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ESTIMATION OF EXPOSURE TO AIR POLLUTION IN DENMARK – A STEP TOWARDS ACTIVITY-BASED DYNAMIC EXPOSURE ASSESSMENT FRAMEWORK

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Abstract: Traditionally in air pollution epidemiology, only the air pollution at the address location is considered in assessment of air pollution exposure. Such static approach does not take into account time-activity patterns of individuals, and may lead to a bias in exposure assessments. The present study demonstrates how consideration of time-activity-based information of individuals and space and time variability of air pollutants' concentrations affect personal exposure using the newly updated Danish AirGIS system. The study provides an overview of presently ongoing work, where new AirGIS is being updated in terms of dynamic exposure assessment to air pollution using measured and modelled data. The focus is on developing a novel dynamic exposure assessment framework to facilitate health-related studies. Our preliminary findings suggest that the exposure estimates based on time-activity patterns of individuals depend on the level of one's mobility as well as location of workplace relative to home etc. The presentation will provide a summary of results based on model calculations. Measurements are planned to be performed soon.

Key words: *dynamic exposure assessment, AirGIS, time-activity patterns, air pollution, real-world data*

INTRODUCTION

Estimating exposure to ambient air pollution, in the present times, remains a challenge. Reason being that an individual's exposure to air pollution is driven not only by the spatio-temporal pattern of pollutants' concentrations, but also by the individual's time-activity patterns (Gulliver and Briggs, 2005; Adams et al., 2009; Dias and Tchepel, 2018). The former is likely to play an important role for the actual exposure, since exposure may substantially be enhanced during commuting and typically, 6 – 8 hours (sometimes even more) are spent at workplace every day. Consequently, the activity-based exposure assessments are likely to provide more accurate exposure estimates as compared to those based on address locations (static estimates).

In Denmark, an extensively validated toolset based on the Danish AirGIS and OSPM® is routinely used to calculate air pollution at any address location. The AirGIS, developed by Jensen et al., (2001) and previously validated by Ketzel et al., (2011), is a GIS-based air pollution and human exposure modelling system. It works in conjunction with the semi-parametrized Operational Street Pollution Model (OSPM) (Berkowicz, 2000a) to estimate air pollution. Recently, AirGIS modelling system is thoroughly updated and validated (Khan et al., 2018c). In the moment, the new AirGIS is being updated with respect to dynamic exposure assessment using both real-world and simulated datasets. The main objective is to develop a novel approach to estimate dynamic exposure to air pollution as implications towards epidemiological studies. This paper provides an overview of ongoing research work and results based on model calculations. Moreover, strengths, limitations and future prospects of the present study are also summarized.

STUDY DESIGN AND METHODOLOGY

The study area is the city centre of Copenhagen (Figure 1a), the Danish capital with highly heterogeneous environments. This area contains Copenhagen central station and a few busy streets namely, H. C. Andersens Boulevard (HCAB), Nørre Søgade (NS) and Øster Søgade (OS). HCAB, in particular, is one of the urban traffic hotspots of Denmark. On the other side of the street NS and OS, however, there are mainly residential houses with less traffic and some highway overpasses (Figure 1a). The choice of the study area was based on where people are most likely to be moving, especially during rush hours.

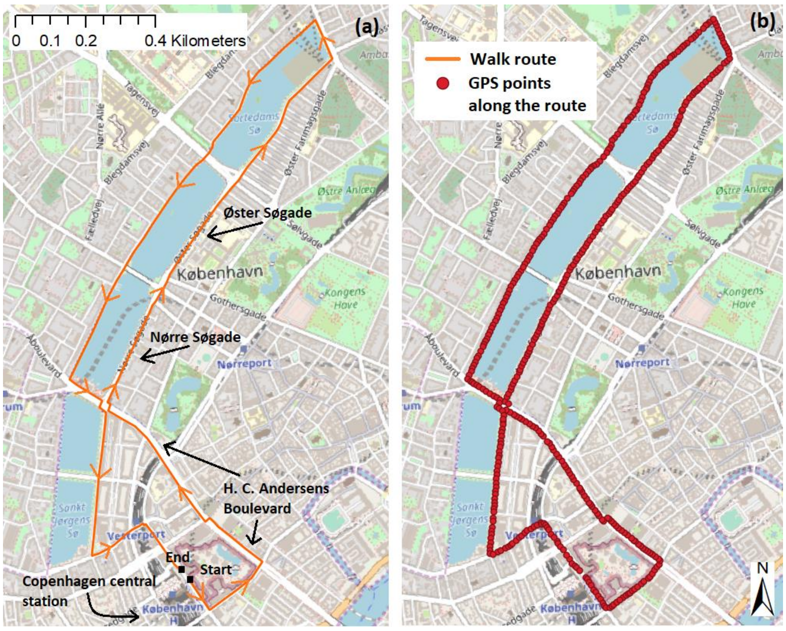

Figure 1. (a) The study area in the city centre of Copenhagen, Denmark. Route showing the walking-based activity (round trip) of the study participants on Monday, 4 February 2019 during 7:00 am – 10:00 am (GMT+1). The busy streets along the route i.e., H. C. Andersens Boulevard (HCAB), Nørre Søgade (NS) and Øster Søgade (OS) are also shown (b) the GPS track points along the route.

This study has focus on developing personal/dynamic exposure assessment framework accounting for time-activity pattern. Subsequently, a walking-based activity (round trip, Figure 1a) was performed by two study participants (two lead authors) on Monday, 4 February 2019 during morning rush hours i.e., 7.00 am – 10.00 am (GMT+1). A Global Positioning System (GPS) application (app), OSM Tracker for Android™ (OpenStreetMap Wiki, 2019) (via smartphone) was used to track the movement of study participants, and acquire time-location data. It is a free, open-source android app based on OpenStreetMaps, available via Google Play Store (Google Play, 2019), and already used in the literature (e.g. Perdana and Ostermann, 2018) in several GPS tracking-based studies. The OSM Tracker recorded date, time, longitude, latitude etc. approximately every 10 s, depending on signal quality. The GPS track points along the walk route are shown in Figure 1b. At these points, air pollution concentrations (NO_x, NO_2, PM_{10}, $PM_{2.5}$ in µg m^{-3}) were calculated using new AirGIS to analyse the modelled dynamic exposure to pollution, which is summarized in the following sections.

The AirGIS system (http://envs.au.dk/en/knowledge/air/models/airgis/), in general, considers air pollution at three different spatial scales handled by a model chain. That is, regional background concentrations (5.6 km x 5.6 km) calculated by DEHM, urban background concentrations (1 km x 1 km) calculated by UBM, and direct street contributions (local-scale air pollution) calculated by OSPM. Air pollution estimates for the specific location are then given by the summation of the above three scales of pollution. The new AirGIS, implemented in open-source PostgreSQL (Postgres) software (via R Studio) follows the same principle as described above (see Khan et al., 2018c for details). The GIS calculations in new AirGIS are handled by PostGIS, the spatial extension of Postgres software.

The input files based on GPS track points (with time exposure window), road network (multilinestring) containing annual average daily traffic (AADT) values (vehicles/day), traffic speed (km/h) etc., and building polygons (with building heights in meters) were imported into a Postgres database. Based on this information, new AirGIS generated input files (information containing street orientation, width etc.) for OSPM in the required format. The locally modelled urban background concentrations of NO_x, NO_2, PM_{10} and $PM_{2.5}$ for 4 February 2019 were not yet available for the specific period. Thus, background levels of NO_x = 22 µg m^{-3}, NO_2 = 11 µg m^{-3}, PM_{10} = 12 µg m^{-3} and $PM_{2.5}$ = 6 µg m^{-3} as well as wind speed and wind direction were estimated based on a nearby measuring station for OSPM calculations. Moreover, the receptor point height was set to 2 m. Subsequently, air pollution estimates (three hourly average for each GPS point) were obtained via OSPM model runs. These air pollution estimates were plotted in QGIS software to produce GIS-based maps. This was done to reflect study participants' exposure (in relation to walking-based activity) to modelled air pollution.

In addition to above, two portable sensor nodes (prototype) were also used to measure air pollution; however, due to issues regarding the calibration, measured exposure data was not available for the evaluation of the model calculations. In the following sections, results from the present study based on model simulations are summarized, and briefly discussed.

RESULTS AND DISCUSSIONS

Figure 2a shows modelled NO_x (µg m^{-3}) at GPS track points of the walking-based activity of the study participants. Depending on the major and the minor roads, in general, new AirGIS reproduced well the variation of modelled air pollution. The modelled NO_x concentrations varied generally smoothly at the start of the journey, in front of Copenhagen central station. Whereas at the end of the journey, calculated NO_x was slightly higher due to nearby busy road.

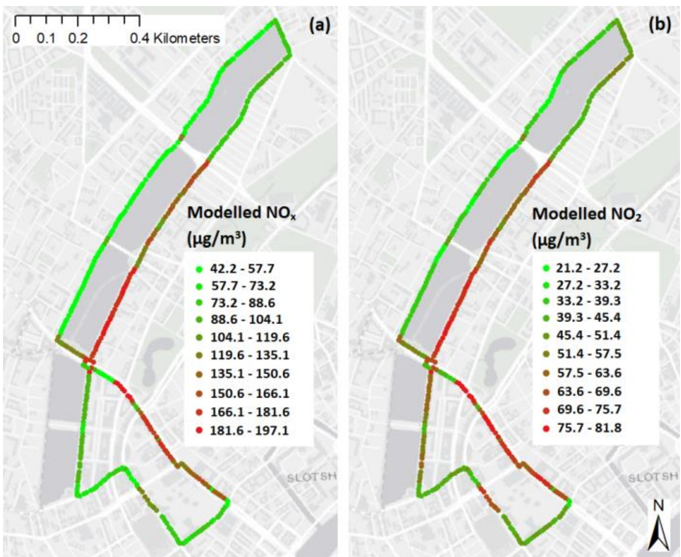

Figure 2. (a) Modelled NO_x (µg m^{-3}) at GPS track points of the walking-based activity of the study participants in Copenhagen, Denmark. The modelled values are for Monday, 4 February 2019 during 7:00 am – 10.00 am (GMT+1) (b) the same for modelled NO_2 (µg m^{-3}).

Opposite to the streets NS and OS (across the lake), NO_x concentrations were low, in the range 42.2 – 57.7 μg m^{-3} (light green dots), mainly due to a street section characterized by residential houses and less traffic. However, at the same side, calculated NO_x was higher close to the highway/busy roads overpasses (dark green dots, Figure 2a). Clearly, the highest values of NO_x were observed along the busy roads, HCAB, NS and OS in the range 119.6 – 197.1 μg m^{-3} (reddish-green and red dots, Figure 2a). Employment status is one the main reasons for individuals' mobility (Wu et al., 2010). In turn, the elevated levels of ambient air pollution, and the large amount of time spent at these traffic hotspots (e.g., due to traffic jams during rush hours) likely place individuals at higher risks of exposure to pollution, and consequently, adverse health outcomes.

Figure 2b shows modelled NO_2 (μg m^{-3}) at GPS track points of the walking-based activity of the study participants. The modelled NO_2 showed a similar pattern to the modelled NO_x along the walk route. That is, NO_2 concentrations were higher along the busy streets HCAB, NS and OS. However, on the other side of NS and OS, modelled NO_2 seems to be generally higher (light green and dark green dots) as compared to NO_x.

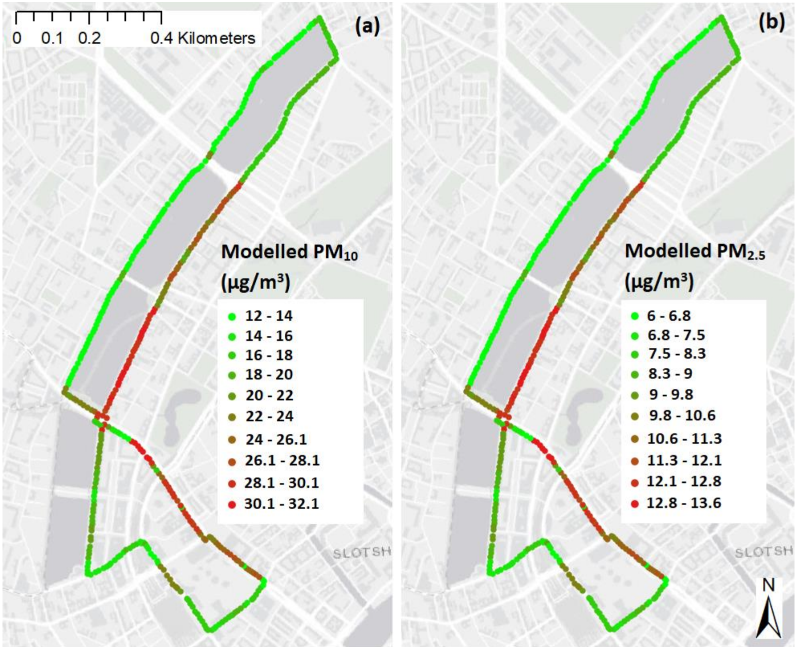

Figure 3. (a) Modelled PM_{10} (μg m^{-3}) at GPS track points of the walking-based activity of the study participants in Copenhagen, Denmark. The modelled values are for Monday, 4 February 2019 during 7:00 am – 10.00 am (GMT+1) (b) the same for modelled $PM_{2.5}$ (μg m^{-3}).

Figure 3a and 3b show modelled PM_{10} (μg m^{-3}) and $PM_{2.5}$ (μg m^{-3}) at GPS track points of the walking-based activity of the study participants, respectively. In this case, also, same patterns of modelled PM_{10} and $PM_{2.5}$ as NO_x/NO_2 can clearly be seen. The modelled PM_{10} and $PM_{2.5}$ were low along the less busy roads in the range 12 – 16 μg m^{-3} and 6 – 7.5 μg m^{-3}. Moreover, as expected, modelled concentrations of the same pollutants were highest along the traffic hotspots HCAB, NS and OS (Figures 3a and 3b).

The strengths and limitations of the present study should be considered. One of the major strengths of this study is the focus on time-activity based exposure assessment, since it can be extremely beneficial to improve the knowledge of actual exposure to air pollution and adverse health effects, especially in the urban commuting environments. Two major limitations are as follows. First, the unavailability of "modelled" background concentrations, and subsequent assumptions of background levels represent one of the limitations of the present study. This might have introduced uncertainties in the air pollution estimates. Second, lack of calibrated air pollution sensors to monitor dynamic exposure to air pollution (during walking-based activity).

CONCLUSIONS

The study demonstrates that time-activity-based information of individuals and spatio-temporal variability of air pollution influence personal exposure using the new Danish AirGIS system for exposure assessment. Time-activity patterns, as demonstrated in this paper, are important to adequately characterize the human exposure to air pollution especially at traffic hotspots. However, exposure estimates based on time-activity patterns of individuals depend on the level of one’s mobility as well as location of workplace relative to home etc.

More work has to be done in the future to (i) monitor dynamic exposure to air pollution based on similar (walking-based) and other (e.g. use of bi-cycle, car and public transport) activities (ii) compare the monitored personal exposure to air pollution with model estimates (iii) incorporate calculated background concentrations (based on availability) into OSPM model computations (iv) conduct surveys in order to analyse time-activity patterns of individuals, and finally, (v) develop android-based customized apps to track the movements of the study participants.

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