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Public perception of rural environmental quality: Moving towards a multi-pollutant approach

Manuella Lech Cantuaria [a, *], Jørgen Brandt [b], Per Løfstrøm [b], Victoria Blanes-Vidal [a]

[a] The Maersk Mc-Kinney Moller Institute, Faculty of Engineering, University of Southern Denmark, Odense, Denmark
[b] Department of Environmental Science, Aarhus University, Roskilde, Denmark

HIGHLIGHTS

- A multi-pollutant approach was implemented to investigate exposures in rural areas.
- Highly spatially resolved atmospheric modeling of 14 air pollutants was used.
- Annoyance responses due to odor, noise, dust, smoke and vibration were investigated.
- Results suggest farming-related emissions as an important source of odor annoyance.
- Traffic-related emissions were found to be associated with noise annoyance.

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ABSTRACT

Most environmental epidemiology studies have examined pollutants individually. Multi-pollutant approaches have been recognized recently, but to the extent of our knowledge, no study to date has specifically investigated exposures to multiple air pollutants in rural environments. In this paper we characterized and quantified residential exposures to air pollutant mixtures in rural populations, provided a better understanding of the relationships between air pollutant mixtures and annoyance responses to environmental stressors, particularly odor, and quantified their predictive abilities. We used validated and highly spatially resolved atmospheric modeling of 14 air pollutants for four rural areas of Denmark, and the annoyance responses considered were annoyance due to odor, noise, dust, smoke and vibrations. We found significant associations between odor annoyance and principal components predominantly described by nitrate (NO_3^-), ammonium (NH_4^+), particulate matter (PM_{10} and $PM_{2.5}$) and NH_3, which are usually related to agricultural emission sources. Among these components, NH_3 showed the lowest error when comparing observed population data and predicted probabilities. The combination of these compounds in a predictive model resulted in the most accurate model, being able to correctly predict 66% of odor annoyance responses. Furthermore, noise annoyance was found to be significantly associated with traffic-related air pollutants. In general terms, our results suggest that emissions from the agricultural and livestock production sectors are the main contributors to environmental annoyance, but also identify traffic and biomass burning as potential sources of annoyance.

1. Introduction

There is a large body of epidemiological evidence demonstrating that exposure to air pollutants can have adverse effects on human health. Air pollution health studies often focus on independently examining the effect of exposure to each single pollutant on health outcomes. However, concerns have been raised over the past years about the potential interpretation errors underlying single-exposure assumptions (Vedal et al., 2003). In addition, since polluted air consists of a complex mixture of multiple components and humans are exposed to many emission sources at the same time, the use of multi-pollutant approaches has been strongly recommended and recognized as a scientific priority (NRC, 2004; EPA, 2008; Johns et al., 2012).

Combining multiple exposures in epidemiological models is not an easy task due to the existence of complex interactions and

* Corresponding author. The Maersk Mc-Kinney Moller Institute, University of Southern Denmark, Campusvej 55, 5230, Odense M, Denmark.
E-mail address: mlca@mmmi.sdu.dk (M.L. Cantuaria).

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chemical transformation in the atmosphere, potential high correlations among pollutants and chemical exposure measurement error (Billionnet et al., 2012; Braun et al., 2016). These daunting issues have been tackled by a number of statistical methods, such as Bayesian approaches (Park et al., 2014), shrinkage methods (e.g. Principal Component Analysis (PCA) and least absolute selection operator (LASSO) regression) (Roberts and Martin, 2005; Dallongeville et al., 2016) and source-apportionment methods (e.g. extended chemical mass balance and positive matrix factorization) (Schreuder et al., 2006).

Previous studies following a multi-pollutant approach have focused on: 1) identifying pollutant profiles and possible clusters of exposure (Austin et al., 2012; Azuma et al., 2016; Dallongeville et al., 2016); and 2) estimating and understanding the adverse effects of multiple pollutants exposure (Billionnet et al., 2011; Coker et al., 2016). Combined exposures have been investigated for different sources and air pollution mixtures such as photochemical air pollutants (Saez et al., 2002), indoor VOCs (volatile organic compounds) (Dallongeville et al., 2016) and urban outdoor air pollutants (Austin et al., 2012; Zanobetti et al., 2014; Coker et al., 2016; Deng et al., 2016). However, information regarding multi-pollutant exposure profiles in rural environments, considering the unique issues and emission sources that are specific to these areas, is scarce.

Even though the term “air pollution” is still constantly applied to describe urban environments, rural areas also encounter a number of air quality issues (Blanes-Vidal, 2017). Rural populations are potentially exposed to a variety of pollutants from local pollution sources (both indoor and outdoor) as well as emissions from urban areas. Agricultural and livestock production activities (e.g. machinery use, grazing animals, soil management and manure storage and application) consist in one of the most predominant sources of rural air pollution, being responsible for the emission of several air pollutants, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ammonia (NH_3) and particulate matter (PM) (Skjøth, 2009). In recent years, livestock industry has faced a period of intensification and concentration of activities, followed by a traffic flow increase in rural roads (Lercher, 2007). Besides, many rural areas are located in the vicinity of highways, being therefore subject to a high number of air pollutants from vehicular traffic, mainly characterized by fossil fuels combustion, brake, tires and road surface wear and resuspension of the road-traffic-related dust, especially from unpaved roads (Williams et al., 2008). Biomass burning, which is a common practice in rural domestic environments (e.g. for heating and cooking) and also characterizes vegetation fires, is also a significant source of primary pollutants, such as CO_2, carbon monoxide (CO), VOCs, nitrogen oxides (NO_x), trace minerals and PM, and secondary ones, such as ozone (O_3), nitrate (NO_3^-) and Secondary Organic Aerosols (SOA) (Youssouf et al., 2014).

Denmark has a very solid and traditional participation in the livestock industry, especially in the production of pork meat, being ranked in 2013 as the fifth exporter country of live animals in the world (Steier and Patel, 2017). The intense production is distributed in a very small country area (43,100 km^2), which results in a high number of residents exposed to agriculture-related air pollutants. The intensification of agricultural operations has led to an increase in traffic volume within rural areas, including personal vehicles, trucks and tractors. Other specific sources of environmental stress are commonly found in rural Danish areas, such as wind energy industry (i.e. the largest energy source of Denmark) (Blanes-Vidal, 2017) and marine traffic, since many rural regions are located close to coast. Wood stoves are also frequently used in some residences, especially for heating purposes, and were considered a source of environmental annoyance by more than 9% of Danish residents (Rasmussen and Ekholm, 2015). In addition, even though Danish legislation prohibits field burning in most of the agricultural situations (DCE, 2014), smaller-scale burning is still allowed during some periods of the year.

In response to the rising amount of air pollutants in the countryside, rural communities are raising voice by reporting various health complaints to government and scientific bodies, which includes sinusitis, nasal and throat irritation, headaches, nausea, diarrhea and, among others, reduced quality of life and annoyance (Wing and Wolf, 2000; Schiffman et al., 2005). Indeed, rural populations are often faced to a number of environmental stressors that may impose behavioral and adaptive changes and may affect human health and well-being (Blanes-Vidal, 2017). Moreover, as reviewed by Das-Munshi et al. (2006), some studies suggest that the mechanism underlying the occurrence of health symptoms after low-level chemicals exposure is mainly psychological, and not a direct response to the chemical itself, pointing out annoyance as an important outcome to be investigated.

The aim of this study is to characterize and quantify residential exposures to air pollutant mixtures in rural populations, provide a better understanding of the relationships between air pollutant mixtures and annoyance responses to environmental stressors, particularly odor, and determine the most relevant air pollutants to predict odor annoyance responses in rural communities. The study setting is rural Denmark, including validated and high spatially resolved atmospheric modeling of 14 air pollutants, and the annoyance responses considered were annoyance due to odor, noise, dust, smoke and vibration.

2. Materials and methods

2.1. The study design

The study population consists of a random selection of 3091 adults (>18 years old) residing in four non-urban regions of Denmark: Anholt, Keldsnor, Lindet and Sundeved. This cross-sectional study was conducted in order to assess environmental conditions and health of rural residents who live nearby agricultural land and animal production facilities. Residents were mailed from October 2015 to February 2016 and were invited to participate in the study by answering either a printed version of the questionnaire or an online version through the use of an anonymous identification code. We sent reminder letters for those residents who had not provided any response after two weeks. This work was approved by the Danish Data Protection Agency (Datatilsynet) and carried out in accordance with principles of the Declaration of Helsinki.

The structured questionnaire was designed based on different previously validated surveys (Brauer et al., 2000; Villeneuve et al., 2009; Blanes-Vidal et al., 2012, 2014), and included questions on demographics, behavior, self-perception of the environment and general health. Odor annoyance and annoyance due to other environmental stressors (i.e. noise, smoke, dust and vibration) were assessed by the following question: “Within the past two years, have you felt annoyed by odor/noise/smoke/dust/vibration inside or outside of your house?”, with response options: “Not annoyed”, “A little bit annoyed”, “Annoyed”, “Very annoyed” and “Extremely annoyed” (Supplementary Table 1).

2.2. Exposure assessment

In this study, we assessed exposure to 14 atmospheric pollutants (i.e. nitrogen dioxide (NO_2), nitrate (NO_3^-), nitrogen monoxide (NO), particulate matter (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), ozone (O_3), organic carbon (OC), black carbon (BC), sulfur dioxide (SO_2), sulfate (SO_4^{2-}), sea salt, ammonium (NH_4^+) and ammonia (NH_3)).