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Combining regression analysis and air quality modelling to predict benzene concentration levels

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ABSTRACT

State of the art epidemiological research has found consistent associations between traffic-related air pollution and various outcomes, such as respiratory symptoms and premature mortality. However, many urban areas are characterised by the absence of the necessary monitoring infrastructure, especially for benzene (C_6H_6), which is a known human carcinogen. The use of environmental statistics combined with air quality modelling can be of vital importance in order to assess air quality levels of traffic-related pollutants in an urban area in the case where there are no available measurements. This paper aims at developing and presenting a reliable approach, in order to forecast C_6H_6 levels in urban environments, demonstrated for Thessaloniki, Greece. Multiple stepwise regression analysis is used and a strong statistical relationship is detected between C_6H_6 and CO. The adopted regression model is validated in order to depict its applicability and representativeness. The presented results demonstrate that the adopted approach is capable of capturing C_6H_6 concentration trends and should be considered as complementary to air quality monitoring.

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1. Introduction

In most European cities emission from road traffic has become the most important source of local air pollution (e.g. Moussiopoulos, 2003; Palmgren et al., 1999). Traffic-related air pollution is considered as one of the most significant urban environmental pressures. A consensus has been emerging among public health experts that air pollution, even at current ambient levels, aggravates morbidity (especially respiratory and cardiovascular diseases) and leads to premature mortality (e.g. Dockery and Pope, 2006; Hurley et al., 2005; WHO, 2003; Hoek et al., 2002; Pope et al., 2002; Kunzli et al., 2000). Although the mechanisms of effects are not fully explained, benzene, C_6H_6, is one of the few chemicals established as known human carcinogens. In urban conurbations which are characterised by high levels of both population density and traffic-related air pollution, traffic is the most important source for ambient air C_6H_6 concentrations. It is therefore of utmost importance to monitor C_6H_6 concentration levels and assess air quality at urban and local scale (e.g. Vlachokostas et al., 2009; Vardoulakis et al., 2002; Colls and Micallef, 1997).

C_6H_6 is classified by International Agency for Research on Cancer (IARC) as Category 1, a known human carcinogen (Official International Agency for Research on Cancer web site, 2010). Additionally, it should be noted that the body breaks down C_6H_6 to metabolites which seem to be more toxic than the parent substance. Although risk quantification is complicated mainly by lack of quantitative data and co-exposures to other potential carcinogens, C_6H_6 has been found to have relatively high population risks in various countries among organic air pollutants. There are many studies, mainly conducted within the last two decades, investigating exposure to C_6H_6 and development of cancer, especially leukaemia (e.g. Crump, 1994). It has been identified as a high priority pollutant by the Critical Appraisal of the Setting and Implementation of Indoor Exposure Limits in the EU (INDEX) assessment, with median cancer risks estimated to be between 8 and 48 per million for various areas in Europe (Kotzias et al., 2005). Higher risks were found for people living in highly trafficked urban areas (Loh et al., 2009). Individual variation in susceptibility or metabolism may also influence the risk at any given exposure.

Despite the fact that monitoring of C_6H_6 is legislated, many urban areas are characterised by the absence of the necessary infrastructure. Given also the practical -and economical- constraints of air quality monitoring techniques, mainly in street canyons at local level (Moussiopoulos et al., 2004), it may be convenient to identify a set of possible empirical relationships between air pollutants. In this sense, the use of environmental statistics can be significant in order to establish reliable associations and assess air quality levels of traffic-related pollutants in urban environments. This paper aims at

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Table 1
Pearson correlations between air pollutants under consideration ($N = 34,960$).

	C_6H_6	CO	NOx	SO_2
C_6H_6	–	0.849	0.786	0.434
CO	0.849	–	0.915	0.483
NO_x	0.786	0.915	–	0.488
SO_2	0.434	0.483	0.488	–

developing and presenting a reliable generic approach, in order to forecast C_6H_6 levels, demonstrated for Thessaloniki, Greece. The area is selected on the grounds that Thessaloniki is considered one of the most polluted cities within Europe as regards air pollution (Vlachokostas et al., 2010a; ORTh, 2008). Moreover, although legislative prescribed (Directive, 2008/50/EC), there are no available C_6H_6 measurements in the area under consideration. The approach presented adopts multiple regression analysis techniques. The developed regression model is validated on a number of independent set of observations of traffic-urban stations in Europe in order to depict its applicability and representativeness. As a next step it is "transferred" to Thessaloniki's metropolitan centre in order to predict C_6H_6 levels. The results are compared to air quality modelling output and demonstrate that the analysis presented is capable of capturing C_6H_6 concentration trends and should be considered as complementary to air quality monitoring.

2. Methodology

2.1. Establishing relationships between traffic-related air pollutants

In order to establish strong statistical relationships between pollutants, it is a prerequisite that the chosen compounds should come mainly from the same emission sources (e.g. road traffic) and have similar "fate" with the group of pollutants they are intended to represent. Estimation of the correlation's strength of any possible air pollution indicator with a number of other pollutants measured in a variety of locations can play a critical role in this direction. It is expected that the relationship between relatively stable chemical species originating from the same source would not vary significantly within urban environments, due to the short distances between sources and receptors.

The residential time of an air mass in an urban micro-environment or street canyon is in the order of minutes and in an urban area in the order of a few hours even in high pressure situations with stagnant wind velocities. The main atmospheric process in which CO, NO_x and C_6H_6 participate once released from sources such as road traffic is the formation of O_3. The photolysis of NO_2 is the only significant process forming O_3 in the lower atmosphere, which is reversed by the rapid reaction of O_3 with NO. This results in O_3 being in a photostationary state dictated by the NO_2 photolysis rate and the NO_2/NO ratio. When VOCs, such as C_6H_6, are present, they react to form radicals which either consume NO or convert NO to NO_2. However the reactivity of C_6H_6, compared to that of other aromatic components is not so high. It is therefore not expected that C_6H_6 is depleted to the same extent as other VOCs in photochemical pollution. CO also constitutes part of the series of cycles of chemical reactions that form O_3. However, chemical removal on a local scale (within an urban area) is negligible, but on a regional scale chemical removal of benzene can be important (Working Group on Benzene, 2008).

On this basis, the negligible chemical reactivity corresponding to the diffusion times of CO and C_6H_6 in urban environments and street canyons as well as their good correlation, suggest that both can be used as traffic pollution indicators. Due to their common origin in urban environments, it is expected that a proportionality relationship can be established between them. The CO to C_6H_6 ratio is expected to remain roughly the same as far as there are no significant changes in vehicle and fuel technology, fleet composition, traffic patterns, ambient temperature or background concentrations in an urban environment (Vardoulakis et al., 2002). Therefore, a statistical relationship may be generally applied to estimate C_6H_6 concentrations using CO measurements in urban areas and vice versa.

A statistical association is not expected to be the case between C_6H_6 and NO_2, since the latter dissociates extremely fast in the presence of light, or between C_6H_6 and NO which also reacts very fast with O_3. Very fast chemical reactions have a significant influence on the measured concentrations. However, a statistical relationship can be expected to be the case between C_6H_6 and NO_x in an urban-traffic environment, having in mind their common origin and considering also the fact that NO_x concentrations are relatively invariant for NO_2 dissociation or the reaction of NO with O_3.

2.2. Multiple regression analysis

In the framework of this work, multiple regression analysis is adopted in order to study the strength of statistical relationships between less frequently measured pollutants such as C_6H_6, and common traffic-related pollutants, such as CO and NO_x. C_6H_6 is monitored only in one station nationally in Greece, which highlights the necessity for the development of additional C_6H_6 monitoring infrastructure in Greek urban conurbations. This "urban-traffic" station is located at Patision street canyon in the city of Athens. Hourly measurements for C_6H_6, CO, NO_x and SO_2 are available through Airbase (Official Airbase web site, 2010) for the period 2004–2008. Almost all measurements (above 99%) are available for CO and NO_x and a high percentage for SO_2 (94%) and

Table 2
Stepwise linear regression ANOVA results and Durbin – Watson statistic index. a. Predictors: (Constant), CO b. Predictors: (Constant), CO, SO_2 c. Predictors: (Constant), CO, SO_2, NO_x.

Model		Sum of Squares	df	F	Sig.	R^2	Adjusted R^2	R^2 Change
1[a]	Regression	463,043	1	89,891	0[a]	0.720	0.720	0.720
	Residual	180,074	34,958					
	Total	643,117	34,959					
2[b]	Regression	463,524	2	45,112	0[b]	0.721	0.721	0.001
	Residual	179,593	34,957					
	Total	643,117	34,959					
3[c]	Regression	463,783	3	30,134	0[c]	0.721	0.721	0
	Residual	179,334	34,956					
	Total	643,117	34,959					
Durbin – Watson	1.015							

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