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Research article

Evaluating the impact of odors from the 1955 landfills in China using a bottom-up approach

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ABSTRACT

Landfill odors have created a major concern for the Chinese public. Based on the combination of a first order decay (FOD) model and a ground-level point source Gaussian dispersion model, the impacts from odors emitted from the 1955 landfills in China are evaluated in this paper. Our bottom-up approach uses basic data related to each landfill to achieve a more accurate and comprehensive understanding of impact of landfill odors. Results reveal that the average radius of impact of landfill odors in China is 796 m, while most landfills (46.85%) are within the range of 400–1000 m, in line with the results from previous studies. The total land area impacted by odors has reached 837,476 ha, accounting for 0.09% of China's land territory. Guangdong and Sichuan provinces have the largest land areas impacted by odors, while Tibet Autonomous Region and Tianjin Municipality have the smallest. According to the CALPUFF (California Puff) model and an analysis of social big data, the overall uncertainty of our calculation of the range of odor impacts is roughly −32.88% to 32.67%. This type of study is essential for gaining an accurate and detailed estimation of the affected human population and will prove valuable for addressing the current Not In My Back Yard (NIMBY) challenge in China.

1. Introduction

With increases in population, urbanization, and living standards, the municipal solid waste (MSW) produced in China has increased continually. In 2012, the harmless disposal rate of MSW reached 84.80%, of which 72.55% went to landfills. Neighborhoods in the proximity of MSW landfills are often burdened with a series of adverse consequences that result from solid waste disposal. One of the major impacts is the unpleasant odors generated from the decomposition of waste. The high moisture content (40–60%) and high content of easily degradable organic waste (50–70%) within the MSW of China often lead to serious landfill gas (LFG) fugitive emissions and air pollution in the form of undesirable odors. The landfill odor problem is an important and highly debated environmental concern of the Chinese public, and it is also the main reason for the public complaints lodged against landfilling. Based on the records of the environmental protection hotline "12369" in 2013, 25 complaint cases were related to landfill odors, which accounted for 1.5% of all cases processed that year (Environment Complaint Center, 2015). Considering that China only had approximately 2000 landfills at that time while industrial enterprises numbered in the millions as well as the fact that air, soil, and water pollution are also severe in China, landfill odors accounted for a disproportionally high percentage of public complaints. This indicates the severity of the problem and a high level of public

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concern about landfill odors. Given these conditions, an accurate and comprehensive understanding of the impacts of landfill odors in China is essential for solving the Not In My Back Yard (NIMBY) issue related to waste management facilities. Providing basic data for improving solutions and policies is therefore a priority. Understanding the effects of landfill odors is also valuable for the identification of locations and the spatial optimization of new landfills (Leão et al., 2004). However, previous research related to the impact of landfill odors in China has simply focused on case studies. A more accurate and comprehensive evaluation of the impact range of landfill odors at national level is greatly needed. In this study, we adopt a bottom-up approach that ensures the accuracy of our calculations and provides full coverage of landfills in China. To our knowledge, this is the first study that evaluates the spatial range of the impacts of odors from each landfill in China.

2. A review and assessment of the impact range of landfill odors

Because odors from landfills can have an obvious influence within a certain range, studying and determining the range of those impacts is important. Studies have shown that sulfides were the main compounds causing landfill-generated odors and that many other complex trace substances also contributed to those odors (Allen et al., 1997; Ding et al., 2012; Duan et al., 2014; Kim et al., 2005; Sarkar et al., 2003; Scheutz and Kjeldsen, 2003; Young and Parker, 1983; Ji, 2011). Governments regulate siting of landfills by specifying the minimum distance between landfill sites and residential areas. The European Union Council Directive 1999/31/EC of 26 April 1999 states that decisions on landfill siting should consider the distance to residential and recreation areas and the Directive proposed a minimum distance of 500 m. However, the final version of the Directive does not specify a minimum distance but only broadly states that an unspecified minimum distance should be taken into consideration. British Columbia's environmental protection bureau requires that the minimum distance from a landfill to residential areas, schools, and hotels should be more than 300 m (British Columbia Ministry of Environment (1993)). The government of South Australia states that the safe distance from landfills to residential areas should be at least 500 m to prevent the influence of landfill gases (South Australia Environment Protection Authority, 2007). The State of Victoria in Australia (2010) requires that the safe protection distance from landfills to buildings should be 500 m. Hasan et al. (2009) reviewed the safe distance of landfills and demonstrated that the distance between landfills to urbanized areas should be at least 500–2000 m. Úbeda et al. (2010) used two methods, simple and commercial Gaussian atmospheric dispersion models, to assess the range of the impact of odors of a landfill in Valencia, Spain. Tagaris et al. (2003) studied CH_4 concentrations from the Lemonou landfill in Greece via a CALPUFF (California Puff) model. Tagaris et al. (2012) thought that the concentration of CH_4 could be representative of most landfill odor gases, and thus the range of effects could be calculated by a dispersion model. Guarriello et al. (2007) recognized H_2S as the main landfill gas producing undesirable odors and that CH_4 could also be used to evaluate the range of impacts from landfill odors. Figueroa (2006) studied the range of impacts from landfill odor of a landfill in Seminole, FL, USA, and they found that an H_2S could be perceived at distances of 800–1200 m away from the landfill.

China has also issued a series of technical specifications and planning guidelines to regulate the impact of landfills on the general public. The Standard for pollution control on the landfill site of municipal solid waste (GB 16889-2008) states that the location of landfills and their distances to the surrounding population should be decided by an assessment of environmental effects. The Urban environmental sanitation planning specification (GB50337-2003) states the minimum distances required to separate MSW landfills from cities and residential areas. The Domestic waste sanitary landfill technology specification (CJJ17-2004) asserts that landfills should not be built within 500 m of residential areas or drinking water sources for humans and animals. Researchers in China have also evaluated the range of the impacts of odors from landfills based on theoretical analyses and field measurements. Yan et al. (2008) and Li et al. (2010) calculated the size of buffers needed around landfills to protect human health at different scales. Lu et al. (2009) studied the range and the diffusion of landfill odor pollutants and their impacts on the surrounding residential areas, showing that the range and diffusion of odor pollutants from large-scale landfills would exceed 500 m.

Table 1 summarizes the size of buffers around landfills required to protect human health based on current regulations and academic research from Chinese and international sources. The results ranged from 500 m to 1000 m. Furthermore, the evaluation subject in these previous studies was either a single landfill or a macro-analysis on landfills which had limited coverage or the final results lacked good accuracy. Thus, a determination of odor emissions and range of their impacts from the bottom-up via incorporating site-specific conditions and local meteorological patterns related to each landfill is greatly needed.

3. Methods and data

We focused on 1955 landfills, including both 1057 sanitary landfills and 898 open dump sites. This represents almost all the landfills in China. A FOD model was used to calculate the odor emissions, and a ground-level source Gaussian dispersion model (hereafter, Gaussian dispersion model) was applied to calculate the diffusion of odor gas around each landfill. The bottom-up research model has several advantages: (1) In contrast with research at the national and regional level, this method calculates a specific landfill odor impact distance for each landfill, which can reflect the differences between landfills; (2) This work ensures that the basic information of each landfill (including waste composition, annual and total landfill amount, and management levels) and the calculation model (FOD model and Gaussian dispersion model) used herein were consistent with those used in single case studies; (3) This study covers almost all the landfills in China with detailed information on each landfill.

In this research, olfactory threshold is the base data used to determine the range of the impacts of odors, and it is defined as the critical point when the odors could be perceived by people. Although landfill odors contain many harmful substances, inhaling the odors does not necessarily cause harmful health consequences, but it can certainly cause unpleasant emotions.

In view of the range of the impacts of landfill odors, the main research method is based on physical models and the olfactory threshold. In addition to the landfill itself, the centralized transportation around the landfills is also an important odor source. Moreover, the impacts of odors are greatly influenced by the subjective feelings of individuals, and the results from the Gaussian dispersion model may underestimate the range of the impacts of odors to a certain extent. Thus, the CALPUFF model and social media data were used to assess the overall uncertainty in the results of Gaussian dispersion model.

3.1. Calculation method of odor gas emission

H_2S is the main landfill odor gas (Ding et al., 2012; Duan et al., 2014; Kim et al., 2005; Sarkar et al., 2003; Ji, 2011; Qiang et al., 2014). We chose H_2S as the representative odor gas, which is the