Methodology for individual air pollution exposure estimation based on data from air pollution concentration maps, daily routes and activities

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ABSTRACT: Air pollution epidemiological studies typically only estimate individual exposure at residence locations. However, people spend a large amount of time away from their homes during the day. Integrating mobility and time-activity data may reduce errors and improve individual air pollution exposure estimation. Using air pollution concentration maps (PM_{10} and NO_2) data and with collecting individual data from each person using surveys (origin/destination location, travel mode used and the reasons for daily movements) it is possible to estimate individual daily exposure to air pollution , integrating all this data in a GIS platform. The methodology described in this work includes all these items and it was adopted in a Portuguese medium-sized city called Guimarães. The results of this methodology showed that there are significant variations in the values of individual exposure to air pollution, compared to the methodology that only considers residence information of the person to calculate individual exposure to air pollution. Moreover, the sociodemographic data of each individual also play an important role in estimating exposure to individual air pollution.

KEY WORDS: Daily individual air pollution exposure, PM10, NO2, air pollution concentration maps, GIS.

1. INTRODUCTION

Air pollution can lead to a variety of health problems, such as respiratory and cardiovascular issues, lung cancer, and even premature death and it is especially harmful to children, the elderly, people with cardiovascular or lung diseases, and people who work outdoors. To better assess the adverse health effects of air pollution on humans, it is important to estimate personal exposure more accurately [1-11].

The levels of air pollution concentrations are constantly changing over time and space, since people are in various places at the beginning of the day spending different periods of time in microenvironments (home, school, work or leisure) throughout the day. Both of these dynamic characteristics and their complex interactions should be considered in order to accurately assess personal exposure levels [12].

Traditional epidemiological studies only consider residence location information data as the sole indicator for estimating individual daily exposure to air pollution and the health risks associated with such exposure [13-17].

In this study, the authors developed a methodology to estimate daily individual air pollution exposure to PM_{10} and NO_2 air pollutants integrating different types of data sources. The scientific toolbox adopted to develop the studies includes the air pollution dispersion model, a survey and a GIS platform. This combination was the basis for calculating daily individual air pollution exposure.

The case study area of this study covers the entire municipality territory of the city of Guimarães in Portugal. Guimarães is a medium-sized city with 158124 inhabitants distributed throughout a territorial municipality area of 241.3 km². The principal air pollution sources in the municipality area are motorized traffic and 10 industrial areas with air pollution emission inventories.

2. MATERIALS AND METHODS

In order to develop this methodology, the following data were required: annual average concentration maps (PM_{10} and NO_2), population sample travel patterns (survey data), individual origin/destination points and the time spent on each trip and each origin/destination points throughout the day (survey data). After collecting all the data needed, the individual daily air pollution exposure was estimated in a GIS platform using geospatial operations integrating all of these types of data.

2.1 Daily individual air pollution exposure to PM_{10} and NO_2

The daily individual air pollution exposure to PM_{10} and NO_2 is calculated using the following equation:

$$E_{i,24h} = \sum_{j}^{J} C_j * F_{inf,j,k} * t_{i,k} \quad (1)$$

$E_{i,24h}$ – Individual daily exposure of the individual i (in µg/m^3.h)
C_j – Outdoor concentration value of the pollutant j (in µg/m^3)
$F_{inf,j,k}$ – Infiltration factor of the pollutant j in microenvironment k
$t_{i,k}$, – Time spent on each individual i in each microenvironment k (in hours)
k – Type of microenvironments (h = home, w = work, s = school, o = other indoor environments, t = travel)

All of the data needed in Equation 1 is explained in Sections 2.2 and 2.3.

2.2 Annual average air pollution concentration maps (PM_{10} and NO_2)

In order to create the air pollution concentration maps (PM_{10} and NO_2), the following data were required: traffic flow (vehicles per hour) and velocities (km/h), industrial emission inventories, annual meteorological data (wind speed and velocity) and geographical data (contour lines, road networks and buildings). The air pollution concentration maps were calculated using the atmospheric dispersion model AUSTAL 2000 [18]. The study area of these developed air pollution concentration maps was the whole territory of the Guimarães municipality. Taking the average concentrations maps of air pollution, the different data of C_j, values can be obtained.

2.3 Individual survey data

The survey data consisted of various individual sociodemographic questions aiming to discover the individual daily travel patterns and individual origin/destination points throughout the day and other types of relevant data (gender, age, occupation and other data).

Participants were asked about the individual travel mode they used. Each travel mode is associated with average travel speeds and PM_{10} and NO_2 infiltration factors ($F_{inf,j,f}$) shown in Table 1.

Table 1. Average speed, PM_{10} and NO_2 infiltration factors for the different travel modes.

Travel Mode	Average speed (km/h) [19]	$F_{inf,PM10}$ [20]	$F_{inf,NO2}$ [21]
Car	56	0.29	0.92
Bus	35	0.29	0.72
Train	61	0.29	0.72
Bicycle	20	1	1
Walking	4	1	1

The individual home postcode is the origin point and the destination point was obtained from a question in the survey. The time spent in each microenvironment depends on each destination purpose (work, school and other destination purposes). The infiltration factors depend on each microenvironment (home, school and other indoor locations). These data are summarized in Table 2.

Table 2. Activity times and microenvironment infiltration factors for PM_{10} and NO_2.

Occupation	Destination time (hrs)	$F_{inf,PM10}$ (home and destination, k= h, w, s and o) [22]	$F_{inf,NO2}$ [23] (k=h)	$F_{inf,NO2}$ [23] (destination, k =w, s or o)	Total time outdoors (hrs) [22]	Daily time at home (hrs)
Employed	8	0.36	0.79	0.71	1.8	$24 - t_{dest.} - 1.8 - (2*t_{travelling})$
Student	5	0.36	0.79	0.71	1.8	$24 - t_{dest.} - 1.8 - (2*t_{travelling})$
Retired and unemployed	6	0.36	0.79	0.72	1.8	$24 - t_{dest.} - 1.8 - (2*t_{travelling})$

2.4 GIS platform

In a GIS database all the data obtained from Sections 2.2 and 2.3 were aggregated in a georeferenced map. Overlapping the air pollution concentration maps and individual daily patterns, the daily individual exposure can be estimated applying Equation (1) described in Section 2.1.

3. RESULTS

In this study, 77 people took part in the survey, resulting in 77 residence locations (origin) and 77 daily travel destinations. From these, 11 were students, 13 were unemployed or retired and 53 were employed. The travel modes used in this sample were: 48 travelled by car, 13 by bus, 14 walked, one by bicycle and 1 by train. Figure 1 a) illustrates the daily travelling patterns of the survey sample and the origin and destination points. Some origin points and destination points are the same for different participants. Figure 1 b) illustrates the PM_{10} annual average concentration map of the Guimarães municipality.

Combining the information shown in Figure 1 a) and Figure 1 b), the individual daily exposure can be estimated adopting the methodology described in Chapter 2.

Tables 3 and 4 show the daily exposure for different types of groups. In Table 3, the results are presented by type of occupation and in Table 4 by type of travel mode used.

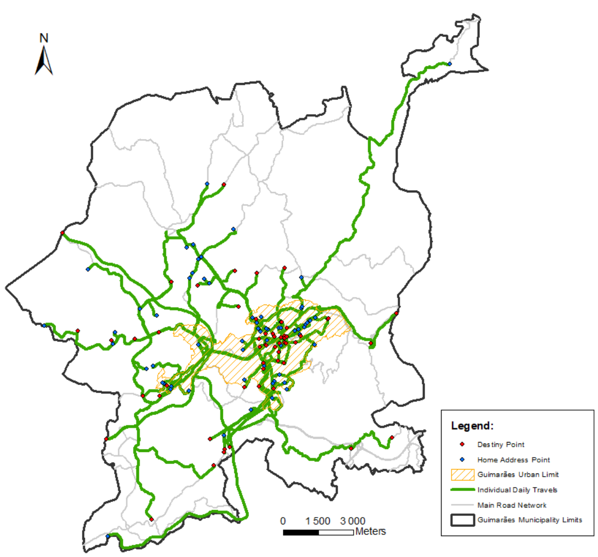

Figure 1 a) Origin/destination points and travel patterns resulting from the individual survey.

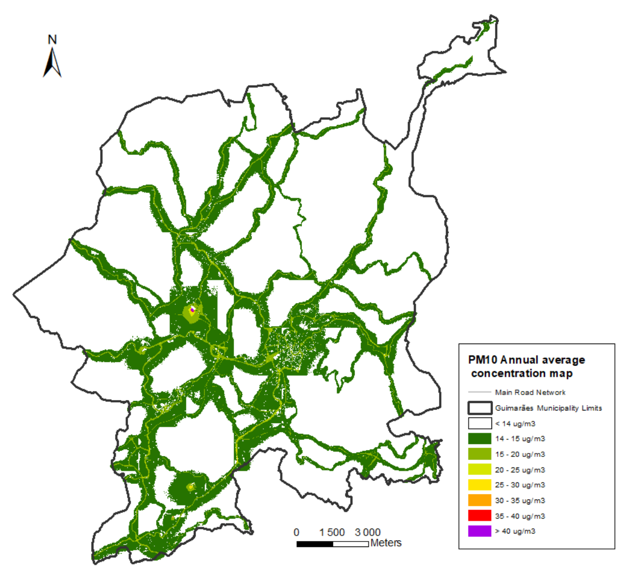

Figure 1 b) PM_{10} annual average concentration map ($\mu g/m^3$).

Table 3. Daily exposure to PM_{10} and NO_2 by type of occupation.

Occupation	Daily Exposure (PM_{10}) (µg/m^3.h)					Daily Exposure (NO_2) (µg/m^3.h)				
	Min	Max	Aver	Median	Str dev.	Min	Max	Aver	Median	Str dev.
Employed (n=53)	116.9	178.1	131.0	128.1	11.8	391.7	1044.7	478.0	443.9	100.5
Student (n=11)	125.1	142.5	131.7	132.0	6.4	348.6	493.1	435.0	428.6	47.4
Unemployed or Retired (n=13)	118.8	189.5	143.6	137.2	22.4	370.2	792.4	490.2	413.19	144.5

Table 4. Daily exposure to PM_{10} and NO2 by travel mode utilized.

Travel Mode	Daily Exposure (PM_{10}) (µg/m^3.h)					Daily Exposure (NO_2) (µg/m^3.h)				
	Min	Max	Aver	Median	Str dev.	Min	Max	Aver	Median	Str dev.
Car (n=48)	116.9	189.5	131.1	127.9	13.2	374.0	1044.7	472.8	443.8	103.4
Bus and Train (n=14)	119.7	189.1	136.8	130.2	18.1	348.6	792.4	498.8	449.9	137.8
Walk and Bicycle (n=15)	123.1	178.1	136.6	134.9	13.4	370.2	633.4	451.0	429.0	62.0

4. DISCUSSION

The results showed that unemployed and retired people are on average more exposed to air pollution to PM_{10} and NO_2 pollutants. The maximum daily exposure to PM_{10} air pollutant is also a participant included in the unemployed and retired group (189.5 µg/m^3.h), however the maximum daily exposure to the NO_2 air pollutant corresponds to a participant in the employed group (1044,7 µg/m^3.h). The least daily exposure to PM_{10} refers to a participant included in the employed group (116.9 µg/m^3.h), however the minimum daily exposure to NO_2 refers to a participant included in the unemployed and retired group (370.2 µg/m^3.h).

Analyzing the daily exposure by travel mode used, the people that use public transport (bus and train) have higher daily exposure to the PM_{10} and NO_2 pollutants (136.8 and 498.8 µg/m^3.h, respectively) on average. The maximum daily exposure to PM_{10} and NO_2 air pollutants refers to a participant included in the group that uses private cars (189.5 and 1044.7 µg/m^3.h, respectively). The least daily exposure to the PM_{10} air pollutant corresponds to a participant included in the group that uses private cars (116.9 µg/m^3.h), however the minimum daily exposure to the NO_2 air pollutant corresponds to a participant that uses buses in their daily trips (370.2 µg/m^3.h).

The explanation for the results obtained above is that the biggest contributions to the individual daily air pollution exposure are the concentrations in the origin and destination points, because it is where the individual spends most of their time during the day. Therefore, if there are higher outdoor concentrations at these points, it results in more exposure during the day to those individuals.

The chosen travel modes also play an important role in individual daily air pollution exposure because of the time spent outdoors and the different air pollution infiltration factors of each travel mode. Let´s take an example of the exposure of two people who take the same route on a daily basis, but one uses the car and the other goes on foot; the individual exposure of the person walking is greater because their travel time and infiltration factors are higher. However, comparing the contribution of travel times associated with the mode of transport used with past times at the points of origin and destination to calculate the individual exposure to air pollution, we conclude that this has a much smaller contribution to the calculation of daily exposure to air pollution, since people spend much more of their time in places of origin/destination than on the journeys.

5. CONCLUSIONS

This study contributes to assessing individual exposure to air pollution and the associated health effects, demonstrating that considering the space-time variability of air pollution, individual human mobility patterns and location in each individual's space origin/destination) throughout the day are extremely important factors in taking into account and improving the calculation of individual daily exposure to air pollution.

The methodology developed is also much more accurate that the epidemiological studies that only consider the residence location to estimate individual daily air pollution exposure [13-17]. because many points in space are considered during the day with different air pollution concentration levels.

The authors also believe that this methodology can be integrated, for example, in individual tracking smartphone apps with exact travel times, exact travel speeds and exact times spent in each microenvironment (indoors or outdoors) to obtain much better and accurate individual daily air pollution exposure estimations.

The main weakness identified in this methodology was the use of annual average air pollution concentration maps (PM_{10} and NO_2) because the simulation computer time is slow (more than 24 hours to obtain air pollution concentration maps). The estimation could be much more accurate if hourly concentration maps were used. On the other hand, the developed maps were established with a high level of territorial detail for minimizing this weakness in this methodology. This issue can be improved in future studies improving computer techniques.

REFERENCES:

[1] Buonanno, G., Stabile, L., and Morawska, L., Personal exposure to ultrafine particles: the influence of time-activity patterns. *Sci. Total Environ.* 468–469, 2014, pp. 903–907.

[2] Dons, E., et al., Impact of time–activity patterns on personal exposure to black carbon. *Atmos. Environ.* 45 (21), 2011, pp. 3594–3602.

[3] Fang, T.B., Lu, Y., Personal real-time air pollution exposure assessment methods promoted by information technological advances. *Ann. GIS* 18 (4), 2012, pp. 279–288.

[4] Kwan, M.P., Liu, D., Vogliano, J., Assessing dynamic exposure to air pollution. In Space-Time Integration in Geography and GIScience: Research Frontiers in the US and China. *Springer, Dordrecht*, 2015, pp. 283–300.

[5] Lu, Y., Fang, T., Examining personal air pollution exposure, intake, and health danger zone using time geography and 3D geovisualization. *ISPRS Int. J. Geo-Inf. 4*, 2015, pp. 32–46.

[6] Pilla, F., Broderick, B., A GIS model for personal exposure to PM10 for Dublin commuters. *Sustain. Cities Soc.* 15, 2015, pp. 1–10.

[7] Ryan, P.H., et al., A field application of a personal sensor for ultrafine particle exposure in children. *Sci. Total Environ.* 508, 2015, pp. 366–373.

[8] Steinle, S., Reis, S., Sabel, C.E., Quantifying human exposure to air pollution- Moving from static monitoring to spatio-temporally resolved personal exposure assessment. *Sci. Total Environ.* 443, 2013, pp. 184–193.

[9] Steinle, S., et al., Personal exposure monitoring of PM2.5 in indoor and outdoor microenvironments. *Sci. Total Environ.* 508, 2015, pp. 383–394.

[10] Yoo, E., et al., Geospatial estimation of individual exposure to air pollutants: moving from static monitoring to activity-based dynamic exposure assessment. *Ann. Assoc. Am. Geogr*. 105 (5), 2015, pp. 915–926.

[11] Park, Y.M., Kwan, M-P, Individual exposure estimates may be erroneous when spatiotemporal variability of air pollution and human mobility are ignored. *Health & Place 43*, 2017, pp. 85–94.

[12] Zhou, J., et al., Health risk assessment of personal inhalation exposure to volatile organic compounds in Tianjin, China. *Sci. Total Environ. 409 (3)*, 2011, pp. 452–459.

[13] Hamra, G.B., Laden, F., Cohen, A.J., Raaschou-Nielsen, O., Brauer, M., Loomis, D., Lung cancer and exposure to nitrogen dioxide and traffic: a systematic review and meta-analysis. *Environ. Health Perspect.*, 2015.

[14] Lee, J.-H., Wu, C.-F., Hoek, G., de Hoogh, K., Beelen, R., Brunekreef, B., Chan, C.-C., Land use regression models for estimating individual NOx and NO2 exposures in a metropolis with a high density of traffic roads and population. *Sci. Total Environ.* 472, 2014, pp. 1163–1171.

[15] Parent, M.-É., Goldberg, M.S., Crouse, D.L., Ross, N.A., Chen, H., Valois, M.-F., Liautaud, A., Traffic-related air pollution and prostate cancer risk: a case–control study in Montreal, Canada. *Occup. Environ. Med. 70 (7)*, 2013, pp. 511–518.

[16] Chen, H., Namdeo, A., Bell, M., Classification of road traffic and roadside pollution concentrations for assessment of personal exposure. *Environ. Modell. Softw. 23 (3)*, 2008, pp. 282–287.

[17] Krämer, U., Koch, T., Ranft, U., Ring, J., Behrendt, H., Traffic-related air pollution is associated with atopy in children living in urban areas. *Epidemiology 11 (1)*, 2000, pp. 64–70.

[18] Austal 2000, German Technical Instruction on Air Quality Control demands for dispersion calculations a Lagrangian particle model in compliance with the German guideline VDI 3945 Part 3. website: http://www.austal2000.de/en/home.html, accessed in January 2019.

[19] Bedogni, L., Di Felice, M., Bononi, L., Context-aware Android applications through transportation mode detection techniques. *Wirel. Commun. Mob. Comput.*, 2016.

[20] Briggs, D.J., de Hoogh, K., Morris, C., Gulliver, J., Effects of travel mode on exposures to particulate air pollution. *Environment International 34 (1)*, 2008, pp. 12-22.

[21] Apparicio, P., Gelb, J., Carrier, M., Mathieu, M-E., Kingham, S., Exposure to noise and air pollution by mode of transportation during rush hours in Montreal, *Journal of Transport Geography 70*, 2018, pp. 182-192.

[22] Zhao, B., Ji, W., Estimating Mortality Derived from Indoor Exposure to Particles of Outdoor Origin, PLoS ONE, 2015.

[23] Tang, R., et al., Integrating travel behavior with land use regression to estimate dynamic air pollution exposure in Hong Kong, *Environment International 113*, 2018, pp. 100-108.