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Bridging the gap between traffic generated health stressors in urban areas: Predicting xylene levels in EU cities

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ABSTRACT

Many citizens live, work, commute, or visit traffic intensive spaces and are exposed to high levels of chemical health stressors. However, urban conurbations worldwide present monitoring “shortage” – due to economical and/or practical constraints – for toxic stressors such as xylene isomers, which can pose human health risks. This “shortage” may be covered by the establishment of associations between rarely monitored substances such as xylenes and more frequently monitored (i.e. benzene) or usually monitored (i.e. CO). Regression analysis is used and strong statistical relationships are detected. The adopted models are applied to EU cities and comparison between measurements and predictions depicts their representativeness. The analysis provides transferability insights in an effort to bridge the gap between traffic-related stressors. Strong associations between substances of the air pollution mixture may be influential to interpret the complexity of the causal chain, especially if a synergetic exposure assessment in traffic intensive spaces is considered.

1. Introduction

Scientific evidence clearly indicates that traffic-related chemical substances released in urban environments are strongly associated with numerous health risks. Many citizens live, work, commute, shop or visit for recreation purposes traffic intensive spaces and are exposed to high levels of health stressors. Traffic-related air pollution is a major concern for community members as epidemiologists continuously provide updated proof (e.g. Pascal et al., 2013; Medina et al., 2009; Carslaw et al., 2007; Beelen et al., 2008; Gryparis et al., 2004). BTEX i.e. benzene, toluene, ethylbenzene, and isomers of xylene (namely meta-, para- and ortho-xylene), have high public health importance (e.g. Zoveidavianpoor et al., 2012; Dash and Barik, 2012; Curtis et al., 2006). However, the vast majority of urban areas worldwide (and in the EU) are characterised by infrastructure's absence to routinely monitor some of the most common stressors found in urban airsheds such as xylene isomers. Public authorities usually support this monitoring inability on economical and/or practical constraints. Nevertheless, xylene toxicological profile states that exposure can pose a great danger to human health in numerous ways (ATSDR, 2007).

Xylene is an aromatic hydrocarbon, flammable, with sweet odour. Human contamination can occur mostly via inhalation, ingestion or skin contact. Usually most of the taken in xylenes are exerted within 18 h. About 4–10% of absorbed isomers may be stored in fat (lipophilic characteristic), prolonging the excretion time needed. Information on the impacts on human health comes mainly from case reports and occupational studies. Depression of the central nervous system, ocular and respiratory irritation are the most commonly reported symptoms following subchronic and chronic inhalation exposure to xylenes (U.S. EPA, 2003). Headache and nausea are associated with concentrations of 435–870 mg/m^3, dizziness and vomiting with 870–2175 mg/m^3. Extremely high concentrations could cause loss of consciousness (>43 500 mg/m^3) (AENV, 2004). Acute effects are most pronounced at high exposure levels (>4350 mg/m^3) (U.S. EPA, 2003). In some causes pulmonary edema can occur, even several hours after exposure (OEHHA, 1999; WHO, 1997). Reversible liver and kidney damage has been reported in cases of severe xylene isomers exposure, as they are broken down by the liver and excreted in the urine. Long term occupational exposure to xylenes could cause irritability, depression, insomnia, agitation, extreme tiredness, tremors, impaired concentration and short-term memory, altogether known as the “organic solvent syndrome”. The International Agency for Research on Cancer, has determined that there is inadequate evidence for the carcinogenicity of xylene isomers in humans, because in the available studies, there was concurrent exposure to other chemicals (IARC, 1999).

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Similar conclusions suggest studies that can be found in reports of the US EPA, (e.g. 2003). However, as animals' studies present, toxicity should not be excluded as a possibility. An extensive review of xylene effects on humans and ecological receptors, endpoints, doses and limit values can be found analytically elsewhere (ATDSR, 2007; AENV, 2004).

Based on the aforementioned toxicological profile, it is crucial to assess health stressors levels such as xylenes in urban-traffic environments and micro-environments both with modelling and monitoring techniques (e.g. Carnevale et al., 2011; Colls and Micallef, 1997). This paper puts forward an approach to identify and establish a set of empirical relationships between xylene and other traffic-related substances, with the same emission origin and similar environmental "fate". This is vital for densely populated urban spaces or micro-environments which usually present high levels of personal exposure to multiple chemical and physical health stressors for considerable amount of time mainly due to the combination of large numbers of citizens and intense traffic. The relationship between relatively stable chemical stressors does not vary significantly within urban environments, due to the short distances between sources and receptors. These models are developed to forecast xylene trends in urbanised EU areas with heavy traffic and are validated on an independent set of xylene available urban-traffic measurements to depict their applicability and representativeness. This work goes beyond current scientific literature (e.g. Vlachokostas et al., 2013) since the "multi-stressors, multi-city stepwise regression modelling methodology" combine multiple cities and their corresponding "maternal stations" with multiple stressors in a more refined and comprehensive statistical approach. A "maternal station" is selected from the pool of available EU stations to provide statistical associations which are transferred and validated to others. The important aspect of this paper is twofold: (i) The statistical methodology is significantly enhanced with the interactions between more than one maternal stations which puts a little stepping stone towards the effort to bridge the gap between traffic-related stressors, (ii) it deals with a large pool of available measurements and with many chemical stressors in parallel, i.e. m,p-xylene and o-xylene are the dependent variables. The validation process provides discussion for "intra-state" issues of such empirical associations.

2. Methodology

2.1. The complexity of the air pollution mix

Due to the complex chemical air pollution mixture from road traffic, it is impractical or impossible to measure all relevant stressors, due to cost constraints, lack of suitable technologies and/or logistical difficulties inevitably involved. All stressors in this mixture are not necessarily of the same concern to health. Usually, a traffic-related marker, such as PM or a classical air pollutant is selected and used for a variety of reasons e.g. air quality management, exposure assessment and epidemiological studies. It is well established that NO_x and/or CO are more often used as markers for transport-related air pollution. However, traffic exhaust emits considerable amounts of VOCs, such as aromatic compounds. In addition, the concentration of benzo[a]pyrene indicates traffic influence on air quality in locations where the impact of other sources (e.g. wood burning) is negligible (WHO, 2005). Probably there are more chemical health stressors in the mixture that science has not put forward up to now. The inherent epidemiological uncertainties can be characterised as significant the least, especially when considering combined or synergetic exposure to the complex pollution mix.

Considering that classical markers are not necessarily the most health-threatening compounds and that many control technologies are quite compound specific, regulation of traffic-related markers may bring few or no health benefits, e.g. NO_2 is a marker for which a WHO air quality guideline value has been set (WHO, 2000), but from a health perspective it may be less harmful than the fresh traffic exhaust mixture which represents. Thus, controlling NO_2 does not necessarily control the associated chemical health stressors and impacts to public health from traffic exhaust. It is probable that the effects observed in epidemiological studies could be attributed to other than the specific pollution indicator used in the study, or they can be attributed to a mixture of stressors. It is still unclear which constituents of traffic emissions are responsible for the observed adverse effects on people's health (WHO, 2005).

Thus, bridging the gap between traffic-related stressors is important e.g. in implementing control mechanisms. Building strong associations between chemical substances released to the air may be influential to explain the complexity of the causal chain. This represents a milestone in order to pass over some limitations in the available knowledge regarding the links between emissions, population exposures and adverse effects on health, especially if a combined or a synergetic approach in traffic intensive spaces for more species of the pollution mix is under consideration (Vlachokostas et al., 2012).

2.2. The multi-stressor, multi-city stepwise regression modelling approach

Multi-stressor, multi-city stepwise regression modelling is put forward to build empirical associations between rarely monitored traffic-related substances such as xylenes and more frequently monitored ones such as benzene and toluene or usually monitored ones, like CO and NO_x. In this framework, a station is characterised as the maternal station when it is selected from the available pool to provide statistical associations mainly due to three reasons: (i) It is a typical urban-traffic station from a large urban area, (ii) it has more than sufficient data availability for a considerable period of time for as much stressors as possible, and (iii) it presents very strong correlations between traffic-related health stressors. Based on the above rationale four maternal stations are selected from the -more or less-limited EU xylene stations pool. The present multi-city study corresponds to traffic intensive urban spaces of Frankfurt, London, Athens and Madrid. These cities, due to their geographical, economical and climatic differences, provide a complementary and representative application field in order to holistically compare and conduct a comprehensive validation of the developed models in regions that cover an important spectrum of the European continent. Available data are provided to the public through Airbase for the four maternal stations: (i) Friedberger Landstraße (Frankfurt), (ii) Marylebone street (London), (iii) Patission street (Athens), and (iv) Plaza del Doctor Marañón (Madrid), and are used in combination to develop, apply and compare regression m,p-xylene and o-xylene models. These data consist of a high-reliable continuous record in order to establish reliable relationships between common traffic-related pollutants such as CO and benzene with less frequently measured ones, such as m,p-xylene and o-xylene.

The German maternal station is located at Friedberger Landstraße in Frankfurt am Main, the fifth largest city in Germany (Airbase code name: DEHE041 – Latitude: 50° 7′ 28″, Longitude: 8° 41′ 30″). With an area of 248.3 km^2 and a population of nearly 700 000 in 2011, it is one of the most densely populated cities (2800 inhabitants/km^2) (FSA, 2011). The station stands in Frankfurt's centre and can be characterised as a canyon type traffic artery ($L/H < 1.5$) with two traffic directions. Data availability is more than sufficient, ranging between 88 and 99% for hourly measurements in the period 2005–2010. The same data exist for o-xylene, but for the period 2008–2010. The traffic consists mostly of light-duty petrol motor vehicles, with a considerable typical share of nearly 30% of diesel passenger cars during the period under consideration (Official EEA web site, 2013).

The UK maternal station is located at Marylebone street in London (Airbase code name: GB0785A – Latitude: 51° 31′ 21″, Longitude: 0° 9′ 16″). London is the largest urban zone and metropolitan area in the UK, with an area of 1570 km^2. The population is 8 173 194 inhabitants (2011) and its density is 5206 inhabitants/km^2 (Greater London Authority, 2013). Marylebone is a canyon street ($L/H < 1.5$) with two traffic lanes in each direction. Available data exceed 80% for the stressors considered in the period 2005–2009. Diesel cars comprise approximately the 25% of the total passenger car fleet (Official EEA web site, 2013).

The Greek maternal station is located at Patission street (Airbase code name: GR0032A – Latitude: 37° 59′ 58″, Longitude: 23° 43′ 58″), a street canyon ($L/H < 1.5$) in the centre of the Athens Metropolitan Area. Athens is the largest city of Greece with 3 074 160 inhabitants (EL.STAT., 2013) and density 7462 inhabitants/km^2. Patission street has two traffic directions and each direction has three lanes. Available measurements vary between 65% and 80% in the period 2005–2010 (Ministry of Environment, Energy & Climate Change of Greece, 2013). Due to national legislation which forbidden diesel private cars to enter Athens metropolitan centre until 2012, traffic consists mainly of light-duty petrol motor vehicles.

The Spanish maternal station is located at Plaza del Doctor Marañón in Madrid (Airbase code name: ES0116A – Latitude: 40° 26′ 15″, Longitude: 3° 41′ 26″). Madrid with an area of 604.3 km^2 and a population of roughly 3.3 million in 2012 (INE, 2013), is one of the most densely populated cities (5390 inhabitants/km^2) in Europe. Data availability exceeds 90% for the stressors under consideration in the period 2007–2009. Marañón station lies in a conjunction of roads located at Madrid's centre. It is an open roadside location characterised with heavy traffic. Dieselisation is approximately 50% in the passenger cars fleet (Official EEA web site, 2013).

Time series of the four maternal stations are the input to SPSS 20.0 software. The statistical approach is analytically demonstrated for Friedberger Landstraße. The results for all maternal stations are presented in the analysis and discussion to follow. Scatter plots suggest a very strong linear relationship between m,p-xylene, toluene, benzene and o-xylene. Table 1 presents Pearson correlations between the stressors under consideration for Friedberger Landstraße. Although the m,p-xylene and toluene linear relationship seems the strongest one (0.911), m,p-xylene is also