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ESTIMATES OF POPULATION EXPOSURE TO AIRBORNE POLLUTANTS IN A REAL CITY: SENSITIVITY ANALYSIS TO THE SPATIAL RESOLUTION OF THE POLLUTANT CONCENTRATION AND POPULATION DATA

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Abstract: The impact of urban air pollution on human health has become an important problem, and the estimation of the amount of pollutants to which people are exposed is a major challenge, due to the complex spatial distribution of pollutant concentration and the usual coarse spatial resolution data of the population distribution. This study aims to investigate the uncertainties of outdoor population exposure estimates associated to the approach used to assign concentration to population. To achieve this objective, the results of Rivas et al. (2019) are used: 1) the annual average NO_2 concentration over the whole city of Pamplona (Spain)computed at high-resolution (~m) by CFD modeling and 2) distribution population from the municipal census, at a resolution of 100m x 100m. Using this detailed information, the population and concentration data were aggregated for different cell resolution, from 100 m x 100 m to 6 km x 5 km (the entire city). The total population exposure was estimated for the different cases and compared with the highest resolution case that was taken as the reference. In addition, the population exposure was estimated using the concentration at the location of different air quality monitoring stations (AQMS). Results suggest that only concentration distributions with equal or finer than 1 km x 1 km provide appropriate estimate of total population exposure. In addition, an in overall, total exposure estimates using concentration at AQMS can induce important errors.

Key words: *Air quality monitoring stations***,** *City scale; Computational fluid dynamics (CFD), NO_2, Population Exposure, Spatial resolution*

INTRODUCTION

The impact of air pollution on human health is an important problem in urban areas, as a consequence of both the high pollutant concentrations and the increasing percentage of people living in cities. In urban environments, the spatial distribution of pollutant concentration is very complex, becoming rather challenging the estimation of population exposure. Traditionally, population exposure to atmospheric pollutants and the associated impacts on human health have been estimated in the literature by using datasets of spatial distribution of pollutant concentration and population at very different resolution (from several kilometers to few meters). Also, different approaches have been used to assign pollutant concentration to population (Rivas et al., 2019; Izquierdo et al., 2020; Gamarra et al., 2021; Santiago et al., 2021). Nevertheless, it is crucial to determine correctly which part of population is exposed to a certain pollutant concentration.

The main aims of this study are:

- to quantify the influence of the spatial distribution resolution of both concentration and population on population exposure estimates, as well as determine the minimum spatial resolution required to obtain a reliable population exposure estimate;
- to evaluate the uncertainties of population exposure estimates using Air Quality Monitoring Stations (AQMS).

METHODOLOGY AND DESCRIPTION OF SCENARIOS

The starting point is the outcome of Rivas et al. (2019), providing:

- Annual averaged NO_2 concentration in an entire mid-size city modelled by means of computational fluid dynamics (CFD) simulations at high spatial resolution (~ 1 m).
- Spatial distribution of the population of the city at high resolution (100 m x 100 m) available from municipality census.

Annual averaged NO_2 concentration and population data are aggregated at different spatial resolutions. Using these data set, total exposure is estimated by multiplying population and concentration at each grid cell and then aggregating these values for all the cells.

$$Total\ Exposure = \sum_{i=all\ cells} (NO_2\ x\ Population)_i \qquad (1)$$

Total exposure computed using the different data set are compared with the highest resolution case (100 m x 100 m), which is taken as the reference. In addition, NO_2 concentration at the location of AQMS of city network are extracted from the map modelled by CFD and total exposure is estimated using these concentrations. The cases studied are:

- **Base case**: total exposure is computed using concentration and population data at a spatial resolution of 100m x 100m.
- **Case 1**: total exposure is computed using concentration and population data at a spatial resolution of 6 km x 5 km. One cell covers the whole city.
- **Case 2**: total exposure is computed using concentration and population data at a spatial resolution of 3 km x 2.5 km.
- **Case 3**: total exposure is computed using concentration and population data at a spatial resolution of 1 km x 1 km.
- **Case 4**: total exposure is computed using concentration and population data at a spatial resolution of 0.5 km x 0.5 km.
- **Case 5**: total exposure is computed using concentration data at a spatial resolution of 100 m x 100 m and a population distribution uniformly distributed in cells of 100 m x 100 m where there are residential buildings.
- **PC case**: Total exposure is estimated using the concentration data from PC AQMS and population distribution with a resolution of 100 m x 100 m.
- **Rotxapea case**: Total exposure is estimated using the concentration data from Rotxapea AQMS and population distribution with a resolution of 100 m x 100 m.
- **Iturrama case**: Total exposure is estimated using the concentration data from Iturrama AQMS and population distribution with a resolution of 100 m x 100 m.
- **Closest station case**: Total exposure is estimated using the concentration data from the closest AQMS and population distribution with a resolution of 100 m x 100 m.

STUDY AREA AND MODELLING APPROACH

The study area is the city of Pamplona, Spain. It is a medium-size city of around 25 km^2 and 200000 inhabitants approximately. AQMS network is composed by three stations: one traffic station (Plaza de la Cruz, PC station) and two background stations (Rotxapea and Iturrama). The locations and the annual average NO_2 concentration map are shown in Figure 1.

Annual average NO_2 concentrations with high resolution (~m) were computed using a numerical methodology (WA CFD-RANS) based on the combination of steady-state CFD simulations (Santiago et al., 2017; Sanchez et al., 2017; Rivas et al., 2019). The numerical domain covers the entire city. CFD simulations are based on RANS equations with Realizable k-ε turbulence model. Neutral profiles of wind speed, turbulence kinetic energy and ε (Richards and Hoxey, 1993) were imposed at inlet and different wind direction was simulated. The NOx dispersion was simulated by means of a transport equation and NO_2 maps were computed from NOx maps by using the ratio NO_2/NOx recorded at AQMS. Results were evaluated using data from AQMS in the city and from a network of mobile microsensors carried by cyclist around the city. More details can be found in Rivas et al. (2019).

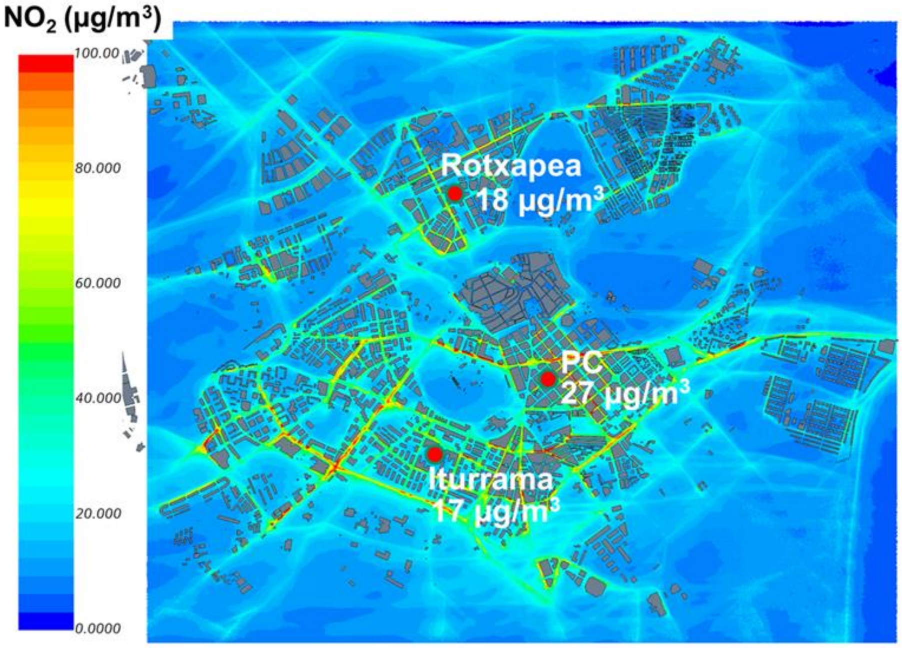

Figure 1. High-resolution map of 2006 annual average NO_2 modelled concentration in Pamplona, Spain. Red dot: Location of AQMS and the values indicates the annual average NO_2 at AQMS locations.

IMPACT OF SPATIAL RESOLUTION ON POPULATION EXPOSURE ESTIMATES

For the coarser-resolution cases, NO2 concentration fields are strongly smoothed when NO2 concentration values are averaged and high-concentration levels are missed. Figure 2 shows that, for Case 2 the maximum concentration is much smaller than in the Base case. More similar values are obtained for Case 4 in comparison with Base case. This is the reason of the strong underestimation of total exposure for Cases 1 and 2 (Figure 3). Appropriate estimates of the total exposure are only provided for spatial resolution finer or equals to 1 km x 1 km (Figure 3).

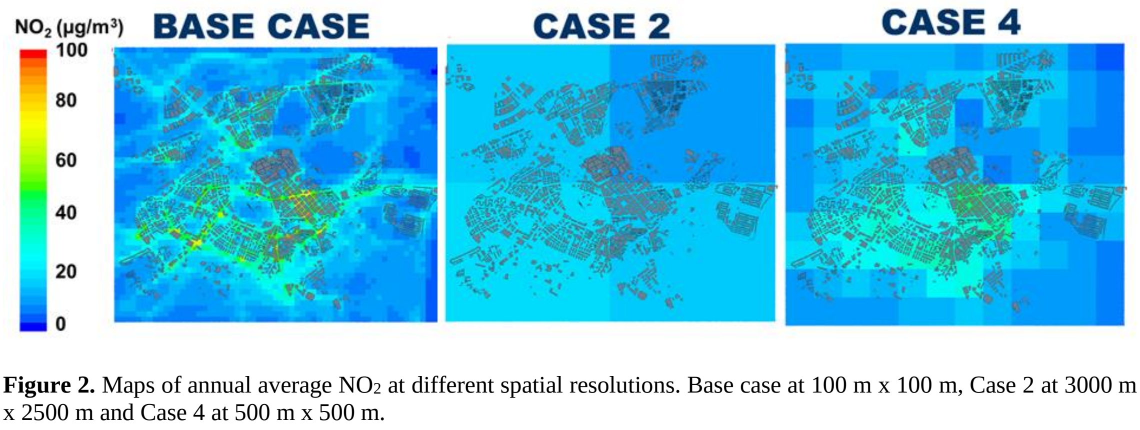

Figure 2. Maps of annual average NO_2 at different spatial resolutions. Base case at 100 m x 100 m, Case 2 at 3000 m x 2500 m and Case 4 at 500 m x 500 m.

In addition, Case 5 is investigated because sometimes detail information of population is not available. In this case, it can be observed that, being population uniformly distributed over the cells with residential building, the total population exposure estimate is quite similar to the Base case (relative differences = 5%) if the concentration resolution is fine (100 m x 100 m).

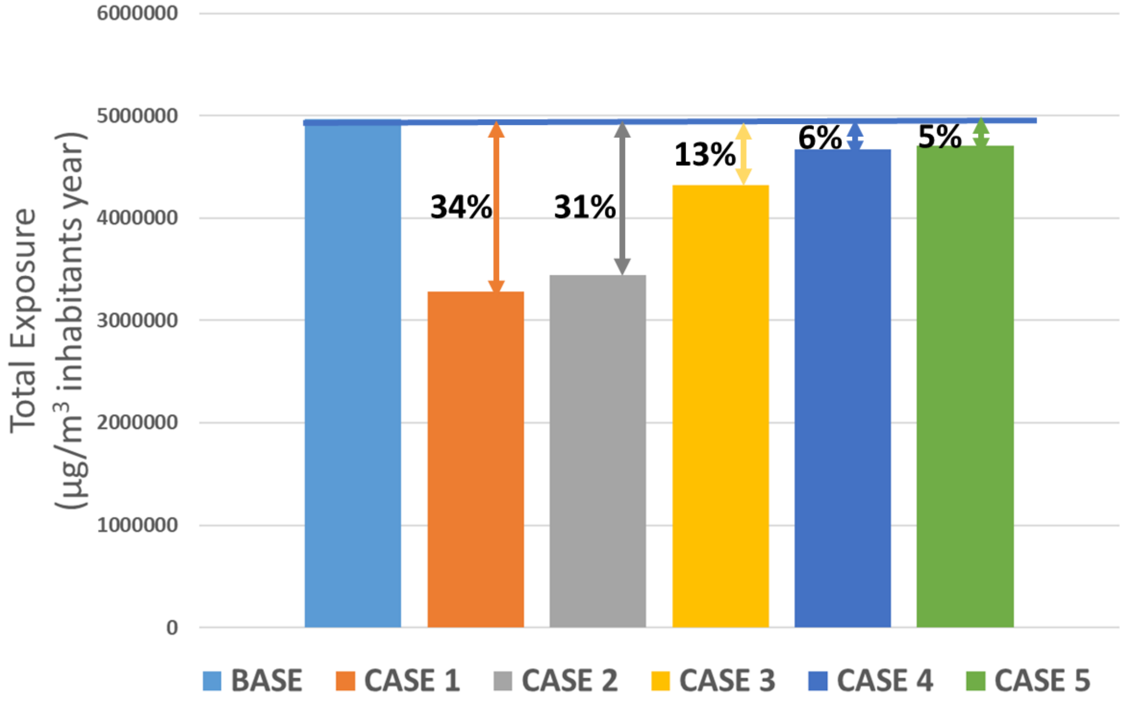

Figure 3. Total exposure estimates at different spatial resolution.

POPULATION EXPOSURE ESTIMATES USING AQMS

Total exposure estimated using concentration from the closest AQMS is 20% lower than the exposure computed in the base case. Using concentration from PC AQMS for the whole city, a better estimate (slight overestimation of 8%) of the total population exposure is obtained. This is due to residential buildings are close to traffic. However, low spatial representativeness of traffic AQMS makes difficult to extrapolate these results to other possible traffic AQMS. Using concentration from background AQMSs (Rotxapea and Iturrama stations) provide worse estimates of the total exposure (an underestimation of 33% and 29%, respectively).

In summary, total exposure estimates in a city using concentration from AQMS can induce important errors due to the low spatial representativeness of urban AQMS.

CONCLUSIONS

The impact of spatial resolution of population and concentration data on the total exposure estimates is very important. Only input data with resolution equals or finer than 1 km x 1 km provide appropriate estimates. Regarding the cases that use the concentration from AQMS, generally the total exposure estimates in a city can induce important errors. Only appropriate estimates in these cases are obtained using the concentration data from the traffic AQMS, but mostly the spatial representativeness of this kind of stations is very small. This research may contribute to improve the knowledge about the methodologies for of population exposure estimates.

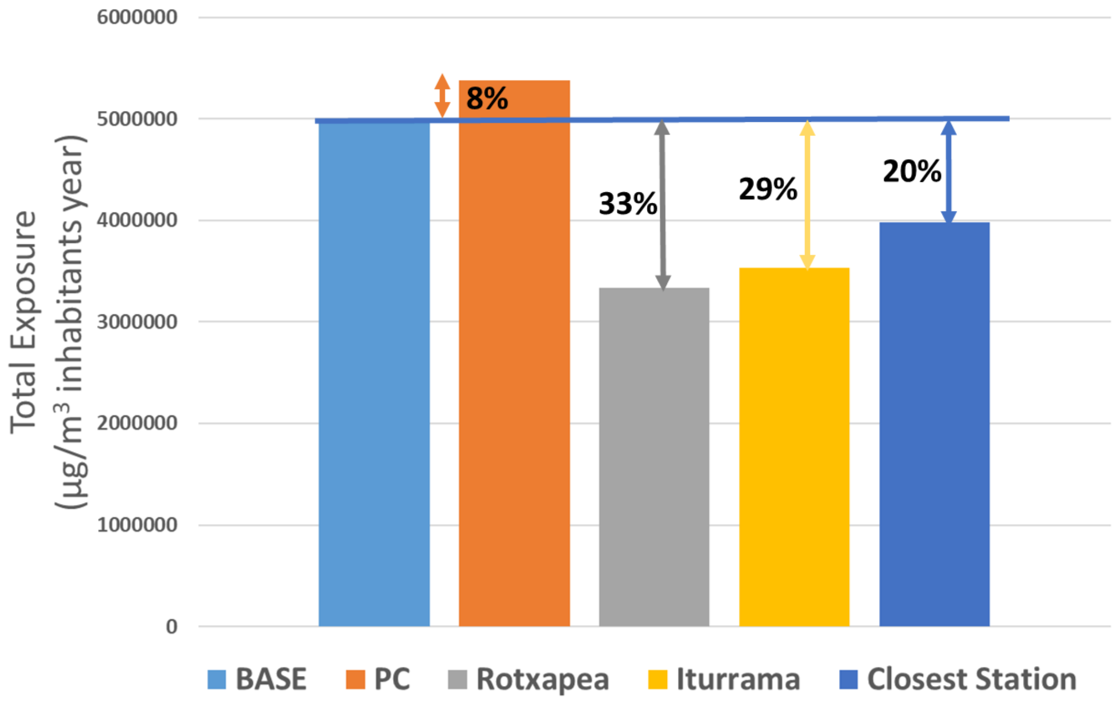

Figure 4. Total exposure estimated using AQMS and comparison with Base case.

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REFERENCES

Gamarra, A. R., Lechón, Y., Vivanco, M. G., Garrido, J. L., Martín, F., Sánchez, E., Theobald, M.R., Gil, V., Santiago, J. L., 2021: Benefit Analysis of the 1st Spanish Air Pollution Control Program on Health Impacts and Associated Externalities. *Atmosphere*, **12(1)**, 32.

Izquierdo, R., Dos Santos, S. G., Borge, R., de la Paz, D., Sarigiannis, D., Gotti, A., Boldo, E., 2020: Health impact assessment by the implementation of Madrid City air-quality plan in 2020. *Environmental Research*, **183**, 109021.

Rivas, E., Santiago, J.L., Lechón, Y., Martín, F., Ariño, A., Pons, J.J. and Santamaría, J.M., 2019: CFD modelling of air quality in Pamplona City (Spain): Assessment, stations spatial representativeness and health impacts valuation. *Science of the Total Environment*, **649**, 1362-1380.

Sanchez, B., Santiago, J.L., Martilli, A., Martin, F., Borge, R., Quaassdorff, C. and de la Paz, D., 2017: Modelling NOx concentrations through CFD-RANS in an urban hot-spot using high resolution traffic emissions and meteorology from a mesoscale model. *Atmospheric Environment*, **163**, 155-165.

Santiago, J.L., Borge, R., Martin, F., de la Paz, D., Martilli, A., Lumbreras, J. and Sanchez, B., 2017: Evaluation of a CFD-based approach to estimate pollutant distribution within a real urban canopy by means of passive samplers. *Science of the Total Environment*, **576**, 46-58.

Santiago, J.L., Borge, R., Sanchez, B., Quaassdorff, C., de la Paz, D., Martilli, A., Rivas, E. and Martín, F., 2021: Estimates of pedestrian exposure to atmospheric pollution using high-resolution modelling in a real traffic hot-spot. *Science of The Total Environment*, **755**, 142475.