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Assessing the resilience of urban areas to traffic-related air pollution: Application in Greater Paris

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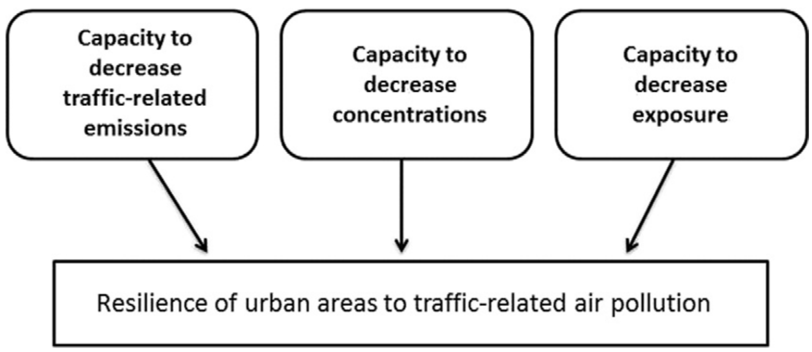
HIGHLIGHTS

- There is a need to adapt urban areas to enable them to tackle issues caused by outdoor air pollution.
- We have developed a "quick scan" method to assess the resilience of urban areas to outdoor air pollution.
- The method is based on the calculation of 3 "resilience capacities", using a GIS-based grid approach.
- The method has been deployed in Greater Paris and helps to localize specific areas where action is needed.

GRAPHICAL ABSTRACT



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ABSTRACT

Recent studies report that outdoor air pollution will become the main environmental cause of premature death over the next few decades (OECD, 2012; WHO, 2014; World Bank, 2016). Cities are considered hot spots and urban populations are particularly exposed. There is therefore an urgent need to adapt urban systems and urban design to tackle this issue. While most European cities have introduced measures to reduce emissions, action is still required to reduce concentrations and exposure, and a holistic approach to urban design is badly needed.

The concept of urban resilience, defined by Holling (1987) as the ability of a city to absorb a disturbance while maintaining its functions and structures, may offer a new paradigm for tackling urban air pollution. We propose to adapt the concept of urban resilience to outdoor air pollution.

A method has been developed to assess the resilience of an urban area to outdoor air pollution. Three "resilience capacities" have been identified: the capacity of an urban area to decrease air pollution emissions, the capacity to decrease concentrations and the capacity to decrease exposure. The calculation is based on the analysis of urban design, defined as the pattern of buildings as well as the structural elements that define an urban area (urban morphology; transport network, services and land use). For each resilience capacity, indicators are calculated using a Geographic Information System (GIS) and a grid-based approach.

This method has been implemented in the Greater Paris area within a 500 m grid-cell system. Greater Paris is one of the densest urban areas in Europe and experiences high air pollution levels. The proposed "quick scan" method helps to localize areas where specific action is needed.

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1. Introduction

A recent study reports that in 2012, around 3.7 million people died as a result of exposure to outdoor air pollution (WHO, 2014). The number of deaths caused by outdoor air pollution is continuously rising (World Bank, 2016; OECD, 2012) and is set to become the main environmental cause of premature death by 2050.

Cities are considered as hot spots and urban populations are particularly exposed. There is therefore an urgent need to adapt cities to improve air quality, and thus to incorporate these issues into urban planning and future design. In cities, transport in particular plays a key role in promoting or degrading health (Khreis et al., 2016).

However, while most of the actions, strategies and plans adopted by decision-makers aim to cut pollutant emissions directly (LEZs, regulations, Euro standards, etc.), decision-makers and urban planners often have no idea of how to factor outdoor air quality into urban design.

Several studies have shown that urban design has an impact on outdoor air quality issues in cities by influencing traffic emissions, pollutant concentrations and population exposure.

1.1. Influence of urban design on traffic emissions

A major part of pollutant emissions in cities are due to traffic (WHO, 2014). In Greater Paris for instance, road transport is responsible for 56% of NO_x emissions and 35% of $PM_{2.5}$ emissions (Airparif, 2016). Parker (1997) has shown that urban design determines the distances people need to travel to reach their daily destinations and also influences which mode of transportation people may choose. For example, Kenworthy (2014) has demonstrated that urban design has a strong influence on automobile dependence. Urban design influences both the "walkability" and the "bikeability" of cities (Marshall et al., 2009; Winters et al., 2013).

The "walkability" of a given area "measures whether community design encourages or inhibits walking" (Marshall et al., 2009), while "bikeability" focuses on how urban design influences cycling (Winters et al., 2013). Both of these indicators may be calculated using a Geographic Information System (GIS). Finally, the public transport network determines the ability of a neighborhood population to use public transport instead of personal cars (Dulal et al., 2011).

1.2. Influence of urban design on pollutant concentrations

Urban areas form rough surfaces which influence local changes to the aerodynamic properties of the atmosphere (Grimmond and Oke, 1999). From an air quality perspective, aerodynamic properties are critical as they describe the movement of air within the urban environment. The aerodynamic properties of urban areas may be described by various parameters, the most important being roughness length (z_0) and zero-plane displacement height (z_d). Estimating these values is critical for predicting air flow and dispersion of pollutants within urban areas (Ratti et al., 2002; Zaki et al., 2014).

1.3. Influence of urban design on population exposure

Recent studies have shown that urban compaction has a strong impact on the exposure of households to pollutants. While higher concentrations are found in sprawling low-density cities, population exposure to air pollution is higher in compact and dense cities since more inhabitants are present in areas with the highest concentration levels (Martins, 2012; Schindler and Caruso, 2014).

Epidemiological studies have shown that populations living near sources of emissions (mainly road traffic) in dense urban areas are the most exposed (Host et al., 2012). In order to assess the exposure of residential areas to atmospheric pollution generated by road traffic, a relatively quick and easy method to implement is based on calculating the distance between the road and the place of residence (Brunekreef et al., 1997; Hoek et al., 2002; Finkelstein et al., 2004; Gehring et al., 2006; Brunekreef et al., 2009). When traffic data are available for the road in question, it is possible to weight the distance by the traffic intensity.

Using strategic maps makes it possible to localize exposure hot spots at a detailed scale by cross-checking air pollution concentrations with vulnerable entities (hospital, school, dwelling etc.) in a GIS. These maps can also be used to implement construction strategies by avoiding building in polluted areas or adapting existing buildings to this unfavorable environment (Roussel, 2014).

1.4. Urban resilience and air quality

While most European countries have introduced measures to reduce emissions, action is still required to reduce concentrations and exposure, and a holistic approach is badly needed. Emissions, concentrations and exposure are linked and the air pollution issue needs to be considered as a whole. The concept of urban resilience, defined by Holling (1987) as the ability of a city to absorb a disturbance while maintaining its functions and structures, may offer a new paradigm for tackling urban air pollution.

Although the concept of urban resilience has been applied to flood risk, not many studies have used it to tackle air pollution. Duh et al. (2008) defined seven air and water quality resiliency factors for urban systems: anthropogenic emissions, natural emissions mitigation, urban form and land-cover change, environmental policy, geography, access to technology and socio-cultural dimensions of risk perception. Ashan-Leygonie and Baudet-Michel (2011) defined resilience to air pollution as the capacity of local stakeholders to develop specific adaptation measures focused on the hazard or vulnerability. While these studies focused on the resilience of urban systems or stakeholders we propose to focus on the resilience of urban design.

2. Research objectives

The aim of this research is to develop a quantitative assessment method for measuring resilience to traffic-related air pollution. In this study, we define resilience as the capacity of an urban area to tackle traffic-related air pollution issues through urban design (urban morphology, transport networks, services and land use). We define the term capacity as the potential of an area to improve a given situation.

The results obtained from this method are intended for use by policy-makers and urban planners. The goal is to provide easy-to-understand scientific information for planners and politicians. For this reason the method uses GIS, which is a powerful tool for presenting layers of information in a geographical way (Ren et al., 2013). Mapping resilience will help to identify areas where actions are needed. In other words, the method aims to localize air pollution "hot spots". The method also aims to be reproducible in different urban areas – from neighborhood to conurbation scale.

The method has been tested in Greater Paris, one of Europe's densest urban areas that regularly suffers from high air pollution levels.

3. Material and methods

In order to assess the resilience of urban areas to traffic-related air pollution, three capacities have been identified: the capacity of an urban system to decrease air pollution emissions, the capacity to decrease concentrations and the capacity to decrease exposure (Fig. 1). The calculation is based on the analysis of urban design, defined as the pattern of buildings as well as the structural elements that define an urban area (transport network, services, land use etc.).

For each capacity, indicators are calculated using GIS and a grid-based approach. The grid resolution – size of each cell - is calibrated in relation to the size of the area studied using the open-source software QGIS.