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The construction dust-induced occupational health risk using Monte-Carlo simulation

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ABSTRACT

A probabilistic risk assessment model was developed to explore the health effects of construction dust on the practitioners in the construction industry based on the United States Environmental Protection Agency (USEPA) risk assessment model and the Monte-Carlo simulation method. The health risk was assessed for workers in five zones during the superstructure construction stage of residential projects in Beijing. Health impairment assessment models were applied to translate health risks into disability-adjusted life years (DALYs), which are more intuitive and easy to understand. Sensitivity analysis methods were used to analyse the various exposure parameters and influencing factors that affect the health risk assessment results. The results indicated that workers in the template zone were exposed to the largest health risk, which followed a lognormal distribution of $1.14 \times 10^{-6} \pm 9.43 \times 10^{-7}$, and the probability exceeding 10^{-6} was more than 40%. The average health risks for workers in the steel, concrete and floor zones were slightly below 10^{-6}, and the workers in the office zone had the lowest health risk. The spearman rank correlation coefficient method and the full factorial designs method were used for a sensitivity analysis and validation. Sensitivity analysis showed that the sensitivities of the average exposure time (AT), exposure duration (ED), exposure frequency (EF) and concentration (C) were larger, while AT and body weight (BW) exhibited a negative sensitivity. Workers in the template and steel zones had the larger health damage, with an average of more than 0.1a.

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1. Introduction

With rapid economic and industrial development, air pollution has become a crucial global environmental problem. Dust can be generated during construction projects, which is a significant contributor to air pollution (Zuo et al., 2017). Construction dust not only causes serious environmental pollution but also threatens the physical health of the construction workers. Because the composition of dust pollutants is more complex, particulate matter is selected as a landmark pollutant when assessing its health risk (Zhang and Wu, 2008). Particulate matter can lead to respiratory organ sclerosis or bleed burden (Brown, 2009) and even lead to respiratory diseases such as cardiovascular disease, cerebrovascular disease, acute respiratory infections, and chronic obstructive pulmonary disease (Rushton, 2007; Hsieh and Liao, 2013). In fact, construction zones, such as office, floor and concrete zones, produce massive amounts of dust that can be inhaled into the human body, and result in physical diseases or environmental problems. Therefore, it is necessary to pay attention to both the construction dust pollution and the construction dust-induced occupational health risk.

Regarding construction dust, researchers have focused on the effects of control measures of building construction dust (Kuusisto et al., 2007; Van Deurssen et al., 2014; Wu et al., 2016) and the implications of human exposure (Harrad et al., 2006). Recently, several reports have been published that focused on the health damage assessment of dust pollution. These researchers provided valuable references for the health risk assessment of construction dust, but also presented some limitations.

Previous studies have used a deterministic method to assess the health risk of construction dust and ignored the uncertainty of the

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dust concentration and various exposure parameters. For instance, Zhang and Wu (2008) evaluated the dust health impairment during construction activities according to the most likely value of dust concentration and other parameters. However, for construction workers, there may be slight differences in the exposure parameters of different types of work due to differences in the work content. The traditional deterministic risk assessment method is based on a reasonable exposure situation—this method is relatively conservative, but it is difficult to measure the degree of conservatism. The probabilistic risk assessment method can provide more information than the deterministic health risk assessment method.

Therefore, based on the United States Environmental Protection Agency (USEPA) recommended inhalation health risk assessment model, a probabilistic risk assessment model was proposed by considering the uncertainty of both exposure parameters and dust concentrations. The Monte-Carlo method was used to evaluate the construction dust-induced health risk of 5 trades in the superstructure construction stage of 5 residential projects in Beijing. In the meantime, the sensitivity analysis method was used to select the parameters that had the greatest influence on the health risk. Finally, the health risks were converted to health damage values to provide a basis for decision-making regarding occupational health management.

2. Literature review

2.1. Health risk of construction dust

From a recent literature review, it was discovered that numerous studies of dust pollution related to construction activities have been carried out during the past few years. An earlier study has been conducted by Bergdahl et al. (2004). In their research, cohort study was used to analyse the relationship between construction dust and chronic obstructive pulmonary disease. Afterwards, Zhang et al. (2007) used the exposure-response function to assess the particulate pollution risk and quantify the public health damage caused by air emissions in Beijing from 2000 to 2004. Using the monetization method, Zhang and Wu (2008) considered a combination of exposure, influence and a damage analysis to establish the quantitative relationship between the dust concentration change and human health damage. In particular, based on the health risk assessment method and the building health impact evaluation method, Li et al. (2015) established a construction dust health damage evaluation framework to assess the dust health effect from various construction activities. By investigating the construction location, this study indicated that the dust health risk assessment is affected by many factors, including the dust concentration, type of construction activity, exposure pathway and exposure parameters of the human body.

However, a very limited number of health probabilistic risk assessment studies have been carried out regarding dust pollution from construction activities. During the process of urbanization, a large number of the old buildings are torn down and new buildings are constructed, producing a large amount of construction dust (Dong and Ng, 2015). The inhalation pathway is usually considered the major exposure pathway for human exposure to dust (Dean et al., 2017). This type of research is important for the understanding of the conditions of employees in a construction environment. Therefore, it is of profound theoretical and practical significance to evaluate the human health risk of construction dust.

2.2. Probabilistic risk assessment

Quantitative health risk analyses are essential to evaluate human health risk and provide a scientific basis for management and decision making. In general, approaches for risk assessments include both deterministic and probabilistic risk assessment method (Zhang and Wu, 2008; Li et al., 2015; Öberg and Bergbäck, 2005). For the deterministic method, health risks are calculated according to the most likely or the maximum values for the human exposure parameters and pollutant contents, which would affect the accuracy of the conclusions (Peng et al., 2016). However, uncertainty is always present in the occupational health risk assessment life-cycle (Li et al., 2012). For example, due to the effects of the construction activity zone, time, weather, season and other factors, the dust concentration is uncertain. Differences in personal physiological factors lead to an uncertainty in the human exposure parameters and then cause an uncertainty in the health risk. Thus, a probabilistic risk assessment method was employed instead of a deterministic risk assessment to evaluate the construction dust-induced occupational health risk in this study.

3. Materials and methods

3.1. Dust sampling and preparation

The superstructure construction stage of 5 residential districts in Beijing City was selected as the sampling area because these projects are high-rise residential with large-scale construction, long construction cycles and many construction workers in the field. The projects are all located between the 5th Ring Road and the 6th Ring Road in northeastern Beijing, which is a relatively concentrated area for building construction. Regular site monitoring was carried out from the beginning of September 2012 to the end of October 2012, which lasted for two months. Through the dust monitoring at the construction site and the filter membrane method used to calculate the dust concentration, a total of 113 dust concentrations were selected as the samples: 17 from the office zone, 24 from the floor zone, 21 from the concrete zone, 25 from the steel zone and 26 from the template zone. The locations of sampling points are shown in Fig. 1.

This study selected the total suspended particulate matter (TSP) concentration in the air as the dust monitoring indicator. The TSPs

Fig. 1. The location of the sampling points in Beijing.

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