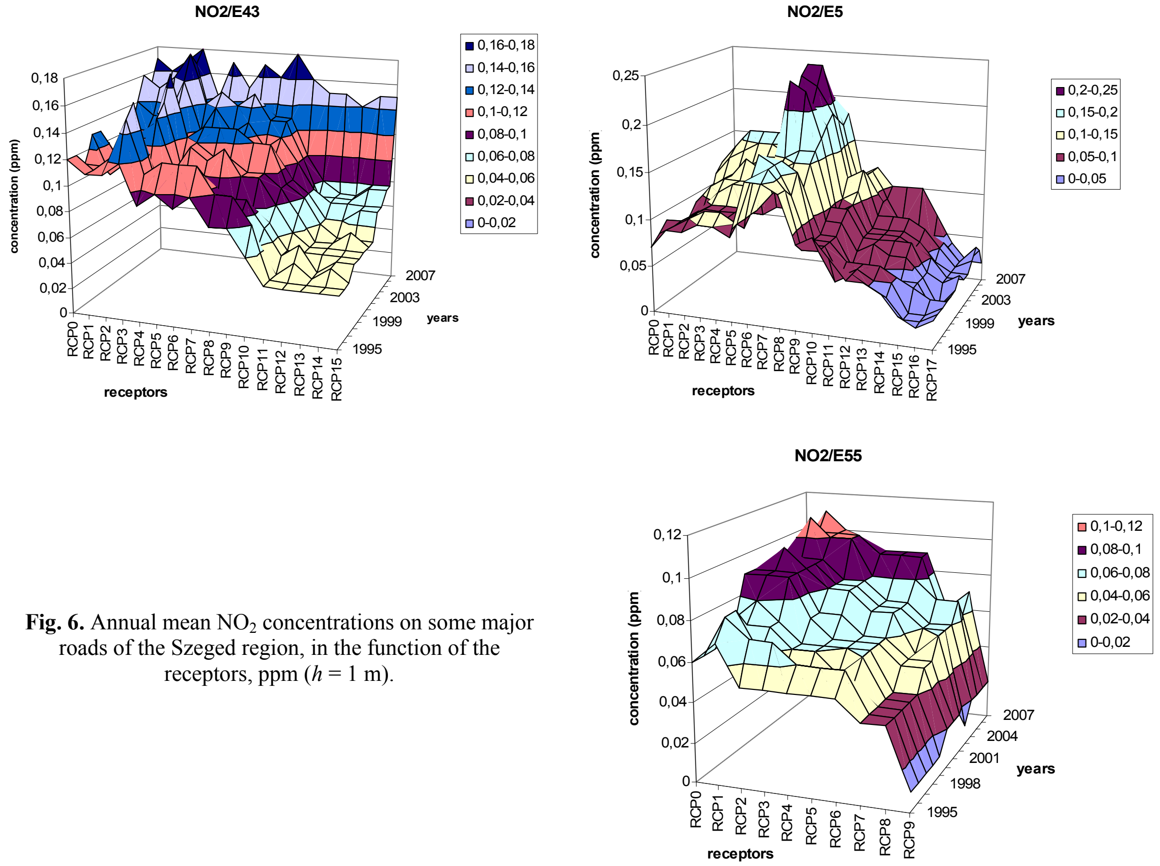
Fig. 4*b*. Annual mean NO$_2$ concentrations, as means of all the receptors, on the major roads of the Szeged region, ppm (h = 1 m).


CO/E43

CO/E5

CO/E55

Fig. 5. Annual mean CO concentrations on some major roads of the Szeged region, in the function of the receptors, ppm (h = 1 m).


NO2/E43

NO2/E5

NO2/E55

Fig. 6. Annual mean NO_2 concentrations on some major roads of the Szeged region, in the function of the receptors, ppm (h = 1 m).

Annual mean CO concentrations on the major roads of the Szeged region are indicated using CALINE4 model for each year between 1995-2007. However, CO load for the starting year (1995) and years 2006 and 2007 are only presented (Figs. 10*a-b*). The figures clearly indicate the increase of CO concentrations from the beginning by the end of the period examined.

Annual mean NO_2 concentrations on the major roads of the Szeged region are also indicated using CALINE4 model for each year between 1995-2007. However, NO_2 load for the starting year (1995) and years 2006 and 2007 are only presented (Figs. 8*a-b*). The figures clearly indicate a much more definite increase of NO_2 concentrations from the beginning by the end of the period examined. Especially striking is the difference between years 2006 and 2007. This denotes to the highly increased traffic through Szeged from Romania and Bulgaria after they entered the European Union on January 1, 2007.

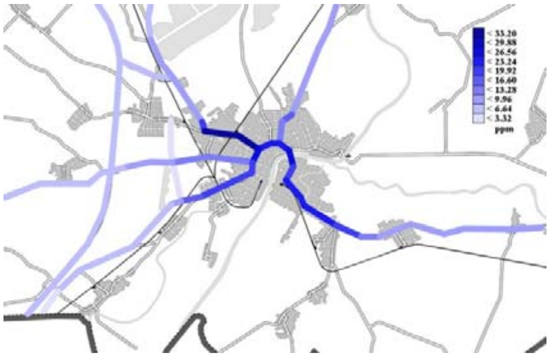


Fig. 7*a*. Annual mean CO concentrations on the major roads of the Szeged region, 2006, ppm (h = 1 m).

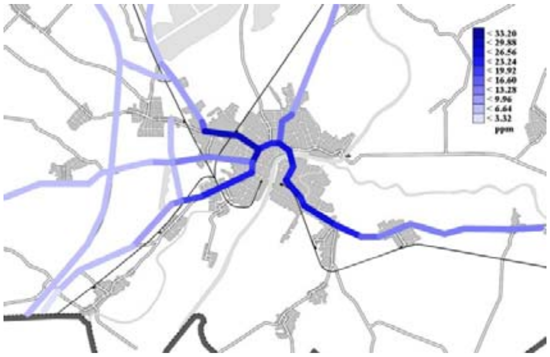


Fig. 7*b*. Annual mean CO concentrations on the major roads of the Szeged region, 2007, ppm (h = 1 m).

Fig. 8*a*. Annual mean NO_2 concentrations on the major roads of the Szeged region, 2006, ppm (h = 1 m).

Fig. 8*b*. Annual mean NO_2 concentrations on the major roads of the Szeged region, 2007, ppm (h = 1 m).

6. CONCLUSIONS

Vehicular traffic of Szeged is permanently increasing. However, in year 2007 an especially striking increase of vehicular traffic was experienced. Due to the EU membership of Romania and Bulgaria (January 1, 2007) number of trucks and lorries going through Szeged from these new EU countries quadrupled in 2007 compared to that in 2006. This increased traffic means a remarkable load of the road no. E43. As a result, houses are cracking, high noise is measured, higher source of danger appears for pedestrians and remarkably higher vehicle originated air pollution can be experienced as it is clearly indicated by CALINE4 dispersion model.

The solution for this problem is to build the highway M43 from Szeged to the Hungarian-Romanian border. This 64 km highway section will be built by 2010 and with this the densely populated region of the main road E43, going through Makó and Szeged cities and many villages, will be relieved mitigating the traffic load and the high accident risk.

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REFERENCES

[1] Benson, P., 1984: CALINE4 – *A Dispersion Model For Predicting Air Pollutant Concentrations Near Roadways.* Report No. FHWA /CA/TL-84/15. State of California, Department of Transportation, Division of New Technology and Research

[2] Hanrahan, P.L., 1999: *The plume volume molar ratio for determining NO_2/NO_x ratios in modelling* – Part I: Methodology**.** Journal of Air & Waste Manageement Association, 49, 1324-1331.

[3] Hung, W.T., 2006: *Taxation on vehicle fuels: its impacts on switching to cleaner fuels.* Energy Policy, 34(16), 2566-2571.

[4] Makra, L., Horváth, Sz., Sümeghy, Z., 2002: *An objective analysis and ranking of cities on environmental and social factors. IGU 2002*. Geographical Renaissance at the Dawn of the Millennium. Durban, South-Africa, 2002. In: Climates in Transition (Nkemdirim, L.C. ed.), Minuteman Press 161-172.

[5] Ministry for Environment, Hungary, 1995-2004. *Traffic related emissions in Hungary.*

[6] Mohl, M., Gaskó, B., Horváth, Sz., Makra, L., Szabó, F., 2002: *2nd Environmental Programme of Szeged, 2003-2007.* Manuscript (in Hungarian) (Mayor's Office, H-6720 Szeged, Széchenyi tér 10, Hungary)

[7] Stevens, G,. Wilson, A., Hammitt, J.K., 2005: *A benefit-cost analysis of retrofitting diesel vehicles with particulate filters in the Mexico City metropolitan area.* Risk Analysis, 25(4), 883-899.

[8] Yedla, S., Dhakal, S., 2007: *Transportation and environment in developing countries.* International Journal of Environment and Pollution, 30(1), 1-7.