Local scale vehicles pollution study in the absence of sufficient data: the case of the city of Thessaloniki

M. J. Assael, M. Delaki & K. Kakosimos
Thermophysical Properties Laboratory,
Chemical Engineering Department,
Aristotle University, Thessaloniki, Greece

Abstract

Air quality in urban environments can today be modelled by a large number of computer models (empirical, box models, CFD). OSPM (Operational Street Pollution Model) is one of the most widely used empirical-box models due to its simplicity and its very good performance. However, in most cases the necessary data, even for such simple computations, are not all available, leading to large errors, especially when employed for future planning. The City of Thessaloniki (Greece) was studied as an example, as although few input-data are available, there are enough measurements to validate the model's results. The current work proposes a methodology for dealing with this lack of data, confirmed by comparison with measured values. Following that, a sensitivity analysis for the most common input parameters is presented. Finally, OSPM is employed to predict the air quality in some highly-possible future scenarios.
Keywords: atmospheric pollution, simulation, models, OSPM.

1 Introduction

Air pollution is one of the most severe problems in urban areas. In recent years, the Thermophysical Properties Laboratory of Chemical Engineering Department in Aristotle University has focused on the study of the atmospheric pollution of the historical centre of Thessaloniki. In order to estimate the air pollution, solely due to traffic, the well-known OSPM model [1], is employed. This model has been widely used in the past [2] and validated for similar cases [3, 4].

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1.1 Overview

OSPM is developed for practical applications and especially for the estimation of pollution due to traffic in street canyons. The model employs a simplified parameterization for the conditions in a street canyon, influenced by the wind flow and the pollutants dispersion. Pollutants' concentrations are calculated by using a combination of a Gauss model (for the direct contribution) and a box model (for the recirculation in the street canyon). To estimate vehicles' technology distribution in future years, the model TRENDS [5] is employed.

Unfortunately the application of models such as OSPM for a certain period of time (e.g. a year), requires a large amount of input data, which in most cases, is not available. For this reason, the authors aim to examine OSPM's application in the absence of sufficient data and to propose specific actions to elaborate this significant drawback. The work presented here, consists of three main parts: i) the enumeration of the input data and their sources, and the identification of the area of interest, ii) a specific evaluation of OSPM and iii) the estimation of some atmospheric pollutants for two future scenarios (table 1).

2 Input data

For the calculations, the following input data are required: i) streets' geometrical configuration, ii) meteorological data (temperature, wind speed and direction), iii) background concentration of each pollutant and iv) pollutants emissions. The latest version of OSPM (WinOSPM/2003) contains a fully integrated emission module that uses the traffic characteristics, such as the technology of the vehicle fleet, a mean speed and vehicles' number, to calculate hourly emissions due to traffic. Table 2 describes the necessary input data and their sources.

Table 1: Description of elaborated scenarios.

No	Description
1	June and February of 2004
2	June and February of 2010 according to TRENDS' estimation
3	June and February of 2010 according to authors' raw estimation

Table 2: Input data sources.

Data	Source
Streets' geometrical configuration	City Traffic Study [6, 7]
Meteorological data	Station SV2BBO [8]
Background concentration	AirBase EIONET [9] (Stations of Panorama & Neochorouda)
Pollutants emissions	COPERT III [10]
Traffic load	Public Works Office [11]
Number of vehicles per technology	TRENDS [5]

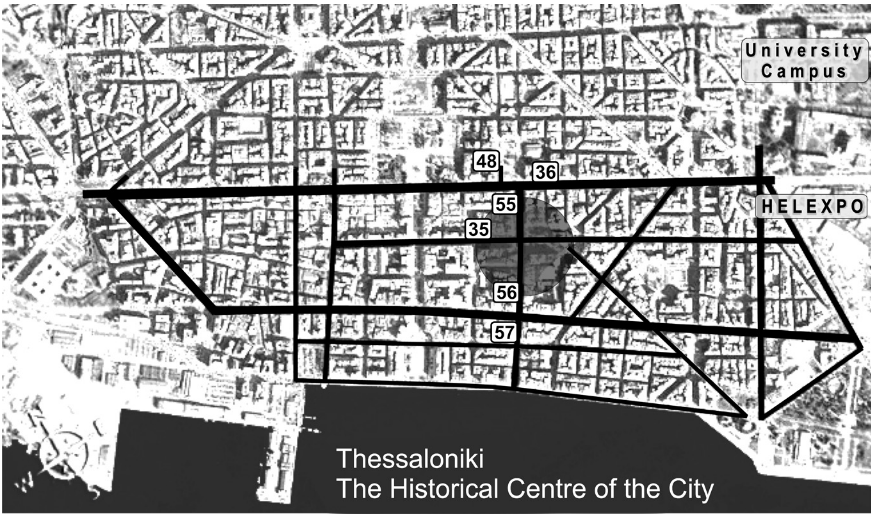

Figure 1: Area map.

2.1 Area of interest

The city of Thessaloniki is located in the northern part of Greece, on the coast and it has almost 1.5 million citizens. It is considered to be one of the most polluted cities regarding the airborne particles (e.g. PM10). Figure 1 shows the area of interest, which is the historical centre of the city.

In figure 1, the highlighted streets are those incorporated into the main model (which will not be shown here), while the numbered ones are the streets in which this work is focused. The area in the grey circle represents the area where measured data are available.

2.2 Missing data

Although in the past OSPM has often been employed [2] and was shown to perform very well, the case of Thessaloniki is a difficult one as a lot of the required data are not available or their accuracy is questionable. In the following sections problems encountered in each dataset will be presented together with the authors' suggestions for ways to overpass them.

2.2.1 Streets' geometrical configuration

The streets' geometrical configuration refers to the street's width, length and the height of the buildings at its side. The width was obtained from literature [6,7], while the length was measured by the authors. The height of the buildings however, can only be estimated as an average, as it differs from building to building.

2.2.2 Meteorological data

There is an abundance of meteorological data (Station SV2BBO [8]). There are in general, available on an hourly base and the station is positioned near to the area of interest. These data are collected by an amateur enthusiast, and there is a lack for some time periods.

2.2.3 Background concentrations

The background concentration strongly affects the calculated total concentration. This is also not available for the whole year and for some specific pollutants, a whole year is even missing. In those cases where the background concentration is not available, comparisons or future scenarios can only refer to contributions to air pollution due to traffic.

2.2.4 Traffic load and vehicles technology

Traffic load for every street is unfortunately, available only for one or two days for each year. This means that, estimating air quality for a whole month or year will be based only on a day's measurements. However, it is noticed that traffic load does not vary much even between consecutive years, which indicates that a limit has been reached. On the other hand, it is also well known that traffic load varies enough between week days, and this is the first drawback for such projects. Table 3 describes the number of vehicles per scenario (defined in table 1), fuel and EURO technology.

Table 3: Number in thousands of vehicles per scenario, fuel and EURO technology (TRENDS [5]).

	Fuel								
	Gasoline			Diesel			LPG		
	EURO Technology								
	No	I-III	≥ IV	No	I-III	≥ IV	No	I-III	≥ IV
Passenger Vehicles									
1	1,156	2,356	-	3	647	-	3.5	4.5	-
2	726	2,525	1,067	-	-	-	2.6	4.9	2.4
3	568	1,898	802	285	539	268	-	-	-
Trucks									
1	544.8	288	-	12.9	79.2	-	-	-	-
2-3	372.2	360	155.9	86.3	97.2	10	-	-	-
Busses									
1	-	-	-	7.5	6.7	0	-	-	-
2-3	-	-	-	5.5	7.7	2.3	-	-	-

Vehicles' technology distribution is well established for the whole country and it is easy to project the same distribution to the second largest city. But the problem is that this distribution might vary between streets and this variation can affect the results. Furthermore, vehicles' average hourly speed is based on a simple assumption that it will vary according to the total traffic load of each street. The lowest and the highest speed were selected and then speeds distribution was set to follow the distribution of the traffic load.

3 Comparison and evaluation

In order to perform the comparison between the OSPM output concentration and the measured one [9], the following ought to be taken into consideration

- average building heights are assumed,
- meteorological data are available more or less (so this is not a problem)
- as the background concentration is only available for NO_2, and also measurements for NO_2 exist, this is the pollutant that the comparison will be based upon (measurements for PM10 are not adequate and data on O_3 were not considered as it is not clear whether OSPM takes into account O_3 photochemical effects, while it does take them for NO_2 [12]),
- although the number and technology of vehicles are available, the traffic load is only available for a single day (May 5th, 2004). Hence, all comparisons will be restricted thereafter for this particular day.

3.1 Results

All results refer to the area of interest (figure 1). The concentration of each neighbouring street is calculated for every hour and shown in figure 2, together with their hourly average, and the measured values. The background concentrations as well as the EU limit for 2004 (given by OSPM) are also shown. As it can be seen from figure 2, the average hourly concentration agrees excellently with the values measured in that area. To our opinion this confirms the validity of our methodology and hence this methodology can be applied to the estimation of other pollutants' concentrations where no measurements or other parameters exist.

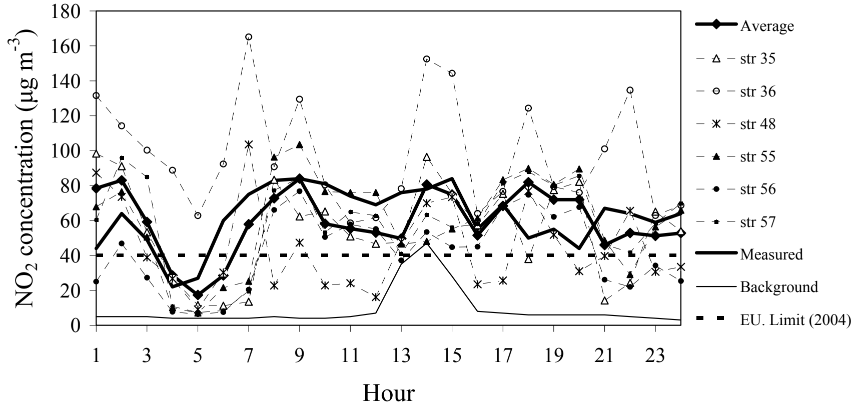

Figure 2: NO_2 concentration ($\mu g\ m^{-3}$) by hour for neighbouring streets.

As an example of this statement, in figure 3, we show the equivalent concentrations for PM10. It is of great interest, that although the concentrations of PM10 are quite high (and surely much higher than the EU 2004 Limit), there are almost no measurements of PM10. Also it is interested to note that even the background concentration of PM10, which is clearly attributed to the industrial area around the city, is much higher than the EU 2004 Limit. These two points, as well as the high NO_2 concentrations, should be of prime importance to the authorities in Thessaloniki.

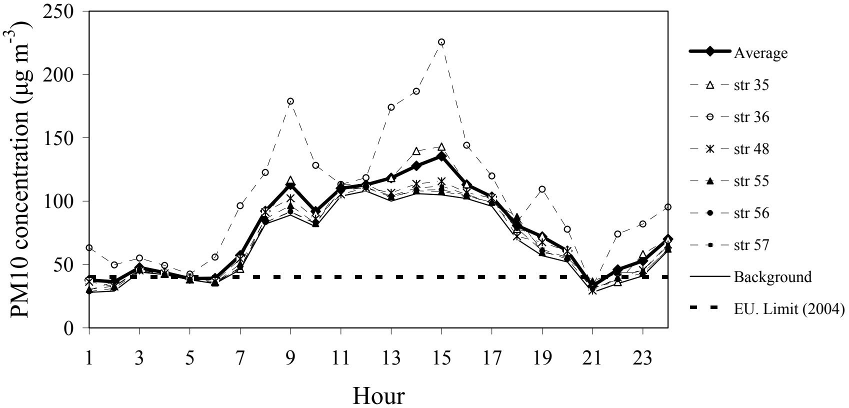

Figure 3: PM10 concentration (μg m^{-3}) by hour for neighbouring streets.

3.2 Sensitivity analysis

In the previous section, by applying our methodology for a particular day, it was shown that the values calculated by OSPM agreed excellently with the measured values. To conclude this analysis, it will be of interest to establish a sensitivity analysis for the five main parameters entering OSPM. Figure 4 illustrates as an example, the influence of these parameters to the calculated concentrations deviating from those for a base case (2004, only passenger cars, street no 55), for five pollutants. It can be seen that the most sensitive parameter, in this case is the width of the street canyon followed by the short vehicle velocity. It can also be seen that the Cold Start parameter has almost no effect.

4 Future scenarios

A complementary aim of the present work is to estimate the future state of air quality in Thessaloniki. Two future scenarios were chosen (see table 1) both for 2010. Meteorological conditions, streets' geometrical configuration and background concentrations were considered identical to the values of 2004. Traffic load and vehicles technology (table 3) for 2010 and the whole country were calculated by TRENDS [5]. To estimate the hourly traffic load per street for Thessaloniki, it was assumed that vehicles distribution per hour and street remains the same as in 2004.

However, the forecasted vehicles' technology distribution predicted for 2010 by TRENDS, assumes that LPG vehicles will replace almost all passenger diesel vehicles and does not take into consideration the fact that the market of diesel vehicles in Greece will be released. For this reason an alternative scenario, scenario 3, is proposed, which is based on a common belief, that 1/4 of passenger vehicles in 2010 will use diesel as a fuel, and not LPG.

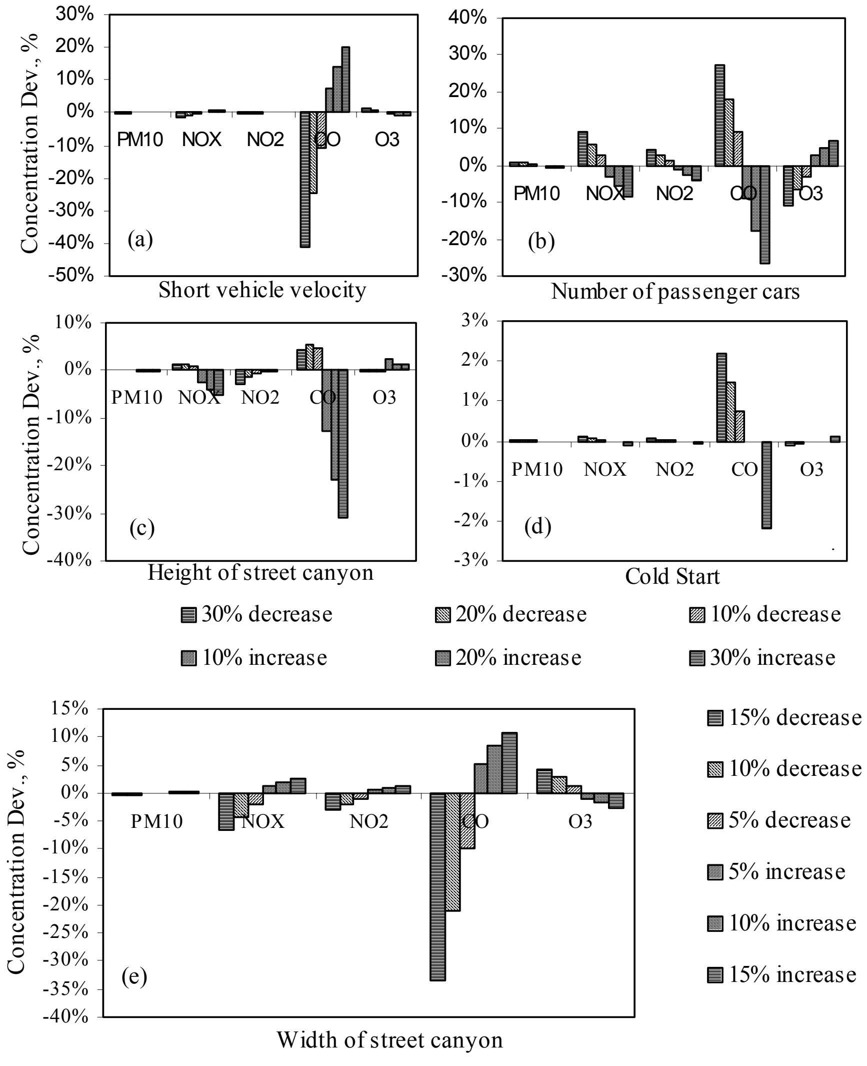

Figure 4: Sensitivity analysis for five important input parameters, for five pollutants.

4.1 Results and discussion

Figures 5-7, illustrate the concentration deviations, for pollutants NO_2, PM10 and CO for scenarios 2 and 3, from scenario 1. Concentrations shown are indicative for the month of February.

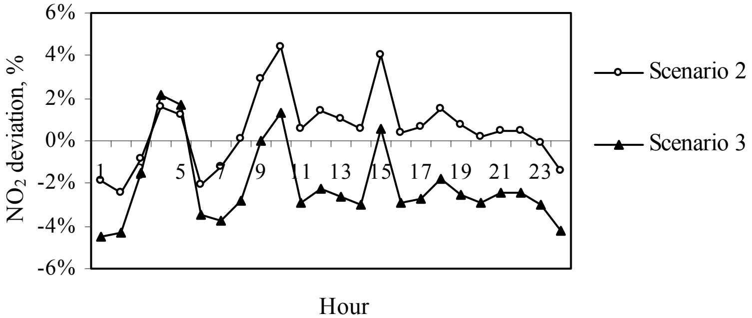

Figure 5: NO_2 hourly concentration deviations (%) from scenario 1.

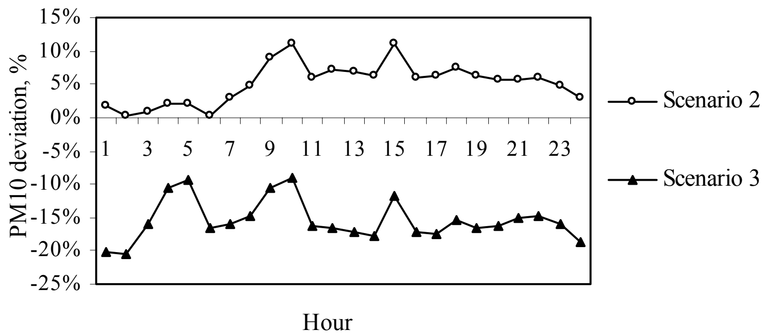

Figure 6: PM10 hourly concentration deviations (%) from scenario 1.

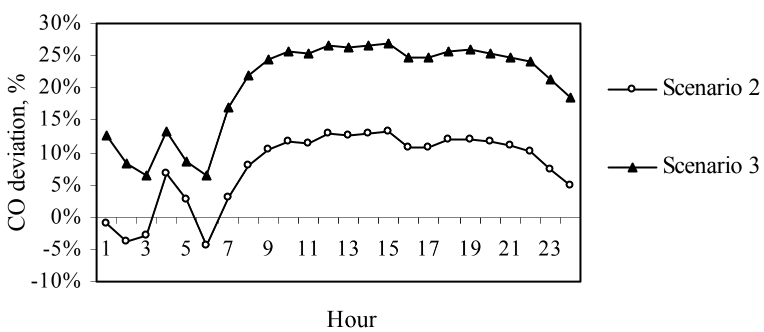

Figure 7: CO hourly concentration deviations (%) from scenario 1.

NO_2 levels of concentration show only a small deviation from scenario 1 (2004), which is expected as: i) gasoline vehicles are the main source of NO_2 [12], ii) number of gasoline vehicles varies 25% between scenario 2 and 3, and iii) as the number of vehicles increases their anti-pollution technology is bound to develop.

On the other hand, PM10 concentration increases significantly between from scenario 2 to 3, mainly because of the increase of diesel cars. This increase in the number of diesel cars (which means decrease in gasoline vehicles) however, will result in a decrease in the levels of CO concentration, which is seen in Figure 7.

5 Conclusions

In this work, a methodology was put forward in order to employ OSPM in cases where insufficient data were available. As an example, the city of Thessaloniki was considered. To complete the successful application of the methodology, as confirmed by comparison with measurements, a sensitivity analysis was proposed. Finally, OSPM was employed to predict air-quality in Thessaloniki in 2010. A probable increase in the number of diesel vehicles will result, as expected, to an increase in the concentration of PM10 and a decrease in the concentration of CO.

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