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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INTRODUCTION

- The **impact of air pollution on human health** is an important problem in **urban areas because of the high pollutant concentration, and the increased percentage of people living in cities**.
- **Population exposure** is rather challenging to estimate due to:
  1) the **complex spatial distribution of pollutant concentration**;
  2) the **usual coarse spatial resolution data of the distribution of population**.
- **Population exposure to atmospheric pollutants** and the associated **impacts on human health** has been **estimated in the literature** by using **distribution of pollutant concentration and population** with **very different spatial resolution** (from several kilometers to few meters) and different approaches to assign pollutant concentration to population (**Rivas et al., 2019; Izquierdo et al., 2020; Gamarra et al., 2021**).
- To determine **which part of population is exposed to a certain pollutant concentration is crucial**.

RESEARCH QUESTION AND OBJECTIVES

- Research question:

  How much can be the error of the population exposure estimates in a real city due to the resolution of spatial distribution of concentration and population (quality of input data) and the methods to associate both variables?
- Main objectives:
  1) To quantify the **sensibility of the population exposure estimates in a real city to the resolution of the spatial distribution of both air concentration and population** (quality of input data).
  2) To determine the **resolution required for an appropriate population exposure estimate**. Also, in cases with very coarse resolution of available population data, to investigate **how to associate pollutant concentration to population, to reduce uncertainties of the total population exposure estimates**.
  3) To **assess the uncertainties of population exposure estimates using Air Quality Monitoring Stations** (AQMS).

METHODOLOGY

- Starting point of this study is the outcomes of Rivas et al. (2019) because:
  1) **Annual averaged NO_2 concentration was modelled by means of Computational Fluid Dynamics (CFD)** simulations at **high spatial resolution in an entire mid-size city** (Pamplona, Spain)
  2) **NO_2 modelled concentration were successfully evaluated** using data from the city network of AQMSs and from a network of mobile microsensors carried by cyclist around the city.
  3) **Spatial distribution of the population of the city at high resolution (100 m x 100 m)** was available from municipal census

Total Exposure Estimates:

- **Annual averaged NO_2 concentrations and population data are aggregated at different spatial resolutions** ranging from a grid cell size of 100 m x 100 m to a coarser resolution where the whole city is covered by only one cell (6 km x 5 km).
- **Total population exposure** is estimated with the different spatial resolution data set and compared with base case (case with highest resolution)** as reference (*Objective 1 and 2*).
- **Extracting the annual average NO_2 concentration at the location of AQMSs from the high-resolution map and estimating the population exposure with these concentrations** (*Objective 3*).

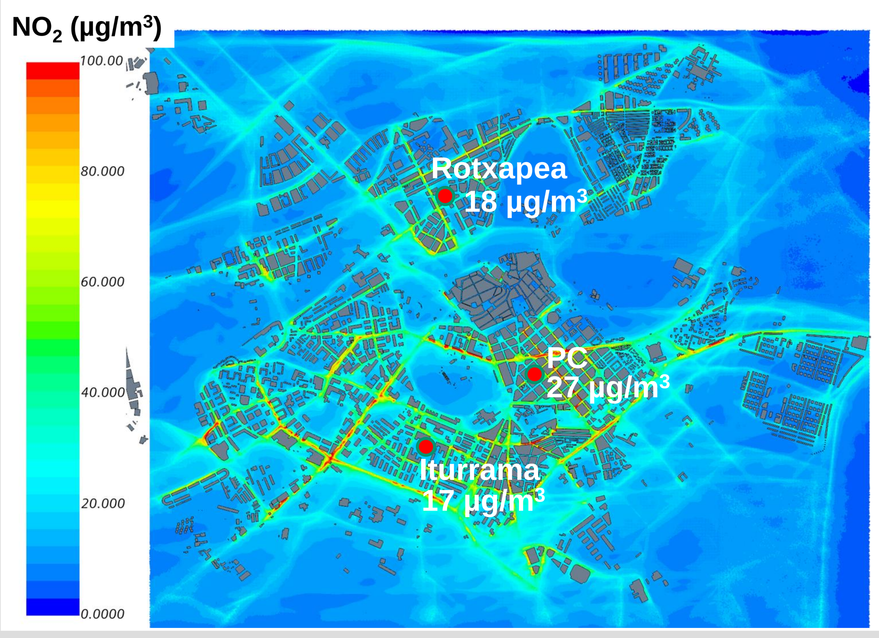

Fig. 1. High-resolution map (~m) of 2006 annual averaged NO_2 modelled concentration in Pamplona, Spain. Red dot: location of AQMS and the values indicate the annual averaged NO_2 concentration.

Cases studied

- **Base case**: Spatial resolution of concentration and population 100m x 100m
- **Case 1**: One cell that covers the whole city (resolution: 6 km x 5 km for NO_2 and population).
- **Case 2**: Four cells covering the whole city (resolution: 3 km x 2.5 km for NO_2 and population).
- **Case 3**: Resolution 1 km x 1 km for NO_2 and population.
- **Case 4**: Resolution 500 m x 500 m for NO_2 and population.
- **Case 5**: Spatial resolution of concentration 100m x 100m and population uniformly distributed in cells of 100m x 100m where there are residential buildings.

DESCRIPTION OF THE STUDY AREA

- Study focused on **Pamplona, located in North of Spain**. A **medium-size city**: around 25 km^2 and 195650 inhabitants
- **Street and building characteristics change depending on the neighbourhood of city.**
- **AQMS network is composed by three stations located in three neighbourhoods: two of urban background (Iturrama and Rotxapea) and one traffic station (Plaza de la Cruz, PC)**

MODELLING APPROACH

- **High-resolution maps of annual average concentration of NO_2 are computed using a numerical methodology (WA CFD-RANS**, Weighted Averaged Computational Fluid Dynamic-Reynolds averaged Navier-Stokes simulations)
- **WA CFD-RANS is based on the combination of steady-state CFD simulations for different wind directions** (**Santiago et al., 2017; Rivas et al., 2019**) in a numerical domain that **covers the entire city.**
- CFD simulations are based on **RANS equations with Realizable k-ε turbulence closure** (STAR-CCM+ model).
- **Neutral profiles are imposed at the inlet.**
- **NO_2 maps are computed from NOx maps by using the ratio NO_2/NOx measured in AQMS.**
- **Results were successfully evaluated** using **data from** the city network of **AQMSs** and from a **network of mobile microsensors** carried by cyclist around the city.

IMPACT OF RESOLUTION ON POPULATION EXPOSURE ESTIMATES

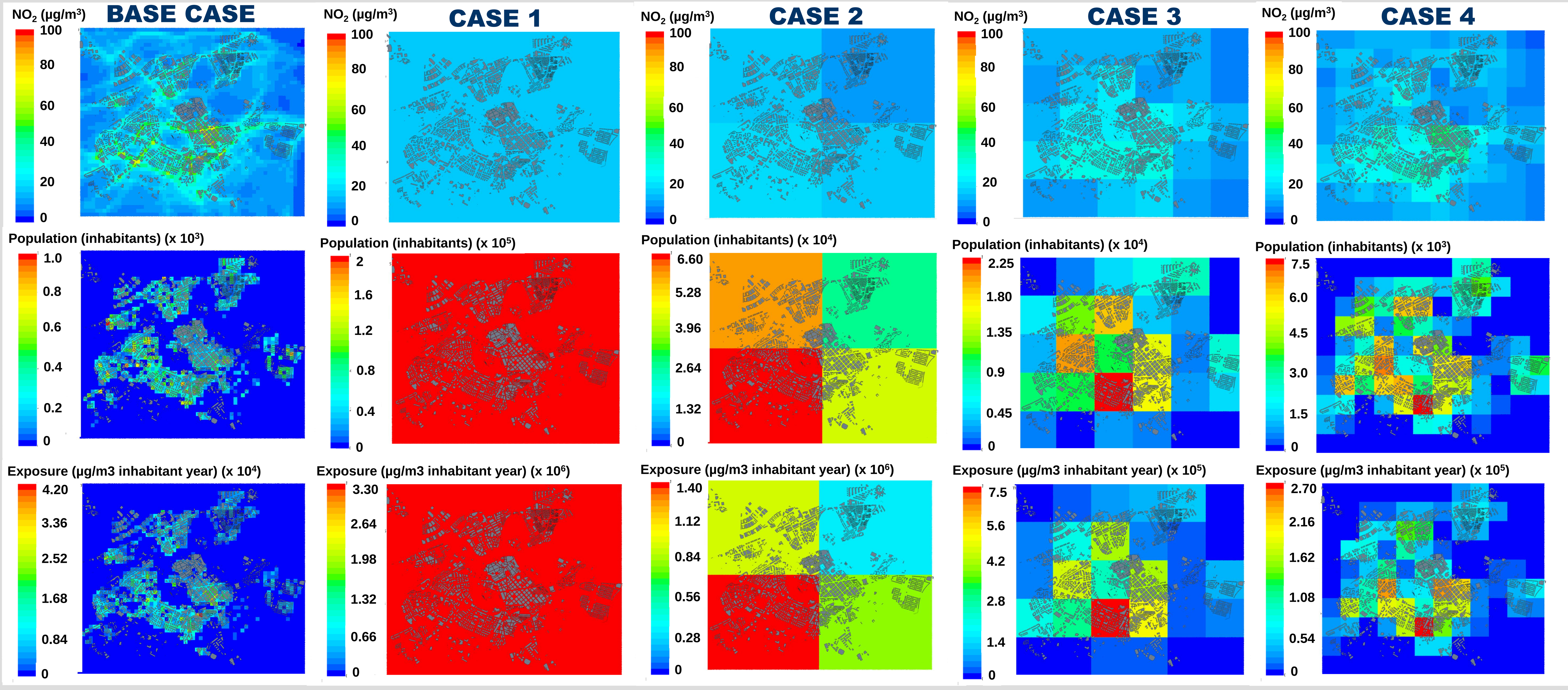

Fig. 2. Maps of NO2, population distribution and exposure estimates for all cases

- **Total exposure is computed multiplying population and concentration in each cell and aggregating the exposure of all cells.**

$$TotalExposure = \sum_{i=all\ cells} (NO_2\ x\ Population)_i$$

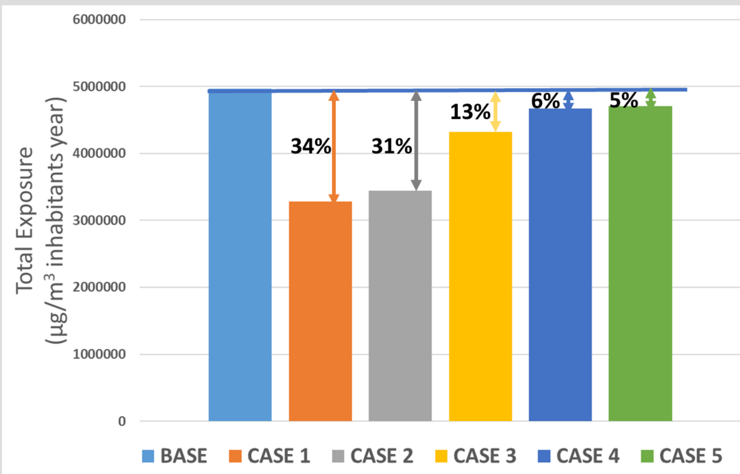

Fig. 3. Total exposure estimated at different spatial resolution.

- For **coarser resolution cases**, **city shape is not well captured**. In addition, **high-concentration levels are not captured** due to the strong gradient of concentration in the city → **Exposure is underestimated.**
- Relative differences of the total exposure estimated for case 1 and 2 are higher than 30%.
- **Appropriate estimates of the exposure** is only provided for **1 km x 1km resolution case (relative differences = 13%)** and for **500 m x 500 m resolution case (relative differences = 6%)**.

•**Case 5 is investigated because sometimes detail information of population is not available**. In this case, we observed that **if population is uniformly distributed over the cells with residential building then, the total population estimates is good** (relative differences = 5%) **if resolution of concentration is fine** (100 m x 100 m).

POPULATION EXPOSURE ESTIMATES USING AQMS

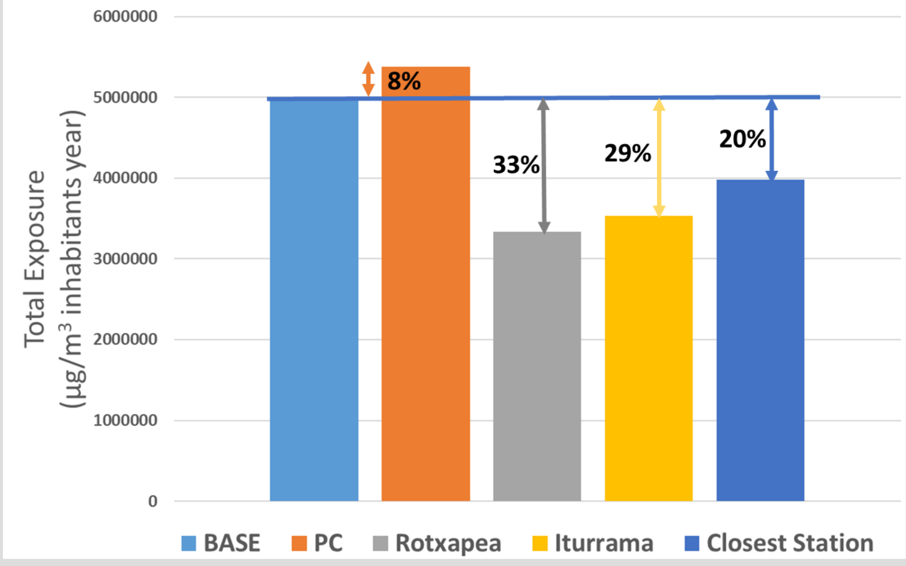

Fig. 4. Total exposure estimated using AQMS and comparison with Base case.

- **Total exposure** is computed multiplying **population in each cell** (resolution 100 m x 100 m) by AQMS concentration and, finally, aggregating the exposure of all cells. These values are compared with the base case.
- **Cases**:
  - **Using concentration recorded by PC AQMS**. Good estimates (slight overestimation of 8%). Residential buildings close to traffic. Low spatial representativeness of traffic AQMS → difficult to extrapolate these results to other possible traffic AQMS.
  - **Using concentration recorded by Rotxapea AQMS**. Bad estimates (underestimation of 33%).
  - **Using concentration recorded by Iturrama AQMS**. Bad estimates (underestimation of 29%).
  - **Using concentration recorded by the closest AQMS**. Regular estimates (underestimation of 20%).
- Overall, total exposure estimates in a city using concentration from AQMS can induce important errors → low spatial representativeness of urban AQMS.

CONCLUSIONS

- This kind of sensitivity analysis is scarce in the literature and these results provide an **estimate of the influence of the input data uncertainties (mainly spatial resolution) in the total exposure computed**. In addition, **recommendations about how to associate concentration and population** are presented.
- The **impact of spatial resolution of population and concentration on a total exposure estimates** is **important**.
- Only input data with **resolution equals or finer than 1 km x 1 km provide appropriate estimates**.
- If population data with high resolution is not available, appropriate total exposure is estimated if population is uniformly distributed over residential buildings and high-resolution concentration is used for the computation.
- Overall, **total exposure estimates** in a city **using concentration from AQMS** can induce **important errors.**
- This research may contribute to provide a **more comprehensive knowledge of the methodologies for the estimates of population exposure**.

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