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Improved impact assessment of odorous compounds from landfills using Monte Carlo simulation

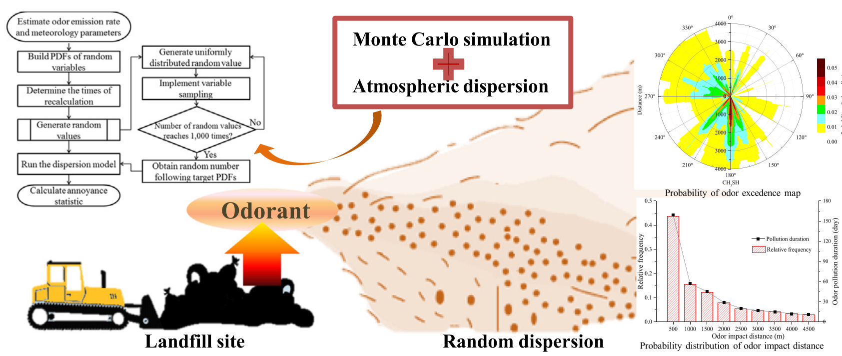
Yanjun Liu [a,c,*], Wenjing Lu [b,c,**], Hongtao Wang [b,c], Xingbao Gao [a], Qifei Huang [a]

[a] State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing 100012, China
[b] Tsinghua University, School of Environment, Beijing 10084, China
[c] Key Laboratory for Solid Waste Management and Environment Safety (Tsinghua University), Ministry of Education of China, Tsinghua University, Beijing 100084, China

HIGHLIGHTS

- A Monte Carlo simulation coupled with a dispersion model (MCDSM) was proposed.
- In MCDSM random values of error components are applied to dispersion model.
- MCDSM produces probabilistic odor impact results.
- The Probability distributions of source and meteorological parameters were studied.
- A probability of odor exceedance (POE) map of CH_3SH near the landfill was plotted.

GRAPHICAL ABSTRACT



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ABSTRACT

Landfills are city infrastructures used for the treatment of municipal solid waste (MSW) in China. However, due to technical failure and/or management problem most of them are facing serious secondary pollution such as groundwater contamination and odor nuisance. The latter is the main reason causing a growing number of public complaints. Atmospheric dispersion models are routinely adopted for odor impact assessment, but these models provide deterministic predictions only. To determine the potential odorant paths and treat the uncertainty of odor pollution, Monte Carlo simulation coupled with an odor dispersion model was proposed and named Monte Carlo-dispersion simulation method (MCDSM). By introducing a series of random values of error components in the dispersion model, MCDSM can produce probabilistic odor impact results. Values of these variances were randomly selected according to their probability density functions (PDFs) due to the imprecise knowledge of the meteorological and emission conditions. After running the odor dispersion model for numerous times, the randomization produces a set of possible results that closely resembles the expected behavior of the odorants. This study applied MCDSM to estimate the odor impact of methyl mercaptan (CH_3SH) on an MSW landfill in Beijing, China. The PDF of the CH_3SH emission rate was derived from the field data. The uncertainty of odor impact was analyzed statistically, and the results were summarized using the probability of odor exceedance (POE). A POE map of CH_3SH was plotted for a particular interest, in which the north downwind direction was the most polluted area. MCDSM provides a scientific approach for the assessment of odor pollution from individual odorant, which can benefit the formulation of standard for odor impact assessment in landfill sites.

* Correspondence to: Y. Liu, State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing 100012, China.
** Correspondence to: W. Lu, Sino-Italian Environmental and Energy Efficient Building, School of Environment, Tsinghua University, Beijing 100084, China.
E-mail addresses: liuyj01@craes.org.cn (Y. Liu), luwenjing@tsinghua.edu.cn (W. Lu).

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1. Introduction

Landfilling is one of the most important approaches for municipal solid waste (MSW) disposal in China. The odor nuisance from landfill sites is arousing public concern and often subject to "not in my backyard" protests. In China, MSW is mixed, collected, and dumped in landfill sites, in which food waste is the prevalent component (>60% wet base) (Chen et al., 2010; Zhang et al., 2010). Consequently, MSW is characterized with high moisture content and a sizable quantity of biodegradable components. A large amount of odorants was estimated to be emitting from MSW in the forms of sulfur compounds, ammonia, and other volatile organic compounds (Y. Liu et al., 2018). Sulfur compounds, such as hydrogen sulfide (H_2S), methyl mercaptan (CH_3SH), dimethyl sulfide, and ethyl sulfide, are major causes of odor nuisance in landfill sites (W. Liu et al., 2018). The working face, where fresh MSW are dumped and compacted, is the most significant odorous source in landfills. Moreover, wastes on the working face are usually exposed to the environment for two to three weeks before being well covered.

The decision of odor impact distance is a complex issue worldwide. Governments regulate the siting of landfills by setting a minimum distance between landfill sites and residents. For example, South Australia proposed a safe distance of at least 500 m between landfills and residents to prevent the negative impacts of landfill gases (South Australia Environment Protection Authority, 2007). The Europe Union Council Directive 199/31/EC proposed a minimum distance of 500 m between landfill and residential areas in the 1999 version but did not specify this distance in the final version. China's Domestic Waste Sanitary Landfill Technology Specification (CJJ 17-2004) asserted a safe distance, that is, landfills should not be built within 500 m of residential areas. The Standard for Pollution Control on the Landfill Sites for Municipal Solid Waste (GB 16889-2008) stated that the distance between landfill and residents should be determined through the performance of environmental impact assessment; however, no method was provided. The decision of odor impact distance still lacks theoretic support.

In academic research, dispersion models have been widely used for odor impact assessment. Figueroa (2006) studied the odor impact of a landfill in the USA and found that H_2S could be perceived at distances of 800–1000 m away from the landfill. Cai et al. (2015) evaluated the odor impact from 1955 landfills in China and concluded that the impact range of most landfills was 400–1000 m. Lu et al. (2013) claimed that the odor pollution of a large-scale landfill site could reach over 500 m. Yan et al. (2008) revealed that the odor impact distance of large-scale landfills was 1000–1500 m. Y. Liu et al. (2018) estimated that trace sulfur compounds could be recognized at an average distance of 495 $\pm$ 96 m away from a landfill at normal meteorology conditions.

Odor dispersion is a random and uncertain process that is strongly conditioned by local atmospheric dynamics and emission strength. The variability of meteorological conditions and source emission must be considered in odor impact assessment. Dispersion models commonly follow Gaussian, Lagrangian, or Eulerian approaches and evaluate plume dispersions for given scenarios (Capelli et al., 2013; Leelossy et al., 2014). However, variations in source and weather conditions cannot be characterized in a single simulation of the model. Treating the variation and uncertainty of odor dispersion is hence still an issue.

Monte Carlo simulations are used to model the probability of different outcomes in a process that cannot easily be predicted due to the intervention of random variables. Such process can involve thousands of recalculations and provide a range of possible outcomes and probabilities. Monte Carlo simulation has been widely used in environmental concerns, especially risk assessment (Safadi et al., 2015). However, applying the Monte Carlo algorithm to atmospheric dispersion modeling remains a computational bottleneck (Katsiolidesa et al., 2017).

This study proposes an improved method to integrate uncertainty into the numerical modeling of odor dispersion, especially at close distances from emission sources. Monte Carlo simulation was coupled with a dispersion model (MCDSM) for the quantitative treatment of the uncertainty, and particular interest was given to the production of probability of odor exceedance (POE). The MCDSM process includes four steps: 1) analyzing the characteristics of the probability density functions (PDFs) for the source emission strength and meteorological parameters; 2) investigating the relationship of the input variables for the dispersion model and generating random numbers by sequence; 3) applying the random numbers into the dispersion model and simulation; and 4) summarizing the results and assessing the odor impact statistically. MCDSM provides a scientific approach to comprehensively understanding odor pollution from MSW landfills. This method can be applied to other MSW treatment facilities for odor impact assessment.

2. Materials and methods

This work evaluated the consequence of odor pollution released from MSW landfills. CH_3SH, a serious landfill odorant, was selected in this study as a typical odorous pollutant in China (Y. Liu et al., 2018; Wu et al., 2018). To achieve this goal, we based the modeling chain on three steps: (i) characterization of CH_3SH emission from the working face of the studied landfill, (ii) simulation of the CH_3SH atmospheric dispersion using MCDSM, and (iii) statistical evaluation of the odor pollution. These steps are detailed in the following sub-sections.

2.1. Field measurement of CH_3SH emission

2.1.1. Site description

The landfill selected in the current study is in Beijing, China (40.16° N, 116.35° E). It is a typical flatland landfill that has an active gas-collecting system with vertical wells and horizontal pipes. The site only receives and treats urban MSW, and the amount of daily landfilled MSW is ~3000 t. Food waste is the dominant component, which accounts for ~65.3% of the wet weight. Other organic fractions, such as plastic, paper, textile, and wood, comprise ~32.1% of the total landfilled waste.

The working face of the site has an area of ~600 m^2, where fresh wastes are dumped and compacted daily. However, the wastes on the working face are exposed to air for two to three weeks before being covered well. The composition of the landfilled waste is plotted and presented in Supplementary material (Fig. S1).

2.1.2. Gas sampling and analysis

Sampling campaigns were conducted on the working face of the landfill on selected days from May 2014 to January 2015, which covered four seasons. A total of 124 valid samples were obtained. The emission rate was measured with use of a modified wind tunnel system designed by the authors, whereas the device and sampling procedure were described elsewhere (Liu et al., 2015). During sampling, gas samples were withdrawn from the system's outlet using a lung-principle sampler (Duan et al., 2014) into a 1 L multilayer foil sampling bag (Dalian Delin Gas Packing Co., Ltd.).

The gas samples were analyzed within 24 h after collection using an Agilent Technologies 7890A gas chromatography (GC) system with a flame photometric detector. Detailed CH_3SH analysis is summarized in Supplementary material S2.

2.1.3. Emissions of CH_3SH

The emission rate of CH_3SH was computed on the basis of its concentration and the flow rate of carrier gas (N_2) blowing through the wind tunnel as follows:

$$ER = \frac{24 \times Q \times c}{B}, \tag{1}$$

where ER is the emission rate of CH_3SH, $\mu g \cdot m^{-2} \cdot d^{-1}$; Q is the flow rate of nitrogen, $m^3 \cdot h^{-1}$, which was fixed at 19 $m^3 \cdot h^{-1}$ in this study; c is