Atmospheric Environment 131 (2016) 289–300

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

A dynamic urban air pollution population exposure assessment study using model and population density data derived by mobile phone traffic

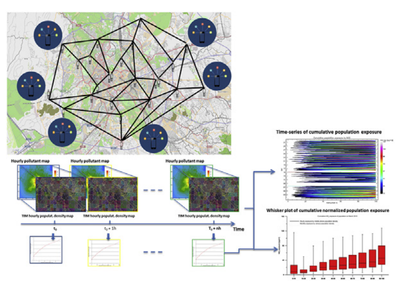
Claudio Gariazzo [a, *], Armando Pelliccioni [a], Andrea Bolignano [b]

[a] INAIL-Research Center, Via Fontana Candida 1, 00040, Monteporzio Catone, RM, Italy
[b] ARPA Lazio, Via Garibaldi, 114, 02100, Rieti, Italy

HIGHLIGHTS

- Mobile Phone traffic data can be used to track urban population.
- Dynamic urban population density maps indicate large mobility.
- Large variations of population exposure are detected.
- Small differences on exposure are estimated for different genders and age ranges.
- Assessment of population exposure based on residence is unable to estimate the actual variability of exposure.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 12 October 2015
Received in revised form
27 January 2016
Accepted 9 February 2016
Available online 10 February 2016

Keywords:
Dispersion model
Urban area
Human mobility
Particulate matter
Gaseous pollutants
Big data

ABSTRACT

A dynamic city-wide air pollution exposure assessment study has been carried out for the urban population of Rome, Italy, by using time resolved population distribution maps, derived by mobile phone traffic data, and modelled air pollutants (NO_2, O_3 and $PM_{2.5}$) concentrations obtained by an integrated air dispersion modelling system. More than a million of persons were tracked during two months (March and April 2015) for their position within the city and its surroundings areas, with a time resolution of 15 min and mapped over an irregular grid system with a minimum resolution of 0.26 × 0.34 Km^2. In addition, demographics information (as gender and age ranges) were available in a separated dataset not connected with the total population one. Such BigData were matched in time and space with air pollution model results and then used to produce hourly and daily resolved cumulative population exposures during the studied period. A significant mobility of population was identified with higher population densities in downtown areas during daytime increasing of up to 1000 people/Km^2 with respect to nigh-time one, likely produced by commuters, tourists and working age population. Strong variability (up to ±50% for NO_2) of population exposures were detected as an effect of both mobility and time/spatial changing in pollutants concentrations. A comparison with the correspondent stationary approach based on National Census data, allows detecting the inability of latter in estimating the actual variability of population exposure. Significant underestimations of the amount of population exposed to daily $PM_{2.5}$ WHO guideline was identified for the Census approach. Very small differences (up to a few μg/m^3) on exposure were detected for gender and age ranges population classes.

* Corresponding author.
E-mail address: c.gariazzo@inail.it (C. Gariazzo).

http://dx.doi.org/10.1016/j.atmosenv.2016.02.011
1352-2310/

1. Introduction

The assessment of air pollution exposure and the consequent epidemiological studies are normally based on either local monitoring measurements or modelling approaches carried out by Land Use Regression Models (LUR) or air pollution integrated models (Özkaynak et al., 2013). Observations are used as simple surrogates of personal exposures and, depending on the epidemiological study design, this approach may introduce exposure prediction errors and misclassification of exposure for pollutants that are spatially heterogeneous (eg. NO_2 and O_3), which in turn influence the strength and significance of the inferences derived from epidemiological investigations. The use of modelling approaches overcomes this limit allowing to obtain refined exposure estimates with a finer degree of spatial and/or temporal resolution than those based on routinely available central-site measurements. In addition, assessment of air pollution exposure suffers of inabilities in estimating the actual exposure experienced by individuals during their typical day life. Examples are assessment of indoor exposure within different microenvironments (eg. office, school, in vehicle, outdoor), which involves the evaluation of pollutants penetration factors (Hänninen et al., 2011; Romagnoli et al., 2014) as well as the collection of time-activity data for different population classes. Recent studies (Gariazzo et al., 2015, 2011; Hänninen et al., 2009) used exposure models to include this specific contribution to the assessment of air pollution exposure.

Based on either measured or modeled concentrations, epidemiological studies (Cesaroni et al., 2013; Stafoggia et al., 2013) use such results to relate this exposure with living population and to obtain an estimation of health effects. In large metropolitan areas, this is normally inferred by matching concentrations with addresses of residence of population based on static census data (Cesaroni et al., 2013). Unfortunately a large part of population spent most of the time away from its living place, introducing an incorrect assessment of its exposure and consequently in the evaluation of health effects. According to a critical review, the Health Effects Institute panel concluded that most epidemiological studies lack of accurate information on the true exposure of the test-persons involved (Health Effects Institute, 2009), recommending for more accurate methods for exposure analysis. Localization of individuals is vital to track population mobility and GPS devices is a viable solution for it, but practical and economic reasons do not allow its application for large-scale population studies. Steinle et al. (2013) reviewed studies on air pollution exposure using GPS data coupled with either fixed station or personal exposure monitoring data. Different authors (Panis, 2010; Dhondt et al., 2012) suggested the use of activity-based models to include human behaviour in modelling exposure as a way to improve air pollution epidemiology.

The availability of new technology and sensing devices allows the tracking of population providing information about their time-space location useful for the assessment of their environmental exposure. Glasgow et al. (2014) tested the use of smartphone technology to collect personal level time-activity data to be related with air pollution exposure. Su et al. (2015) applied a momentary study location tracking services supplied by smart phones, to identify an individual's location in space–time for three consecutive months to be coupled with a LUR model for assessment of individual's exposure. De Nazelle et al. (2013) demonstrated the usability and relevance of the CalFit smartphone technology to track person-level time, geographic location, and physical activity patterns for improved air pollution exposure assessment. In a review paper, Steinle et al. (2013) identified a clear trend towards GPS based real-time tracking of individual time-activity patterns for personal exposure assessment, but also the need of new technologies for the design of future studies. In a recent paper, Reis et al. (2015) illustrate about current developments in the integration of modelling with smart sensor for environmental and human health, introducing the concept of BigData.

However, large scale population studies, as those related with urban metropolitan population, are not feasible using personal GPS or smart sensors based device for technical and economic reasons. In the past few years, research activities (Calabrese et al., 2011a, 2011b) have begun to explore the usage of data obtained from mobile cellular networks. Mobile phone positioning techniques generally provide less accuracy than GPS. However, the wide diffusion of mobile equipment in urban areas makes such positioning techniques very appealing for large-scale population mobility studies. Mobile phone location data are abundant and can be used to get information on mobility of urban population across the city or to complement and integrate with those coming from traditional sensor networks or modelling results. In addition, the demographics information related to the owner of mobile phone provide details useful to evaluate gender or age peculiarities in the assessment of exposure.

This paper aims at using mobile phone derived urban population distribution data to increase the spatial and temporal accuracy in the assessment of air pollution exposure, as well as to obtain information on the its demographics characteristics. With respect to the stationary census based approach, this is a novel one in assessing air pollution exposure for large-scale population, as it includes dynamic aspects in the estimation of exposure. Chapter 2 will describe the studied area, the datasets used, the integrated air pollution model used for providing gridded air pollution ambient concentrations and the methodology applied for calculation of population exposure. Chapter 3 hosts the main results and a discussion about outcomes.

2. Materials and methods

2.1. Study area

The urban area of Rome, Italy, has been selected as the study area for an assessment of the dynamic air pollution population exposure. It is one of the greatest urbanized cities of Mediterranean area with an extension of 1290 km^2 and about 2.5 millions of inhabitants (average density of about 1900 people/km^2). The air pollution of the city is characterized by high levels of NO_2, O_3 and PM_{10}. Several studies have reported severe health effects on population due to air pollution in this urban area. Long-term exposure to NO_2 and $PM_{2.5}$ has been linked with natural and cardiovascular mortality (Cesaroni et al., 2013). According to the ESCAPE study, long-term exposure to fine particulate air pollution is associated with natural-cause mortality (Beelen et al., 2014). In addition, short-term effects on mortality, cardiovascular and respiratory hospital admissions have been associated with exposure to $PM_{2.5}$ (Stafoggia et al., 2013).

2.2. Mobile phone derived population data

In the frame of TIM BIGDATA Challenge 2015 (www.telecomitalia.com/bigdatachallenge) a few datasets were made available for their use in project proposals. They include the following data: telecommunication traffic; presence of population and its demographics characteristics; presence of vehicles and trips performed as monitored by traffic companies (eg. Viasat, Infoblu); social pulse data derived from an analysis of geolocalized tweets; list of companies, headquarters and branches located in a city census data. Each dataset was associated to a list of Italian cities and surrounding areas (about 30 km from the city centers): Bari, Milan,