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Comparative analysis of spatio-temporal exposure assessment methods for estimating odor-related responses in non-urban populations

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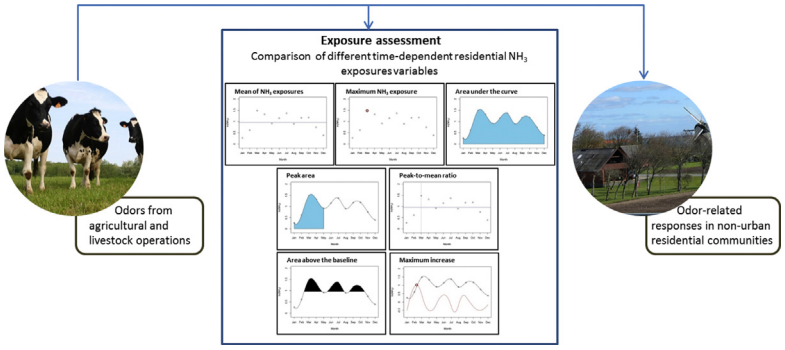
HIGHLIGHTS

- Many odor pollution studies do not consider temporal variability of emissions.
- The association between atmospheric NH_3 and odor responses is investigated.
- We explore the use of different spatio-temporal exposure assessment methods.
- Short-term NH_3 exposures are superior in predicting livestock odor annoyance.
- Odor perception responses were better predicted by long-term NH_3 exposures.

GRAPHICAL ABSTRACT



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ABSTRACT

The assessment of air pollution exposures in epidemiological studies does not always account for spatio-temporal variability of pollutants concentrations. In the case of odor studies, a common approach is to use yearly averaged odorant exposure estimates with low spatial resolution, which may not capture the spatio-temporal variability of emissions and therefore distort the epidemiological results. This study explores the use of different exposure assessment methods for time-variant ammonia exposures with high spatial resolution, in rural communities exposed to odors from agricultural and livestock farming activities. Exposure estimations were based on monthly ammonia concentrations from emission-dispersion models. Seven time-dependent residential NH_3 exposures variables were investigated: 1) Annual mean of NH_3 exposures; 2) Maximum annual NH_3 exposure; 3) Area under the exposure curve; 4) Peak area; 5) Peak-to-mean ratio; 6) Area above the baseline (annual mean of NH_3 exposures); and 7) Maximum positive slope of the exposure curve. We developed binomial and multinomial logistic regression models for frequency of odor perception and odor annoyance responses based on each temporal exposure variable. Odor responses estimates, goodness of fit and predictive abilities derived from each model were compared. All time-dependent NH_3 exposure variables, except peak-to-mean ratio, were positively associated with odor perception and odor annoyance, although the results differ considerably in terms of magnitude and precision. The best goodness of fit of the predictive binomial models was obtained when using maximum monthly NH_3 exposure as exposure assessment variable, both for odor perception and annoyance. The best predictive performance for odor perception was found when annual mean was used as exposure variable (accuracy = 71.82%, Cohen's Kappa = 0.298) whereas odor annoyance was better predicted when using peak area (accuracy = 68.07%, Cohen's Kappa = 0.290). Our study highlights the importance of taking temporal variability into account when investigating odor-related responses in non-urban residential areas.

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1. Introduction

The emission of air pollutants, including odorous compounds, is generally characterized by a temporal variability, consisting of periods of high emissions interspersed with periods of low emissions (Cyrys et al., 2012; McGuire and Noll, 1971). The concentration of pollutants and odorous compounds in the atmosphere changes over time due to a variety of factors, such as the nature of the emission sources, human behavior and meteorological conditions (Batterman et al., 2015; Guttikunda and Gurjar, 2012; Henschel et al., 2015; Jang et al., 2016; Moreno et al., 2009; Whiteman et al., 2014). Despite its time-dependency, the assessment of exposures in epidemiological studies does not always account for temporal variability of pollutant's concentrations (Batterman et al., 2015). Studies often rely on annual averaged concentrations of pollutants as exposure metrics, thereby not capturing the temporal pattern of emissions and its seasonality (Arx et al., 2004; Moreno et al., 2009).

Previous air pollution epidemiological studies have demonstrated the importance of considering the time variability of exposures. Hsieh and Liao (2013) showed that the fluctuations in air pollution time-series (by means of PM_{10} and O_3 levels) were the main contributor for asthma hospital admission; while Stieb et al. (2016) found stronger associations between adverse pregnancy outcomes (i.e. small for gestational age and term low birthday weight) and NO_2 exposure when using monthly data in comparison to annual data. In the case of odor pollution, some studies have highlighted the importance of considering temporal variability (i.e. by analyzing exposure peaks) instead of using long-term averaged exposures when assessing odor emissions from sources such as rusk bakery, landfill sites, painting-related organic solvents and livestock farming industry (Both et al., 2004; Drew et al., 2007; Schauberger et al., 2014; van Thriel et al., 2007). In contrast to these findings, Cavalini et al. (1991) showed that averaged long-term concentrations are superior in predicting odor annoyance than short-term peaks.

Odor can be defined as a "sensation associated with one or more compounds which, when present in sufficiently high concentrations, can trigger olfactory responses in exposed individuals" (Nicell, 2009). Since odor responses can be instantaneously induced, odor peaks may create more annoyance than longer lasting odor emissions (assessed from e.g. averaged emissions), due to human olfactory adaptation (Both et al., 2004; GOAA, 1999). An additional challenge in odor pollution epidemiological studies is the fact that odorant responses are usually triggered by a complex mixture of components and the odor effects depend on the character and interaction of these components and the subjective reactions of exposed individuals (Nicell, 2009). A common practice is to assess odor exposure on the basis of a single indicator compound that well represents the sources under consideration.

Quantifying the impact of odor on public health and quality of life of rural citizens is gaining increasing importance (Wing et al., 2008). Previous studies have provided evidence that ammonia (NH_3), which is characterized by its irritant and odorous properties, can be used as a predictor of odor annoyance in communities exposed to biodegradable wastes from animal production and agricultural activities (Blanes-Vidal et al., 2012a, 2012b). In these studies, the exposure assessment was based on long-term ammonia exposures, which might have masked short-term peaks of exposures that are actually experienced by the population due to the temporal variability of emissions throughout the year. Most NH_3 emissions are originated from agricultural activities, which can be intensively dynamic, with strong daily, monthly and seasonal variation patterns. A large part of these emissions are related to animal wastes management processes that can be either characterized by short-term emissions and high temporal variability (e.g. manure application) or by long-term emissions and lower variability (e.g. manure storage and animal housing) (Gyldenkærne et al., 2005; Pinder et al., 2004).

The objective of this study is to investigate the optimal strategy to assess time-dependent NH_3 exposures in odor epidemiological studies, by: 1) analyzing the associations between different time-dependent residential NH_3 exposures variables and odor-related responses (i.e. odor perception and annoyance); and 2) determining the specific aspects of exposure history that are predictive of these odor impacts.

2. Materials and methods

2.1. Questionnaire data collection

The study is based on cross-sectional questionnaire data obtained from four non-urban regions of Denmark: Anholt (A), Keldsnor (B), Lindet (C) and Sundeved (D) (Fig. 1). A total number of 3091 households were randomly selected and contacted by mail during the period of October 2015 to beginning of March 2016, when field application of animal slurry is restricted by law in Denmark. Adult residents (>18 years old) were requested to anonymously participate in the study by responding to an extensive questionnaire on social demographics, local environment and health. The initial cover letter presented two options for the study participants: 1) Fill in a printed questionnaire and return it by mail; 2) Answer an online version of the questionnaire by accessing a link and providing an anonymous identification code. Reminder letters were sent to those households who had not responded to the questionnaire. This study was conducted in accordance with principles of the Declaration of Helsinki and was approved by the Danish Data Protection Agency (Datatilsynet).

The questionnaire was developed based on previously validated questionnaires on indoor climate (Brauer et al., 2000) and health (Villeneuve et al., 2009), and also included relevant questions as used in previous research (Blanes-Vidal et al., 2012a, 2012b, 2014a, 2014b). The questionnaire consisted of three main sections: the first section comprised information on sociodemographic characteristics and behavioral habits (e.g. gender, age, smoking status, job condition, days away from the residence); in the second section, the participants were requested to provide information about their surrounding environment and different environmental stressors, including information on the frequency of odor perception (i.e. daily, several times per week, several times per month, several times per year, rarely/never), their level of odor annoyance (i.e. not annoyed, slighted annoyed, moderately

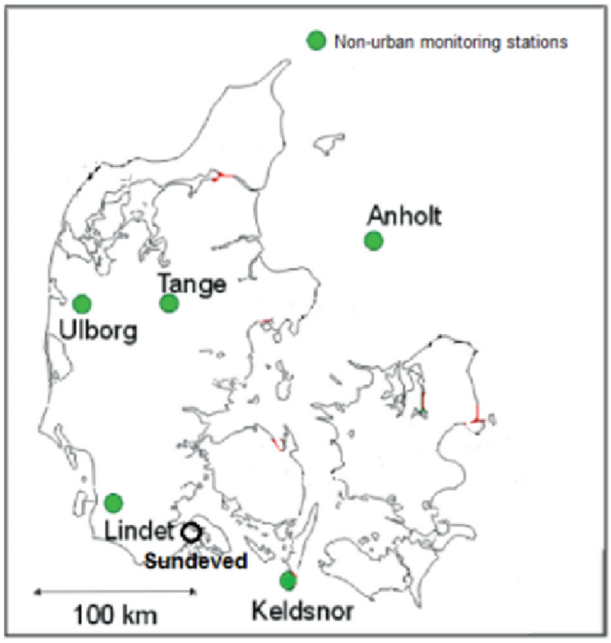

Fig. 1. Study regions (Anholt, Lindet, Sundeved and Keldsnor).