AIR QUALITY MODELLING IN EUROPEAN CITIES: A LOCAL SCALE PERSPECTIVE

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INTRODUCTION

The deterioration of air quality in urban areas is a cause of serious concern in practically all developed countries. The full application, enforcement, and implementation of the existing environmental legislation have become a worrying issue for national and international authorities. Most of these authorities are currently involved in assessing the status of urban air quality aiming to affront anthropogenic pollution by introducing suitable abatement scenarios in activities that create environmental pressures, such as transportation. In this perspective, atmospheric pollution modelling has lately received an increasing attention from decision-makers but, on the other hand, credible results are also expected to contribute to the definition of strategies for sustainable cities.

The main purpose of this paper is the study of air pollution in sensitive areas of different five European cities (Gdansk, Genoa, Geneva, Lisbon and Thessalonica) through the application of a numerical system composed by two different models, which were developed at the University of Aveiro: the Transport Emission Model for Line Sources (TREM) and the local scale dispersion model VADIS. In order to promote sustainable urban development, current and future transportation scenarios were developed and analysed using results from TREM and VADIS application.

MODELLING SYSTEM

The modelling system applied in this study, developed to provide the information required for the analysis of air pollution problems in urban areas, is briefly presented.

Traffic emissions estimation

The main purpose of the Transport Emission Model for Line Sources (TREM) is the estimation of the quantity of pollutants released to the atmosphere from on-road vehicles, implemented in GIS environment and particularly designed for line sources (Tchepel, O. *et al*, 2002). The model is based on average speed approach and uses the emission functions derived from MEET/COST methodology. Different technologies (engine type, model year) and engine capacity are distinguished in TREM to derive emission factors. TREM allows the estimation of the following pollutants: Carbon Monoxide (CO); Nitrogen Oxides (NO_x); Volatile Organic Compounds (VOC), including methane; Carbon Dioxide (CO_2); Sulphur Dioxide (SO_2) and Particulate Matter (PM). Furthermore, as an indicator of model performance, fuel consumption is calculated in order to provide additional data to be compared with statistical information.

The insufficiency and uncertainty associated with the input data required by TREM model, which is characterised, basically, by vehicle fleet composition, traffic volume for each road segment and average vehicle speed, are factors that affect, naturally, the quality of results. In order to investigate how the input data uncertainties influence emissions estimation, the Monte Carlo analysis has been applied. The results of simulations for different pollutants indicate that uncertainty of emission estimation induced by input data is of about 4% (TREM, 2002).

Flow and dispersion modelling

VADIS, a near-field model also developed at DAO-UA, allows the calculation of urban street canyon air pollution due to traffic road emissions and the estimation of local *hot-spots*, particularly under unfavourable dispersion conditions, as thermal stability and low wind speeds (Borrego, C. *et al*, 2000). This model supports multi-obstacles and sources definition and the characterization of time varying flow fields and emissions.

VADIS functioning scheme is based on a two-module structure. Firstly it applies the three-dimensional (3D) Reynolds averaged Navier-Stokes equations and the k-ε turbulence closure to the calculation of 3D fields of wind, turbulent viscosity, pressure, turbulence and temperature. This information is needed as input for the second module, which applies a Lagrangian approach to the computation of the 3D concentration field.

The input data required by the model is related with local meteorological conditions characterization, with buildings volumetry and emissions definition.

CASE STUDIES

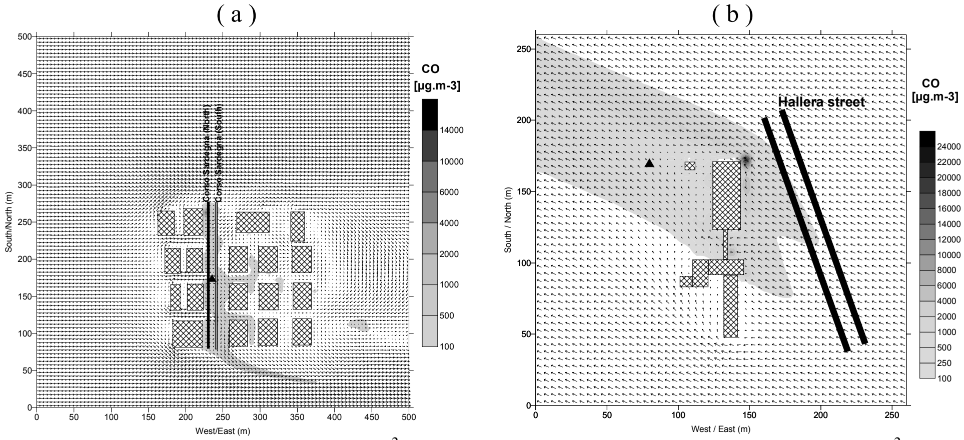
The developed modelling system was applied to specific areas of the five European cities (Gdansk, Genoa, Geneva, Lisbon and Thessalonica), which are characterised by heavy traffic emissions and where local hot spots air pollutants levels are expected to occur. The city areas are characterised by distinct configurations, buildings geometry, meteorological conditions and different traffic fluxes and consequently modelling results can not be directly compared.

An important factor to the validation process of the modelling system is the existence of an air quality station in the considered simulation domains. In the scope of this work, the CO concentration fields for some selected hours with specific dispersion conditions were calculated by the numerical system in order to test the model performance.

For the Lisbon application, the selected area is situated in the downtown and it is characterised by strictly perpendicular streets including several one-way roads and a pedestrian zone. The study domain covers an area of 450 m x 450 m. In order to obtain CO concentration levels and to evaluate the air pollution associated to road traffic in the study domain, the modelling system was applied to a 24 hours simulation. Information on buildings volumetry, traffic countings, vehicles characterization and meteorology was introduced as input data to the model. Based on the data obtained from a typical summer day simulation, the CO concentration values are not exceeded within the study domain, in comparison with European Air Quality legislation (Tchepel, O. *et al*, 2002).

Concerning Genoa and Gdansk cases the same methodology was used. Buildings simple configuration and single major sources characterise these domains. Figure 1 represents an example of the wind and dispersion fields of Genoa and Gdansk cases, corresponding to 8 a.m. and 11 a.m., respectively. The results obtained with the hourly simulation show that CO concentration values measured and estimated are considerably low compared to the 8-hours average limit value (10 000 $\mu g.m^{-3}$) of the new European Directive. On the other hand, a non-significant difference between model output and air quality measured data was found, indicating a good modelling system performance.

(a) (b)



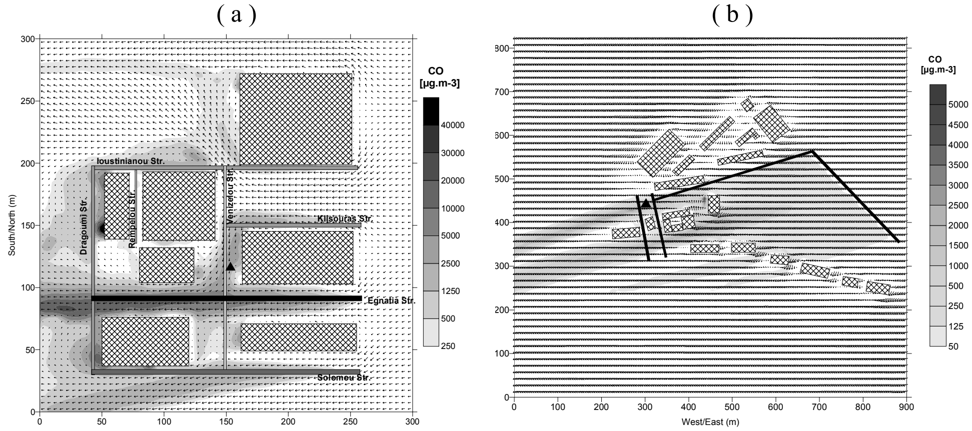
8:00 - 9:00 (▲ CO - 1260 µg.m^{-3}) Wind dir.: 292º; Wind vel.: 5,9 m.s^{-1}

11:00 - 12:00 (▲ CO - 474 µg.m^{-3}) Wind dir.: 113º; Wind vel.: 1,3 m.s^{-1}

Figure 1. CO dispersion simulation for Genoa (a) and Gdansk (b) cities.

For the Thessalonica and Geneva cases the central part of the cities characterised by intense traffic were selected for the study. A comparison between CO concentration values estimated by the modelling system for the two cities and the air quality measured values show a good agreement. Air Quality directive values are not exceeded for the Geneva domain, however, the European legislation is largely exceeded in the Thessalonica case, where values above the 40 000 µg.m^{-3} can be found. According to the CO emission values for each line source considered in the domain, Egnatia street has an important contribution on the elevated values of CO pollutant concentration found in this street and in the adjacent Dragoumi street (Figure 2. (a)).

(a) (b)



9/9/1998 7:00 - 8:00 (▲ CO – 2900 µg.m^{-3}) Wind dir.: 82º; Wind vel.: 1,5 m.s^{-1}

13/01/2001 - 15:00 - 16:00 (▲ CO – 1450 µg.m^{-3}) Wind dir.: 72º; Wind vel.: 4,9 m.s^{-1}

Figure 2. CO dispersion simulation for Thessalonica (a) and Geneva (b) cities.

In order to promote a sustainable development in these European cities, air quality standards should be accomplished with adequate abatement strategies. In this scope, the development of future transportation scenarios and the utilization of suitable numerical tools to predict future air quality concentration values are important policies to take into account in urban management.

INDICATORS AND SCENARIOS

Scenarios are a way of understanding the dynamics influencing the future, representing sequences of events over a certain period of time and exploring the different outcomes associated with "what if" questions (Jungermann, H., 1985). In this way the scenarios become a very useful tool to decision-makers. However, it is very important to identify the issue to address and what will be used as a test of relevance during the scenario-making process. That is why indicators are central to scenario development. Also, indicators are very useful when the evolution of a process or the results of a particular action on a complex system, such as the environment, needs to be evaluated.

In the present case-studies, having as main purpose the analysis of air pollution related to transport emissions, a set of relevant indicators has been developed. The indicators were classified in four different categories: demographic, economic, technology and land-use indicators (Caratti, P. *et al*, 2002). Table 1 shows the set of indicators used in the study.

Table 1. Set of indicators for the scenarios definition

Demographic Indicators	Economic Indicators	Technology Indicators	Land-use Indicators
▪ Size of the population ▪ Age structure of the population	▪ Population employed at the service sector ▪ Home-based teleworking	▪ Passenger car occupancy rate ▪ Public transport share ▪ Information technology in traffic control ▪ Penetration rate of new vehicle propulsion technologies	▪ Mixed-land-use index

High growth and low growth scenarios were built using a combination of evolution trends for some indicators in order to interpret different urban transportation scenarios consequences on sustainability and development. These scenarios were applied for each city, using the numerical tool already described, and the results are being analysed.

CONCLUSIONS

The application of the modelling system to the five European cities has shown that a good agreement between measured and estimated values was accomplished. The analysis of concentration values magnitude for each specific city, identify the Thessalonica domain as the situation of more concern, where air quality standards are largely exceeded. In these kind of situations important measures on traffic management should be taken in order to reduce pollutants concentration to acceptable values. The development of future scenarios and the application of modelling tools to predict air quality can have an important role in gathering information for decision-makers and to accomplish air quality policies.

The harmonization of European air quality policies based on the recent Framework Directive establishes new requirements for air quality modelling including the definition of the Modelling Quality Objectives as a measure of modelling results acceptability. In this scope, models can be used to evaluate air quality management options, not only as a tool for obtaining information but also for planning and strategic development.

The application to the specific city cases constitutes the real proof of the capability of this numerical tool to simulate air quality for different traffic scenarios, confirming its importance in air quality assessment and policy support, namely in emergency planning and with regulatory purposes. The interpretation of model results allowed to obtain air quality reference values at the simulated area, which can be used in traffic management as a way to improve citizens' life quality.

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