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Parameter sensitivity to concentrations and transport distance of odorous compounds from solid waste facilities

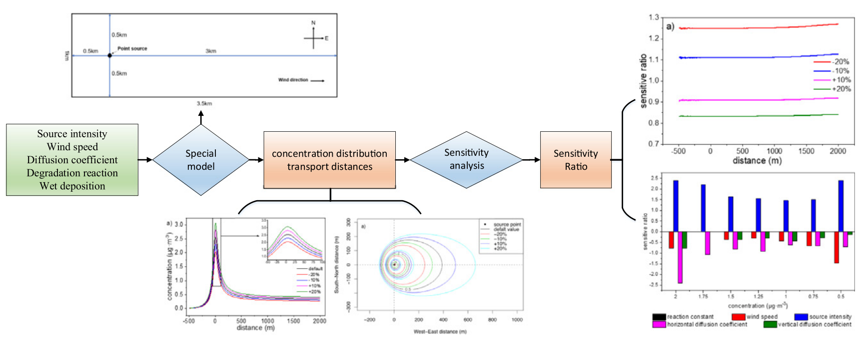
Huimin Chang [a], Yan Zhao [a,b,*], Haobo Tan [a], Yanjun Liu [d], Wenjing Lu [b,c], Hongtao Wang [b,c]

[a] School of Environment, Beijing Normal University, Beijing 100875, China
[b] Key Laboratory for Solid Waste Management and Environment Safety, Ministry of Education of China, Beijing 100084, China
[c] School of Environment, Tsinghua University, Beijing 100084, China
[d] State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing 100012, China

HIGHLIGHTS

- Dispersion of odorous compounds simulated by using a specialized model
- Sensitivity analysis applied to identify the influence of key parameters
- Source intensity and wind speed are sensitive parameters in different directions.
- Degradation reaction constant and wet deposition are not sensitive.
- Key parameters influencing concentrations also influence travel distance.

GRAPHICAL ABSTRACT



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ABSTRACT

Treatment facilities dealing with municipal solid waste (MSW) are typical pollution sources of urban odor nuisance which threatens public health and environmental safety. Dispersion simulation with specialized models is an important approach for simulating the concentration distribution and estimating the transport distances of the released odorous compounds. Given that the temporal and spatial distribution are affected by many factors with different variations and functions. This study investigated the influence of key parameters on the dispersion of odor compounds on the basis of a numerical atmospheric dispersion model. The sensitivity analysis was applied to quantitatively identify their influence on the concentration distributions and transport distances. The results reveal that source intensity is a sensitive parameter in the whole domain under the specified dispersion conditions, with the sensitivity ratios around 1 to concentrations and of 1.5–2.5 to transport distances. Wind speed possesses higher sensitivity ratios at the upwind direction than the downwind direction. Horizontal diffusion coefficient is sensitive to concentrations only in the area of a typical radius of 500 m from the source. Degradation reaction constant and wet deposition are not sensitive in either concentration distribution or transport distances. The most sensitive parameters present respective importance to the transport distances when different olfactory thresholds of compounds are applied to determine the protection area of odor pollution. This study thus provides important information to the application of dispersion models and the data collection of the most sensitive parameters in odor pollution evaluation and management.

* Corresponding author at: School of Environment, Beijing Normal University, Beijing 100875, China.
E-mail address: yanzhao@bnu.edu.cn (Y. Zhao).

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1. Introduction

With the accelerating process of urbanization in developing countries, the pressure on the treatment and disposal of municipal solid waste (MSW) in cities is constantly increasing (Gu et al., 2017). For instance, the total amount of MSW generated in Beijing, China reached 8.7 million tons in 2016, with an annual increasing rate of 0.1% (China, 2018). To deal with all the generated waste, many facilities including transfer stations, composting plants and landfills spread over the cities. Due to the high contents of moisture and organic fractions in mixed MSW, these facilities can easily release a large amount of volatile organic compounds (VOCs) and inorganic compounds such as H_2S and NH_3 during the treatment processes, becoming important pollution sources of urban odor nuisance that threatens public health and environmental safety (Capelli et al., 2011; Scaglia et al., 2011; De Feo et al., 2013). Many studies investigated the emission characteristics of the odorous compounds from different MSW facilities, indicating that these compounds were normally present at high volatility, low concentration and low olfactory threshold (Ding et al., 2012; Palmiotto et al., 2014; Zhao et al., 2014; Liu et al., 2016). In particular, the potential impacts of the odorous compounds vary transiently because of the influence of releasing rates and meteorological conditions (Gallego et al., 2014; Liu et al., 2015). Therefore, clarifying the dispersion law of the compounds is crucial to provide evidence to the separation distance and protection area of odor pollution (De Feo et al., 2013).

Dispersion models are important tools to simulate the concentration distribution around the sources and estimate the transport distances of odorous compounds (Capelli et al., 2013). Gaussian and Lagrangian models like AERMOD and CALPUFF are the most common atmospheric dispersion models (Cimorelli et al., 2005; Leelőssy et al., 2014), which have been applied in describing the dispersion of odorous compounds as well (Gibson et al., 2013; Steven et al., 2005; Wang et al., 2006). These models are either suitable only for simulating the air dispersion under steady state, or designed for the study scale ranging from several to dozens of kilometers (Capelli et al., 2011; Leelőssy et al., 2014). However, the volatile compounds released from MSW facilities are usually of low concentration and thus have limited transport capability and local impacts, which are restricted to areas from dozens of meters to several kilometers (Piringer et al., 2015; Ranzato et al., 2012). In addition, the dispersion conditions such as wind direction and velocity change constantly. In these instances, the conventional atmospheric dispersion models show inapplicability in odor pollution assessment, and specialized odor dispersion models favoring small-scale, high-precision and non-steady state are desired.

So far, only a few dispersion models specialized for odor pollution were reported (Capelli et al., 2013). On the basis of Gaussian model, Piringer and Schauberger (2013) applied the AODM software for odor pollution assessment, and compared the results with those obtained from the Lagrangian model LASAT under the non-steady state simulation (Piringer et al., 2015, 2016). Odor Gas Atmospheric Dispersion Simulation software (ModOdor) was recently developed by the authors based on Eulerian model (see the Supporting Information) and has been applied to the evaluation of odor pollution from MSW landfills and transfer stations. Different from the Gaussian and Lagrangian models, ModOdor applies finite difference method to three-dimensional numerical simulation with discrete points in the study domain, providing the resolution as precise as several meters (see the Supporting Information). This model presents a good applicability to the dispersion simulation of trace odor compounds, and its ability has been verified in some case studies.

In the dispersion simulation process, the temporal and spatial distribution of odor compounds will be affected by many factors, including compound characteristics, source intensity, degradation, deposition, terrain, wind speed and direction, and other meteorological conditions (Lu et al., 2015). At the same time, most of these parameters present a high level of variation (Cai et al., 2015; Dincer et al., 2006). For example, the source intensity of odor compounds released from landfills varies with the waste composition, water content, temperature, and wind speed, which also vary with large ranges and high frequencies (Chiriac et al., 2011). The wind speed and other meteorological conditions may affect the atmospheric stability and diffusion coefficients, which are important to any dispersion model. The fluctuation of these parameters will thus cause uncertainty of the dispersion simulation results through modelling, and in particular, different dispersion models may have different responses to these parameters.

Given the different variations and functions, minor changes in some parameters may result in significant changes in the dispersion and vice versa. In this study, the influence of the parameters on the dispersion of odor compounds was investigated on the basis of the model ModOdor. With a point source as an example, the sensitivity analysis of key parameters including source intensity, wind speed, diffusion coefficient, wet deposition and degradation reaction constant was performed to quantitatively identify their influence on concentration distribution and transport distances of odor compounds. The most sensitive parameters identified in this study require more attention and accuracy in further data collection, and the possible fluctuation in transport distances can be predicted from their sensitivities. This study thus provides important support to the application of dispersion models on odor pollution evaluation and prediction, as well as guidance to the relevant data collection.

2. Approach and methods

2.1. Study domain and parameter definition

Though the model ModOdor applied in this study can deal with different terrains, it is hard to quantify the impacts of the terrain variation. For simplification purpose, the study domain was defined as a flat square area of 3.5 km × 1 km in horizontal directions, with a point source located at the place with 0.5 km to west, north and south directions, and 3 km to east (Fig. 1). x and y axes were defined as east-west and north-south directions. The height of the study domain was assigned as 123 m, with z axis defined as vertical direction. The boundaries of the study domain were assigned open at the top and all sides except for the bottom due to the ground barrier. The point source was assigned with a height of 22 m in z direction according to field survey of a typical large transfer station with a stack of 22 m high.

According to our in-situ monitoring and previous study in the large transfer station, ethanol was chosen as the typical odor compound given its highest releasing rate and contribution to the odor pollution of the transfer station (Zhao et al., 2015). Five key parameters were investigated and their default values were listed in Table 1. The default source intensity was assigned in terms of the typical monitoring data in the same transfer station at 11 AM on 1st June 2017. The default wet deposition washout coefficient and first-order reaction constant were derived from references (Carruthers et al., 1994; Atkinson et al., 2007, 2008). The default wind speed was the real wind speed at the monitoring time, and the default diffusion coefficients were calculated from the real meteorological conditions according to the atmospheric stability method (General Administration of Quality Supervision and China, 1991). Accordingly, temperature was not chosen as a key parameter because it affects the dispersion indirectly, through affecting the atmospheric stability and thus the diffusion coefficients.

2.2. Numerical simulation approach and modelling tool

In this study, ModOdor model, which was specially developed for simulation and prediction of atmospheric dispersion of odorous gases generated from solid waste disposal facilities and other sources, was used to simulate the dispersion of odor compounds. ModOdor applies three-dimensional numerical simulation approach, and its governing equation is shown in the Supporting Information.