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Health Cost of Dust Pollution of Architectural Engineering Construction in Construction Site: Evidence from China

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ABSTRACT

Toxic and harmful gases, noise, industrial dust, loads, and job posture in architectural engineering construction are the different factors that influence health loss of construction workers. Among them, construction dust is a primary occupational health threat among construction workers. Accordingly, this study aims to analyze the dust pollution hazard in the architectural construction process and quantitatively estimate the health loss of construction workers. It uses a case study based on an earthwork stage in a construction site at Zhengzhou City, Henan Province, China. Environmental health risks were evaluated by using the exposure parameter method, while estimating the health losses of different objects caused by earthwork in this construction site. Results demonstrated that dust in the earthwork site was caused by the cement process and moving vehicles. Cementers and road cleaners suffered the most threats from dust with dust exposure dosages of 0.48 and 0.21 mg/kg·d, respectively. The health losses of cementers and road cleaners reached CNY 19,342.74 and CNY 14,532.36, respectively. A reduction on health costs caused by dust pollution in architectural engineering construction is possible through the following proposed measures: strengthening the monitoring of the construction workers' level of exposure to dust pollution, establishing a health management system for construction workers, focusing on the effect of environmental supervision mechanism, and standardizing the emission standards of construction dust pollution. Results could provide some references in understanding the current status and distribution law of dust pollution in construction sites, promoting the implementation of health management and protection system for construction workers, enhancing the working environment of construction workers, and quantitatively estimating the total health influences of architectural engineering.

INTRODUCTION

A considerable amount of dust is produced during architectural construction. Construction dust accounts for a large proportion of the total dust pollution in urban areas. Dust pollution threatens the physical health of workers in the architectural construction site and the people conducting activities in surrounding places. Long-term exposure to high-concentration construction dust may significantly increase the annual morbidity and death rates from cardio-cerebrovascular diseases. Atmospheric particle pollutants and health-effect endpoint, especially their relationship with death, have been proven in different countries with different types of atmospheric pollution and different pollution ranges. Architectural construction uses several machines for foundation excavation, piling, and concrete stirring while producing remarkable noise. Long-term exposure to noises may seriously influence physical health. Harmful gases (e.g., formaldehyde, benzene, and radon) produced during the decoration and use of buildings can stimulate the eyes, nose, throat, and skin and trigger the cancerization of cells in the human body. This phenomenon increases the probability of leukemia and nasopharynx and lung cancers. Dust pollution can affect the physical health of construction workers and people conducting activities in surrounding areas. Given that dust pollutants have a complicated composition, particulate matters are chosen as the symbolic pollutants in the quantitative assessment of health loss caused by atmospheric pollution. The total suspended particulate (TSP) is defined in aerodynamics as the sum of particulate matters smaller than 100 μm and closely related to the epidemiology of health-effect endpoint of a certain group.

As a provincial city of Henan Province in China, Zhengzhou has a large population and rapid development in the architectural construction industry. Fig. 1 shows that the annual growth rate of investment in real estate development and constructed floor area of real estate enterprises in Zhengzhou City increased significantly from 2007 to 2017 at 102% and 34%, respectively. Despite the rapid growth of architectural engineering in Zhengzhou City, the improvement of health

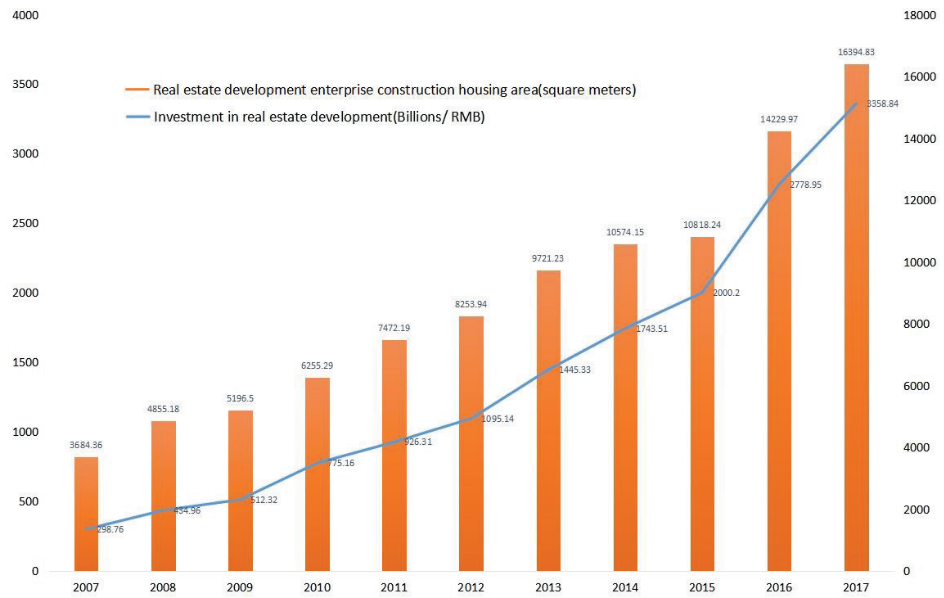

Fig. 1: Investment on real estate development and construction floor area of real estate enterprises in Zhengzhou City from 2007 to 2017. (The data are collected from the Statistical Yearbook of Henan Province.)

loss remains unclear. At present, determining whether or not dust emission and health cost caused by construction activities exceeds the requirements of national standards is difficult without an objective monitoring and assessment system of dust-induced health cost. In addition, the emission intensity of dust varies in the different construction stages, and various groups in the site suffer diverse health losses from dust. This difference further increases the difficulties in the practical implementation of relevant laws and regulations. The distribution law of practical dust-induced health cost in different construction stages and worker groups can be established by investigating the current status of dust pollution in construction sites and distribution patterns in different stages to enable the adoption of additional effective protective measures for different worker groups and subsequently formulating relevant regulations. Doing so will pave the way for the implementation of a feasible health management and security system for construction workers to improve the working environment of construction workers.

EARLIER STUDIES

Studies have reported on the health loss caused by architectural construction. These studies have focused on the health cost analysis in the different construction stages, construction workers, and construction procedures. As for environmental pollution caused by dust in construction sites, Ghandour et al. (1983) explored the dust deposit rate and composition in the Helwan industrial zone in Cairo, Egypt; they then found that construction cement industry is the main source of atmospheric pollution. Lee et al. (2001) believed that abundant building sand and gravel supported the development of civil constructional engineering in Taiwan's economy, but the processing plants of building sand and gravel were a major source of air pollution and dust emission. Chow et al. (2003) collected profile data concerning six chemical sources of geological dust in San Joaquin Valley, California by using the systematic sampling and analytical method. Accordingly, considerable amounts of dust were found to contain many heavy metal elements that might damage physical health. Svoboda et al. (2016) demonstrated that the population in urban areas was highly concentrated due to accelerated urbanization, while dust pollution produced by construction activities remarkably influenced the environment. Wu et al. (2017) offered that modern industrialized development in China led to the continuous growth of construction dust emission and thus intensified environmental pollution. Meanwhile, they investigated the status of dust control in China's construction industry and put forward an insight into relieving dust pollution in the construction industry. Zuo et al. (2017) determined that dust pollution in the process of architectural construction is an inevitable type of environmental pollution, and managers must learn how to control dust pollution in the environment and use innovative technologies for dust pollution control. Xue et al. (2017) specified that construction areas in Beijing increased due to population growth, economic development, and continuously increasing demand for living and office spaces; consequently, such factors led to dust pollution from different construction activities. The continuously increasing dust emissions in construction sites in Beijing City have been found to cause a remarkable pressure over environmental pollution. With respect to health loss caused by dust pollution in construction sites, Bergdahl et al. (2004) conducted a follow-up survey on 317,629 male construction workers exposed to air containing inorganic dust (including asbestos, man-made mineral fiber, cement, concrete, and quartz dust) in Sweden from 1971 to 1999, their findings showed that construction workers' occupational exposure might increase the death rate caused by chronic obstructive pulmonary disease. Tak et al. (2008) assessed the occupational health conditions of workers in a highway tunnel project from the perspective of ergonomics and represented the degree of distortion of relevant body parts during construction operations. Zhang et al. (2008) pointed out that dust produced by construction projects was an important cause of atmospheric pollution and might cause harm to the physical health of humans. They then proposed a method for evaluating the environmental influences of dust and proved the scientificity of this evaluation system through a case study. House et al. (2010) investigated the morbidity of hearing loss among 169 construction workers and concluded that a statistically significant correlation exists between construction work and low hearing level. Johncy et al. (2011) carried out a tracking detection on the cardiopulmonary functions of 61 construction workers and compared them with another set of 61 ordinary people (control group) with similar physical conditions. They found that construction work caused certain influences on the cardiopulmonary function of the human body, and such influences became very significant after working in the construction industry for more than 10 years. Šukys et al. (2011) examined the economic loss in the construction industry due to failure in occupational safety and health requirements. Their research method reflected the occupational safety and economic benefits of health investment. Finally, certain policy suggestions were proposed to reduce the quantity of occupational diseases and working accidents. Abrar et al. (2017) evaluated the health conditions of workers during a highway restoration work in Lahore City by choosing six sites; they then concluded that noises, vibration, dust, asphalt smoke, poor working postures and injuries in the construction site were major threats to the physical health of workers. Nioi et al. (2018) determined that construction workers exposed to sunshine for a long time and excessive exposure to solar ultraviolet light triggered the workers' susceptibility to skin cancer. According to existing studies, developed countries abroad all believed that dust pollution caused by construction activities seriously affected the physical health of different types of workers. Tracking investigation is a popular research method that analyzes the damaging effects of different construction factors based on practical health conditions of workers and construction activities and the environment of different worker groups. Given the existence of many construction sites, acquiring the environmental data of construction sites is easy. The management level of different construction sites may also cause different health losses of construction workers. In this study, environmental parameters can correspond to health parameters of construction workers by introducing the exposure parameter method to analyze the physical health of construction workers. This study aims to provide good references for health management of architectural construction and the quantitative assessment of other health loss factors.

BRIEF INTRODUCTION TO THE MODEL AND DATA SPECIFICATION

Brief Introduction to the Model

The exposure parameter method is an important approach for assessing the environmental health risk of one or several harmful compounds. It describes the quantity and rates of exposure of the human body to foreign matters through breathing, oral intake, and skin by using the exposure parameters. Hence, this method can calculate the absorbed dosage of harmful substances by the human body from the environment. Based on accurate estimation of the human body's absorbed dosage of harmful substances, harmful compounds in the existing health risk evaluation system are divided into threshold (generally non-carcinogenic) and threshold-free (generally carcinogenic) compounds.

The accurate calculation of *ADD* in the health risk assessment is important:

$$\text{ADD}=\frac{C \times IR \times EF \times ET \times ED}{BW \times AT} \quad \dots (1)$$

Where, C is the environmental concentration of harmful substances and acquired directly from the original monitoring data before this study (mg/m^3). IR is the respiratory rate that refers to the volume of absorbed human by human in the unit time under a certain temperature (m^3/h). EF is the exposure frequency that refers to the frequency of the human body being exposed to the environment and expressed by the number of exposure days in a year. In this study, EF is the annual number of construction d/a workers' working days (d/a). ET is the continuous exposure time (h/d). ED is the continuous exposure time (a). BW is the body weight used as the main reference of evenly distributed exposure dosage (kg). *AT* is the total exposure time that refers to the time a human body is exposed to the environment throughout his/her life; *AT* refers to the total years of construction work from employment to retirement (a). Finally, the unit of calculated *ADD* is mg/kd·d.

After calculating *ADD*, its health risk is represented by the damage index (*R*) in the health risk evaluation because TSP in dust belongs to the threshold compound. Health risk is calculated as follows:

$$R=\frac{ADD}{RFD}\times 10^{-6} \quad \ldots(2)$$

Where, *ADD* is the calculated exposure dosage of the human body to harmful substances in the exposure parameter method. It refers to the human body's adsorbed dosage of harmful substances when the concentration of harmful substances reaches a certain value. *ADD* is calculated by using the Eq. (1). *RFD* is the reference dosage of the substance, and the numerical value of different compounds was obtained from the exposure parameter manual issued by United States Environmental Protection Agency. *R* is a dimensionless parameter denoting the health risk of health exposure of the human body.

Risk is distributed to the relevant diseases according to proportions, and the disability-adjusted life year (*DALY*) was calculated on the basis of the damage factor of different diseases. In addition, the risk in Eq. (2) is a life-long exposure risk. Therefore, the following risk of practical damage is the product of the calculated life-long exposure risk and the ratio of continuous exposure time and lifetime:

$$DALY=n\times\sum_{t} R\times Q_i\times W_i\times L_i\times P_i \quad \ldots(3)$$

Where, *R* is the health risk of dust calculated from Eq. (2). Q_i is the risk factor of different diseases, that is, the distribution proportion of risks in different types of damage. W_i is the damage factor of the disease with a value between 0 and 1. L_i is the average expected residual life. P_i is the number of affected people. *n* is the number of exposure times, that is, the relevant days in the construction stage. Finally, the value of life year (WTP) of health loss caused by dust is calculated as follows:

$$WTP = DALY \times VLY \quad \ldots(4)$$

Where, *VLY* is the value of life year per unit *DALY*. Therefore, the year of disability and loss can be expressed by the currency (RMB/year). From Eqs. (1) to (4), the social payment willingness of *VLY* for dust-induced health loss can be calculated.

DATA SPECIFICATION

Dust-induced health loss analysis requires days in the construction period and number of workers in the different stages of a specific project. The construction period in the different stages somewhat varies in each project. On the basis of the analysis of a residential community in Zhengzhou City, the construction process can be divided into earthwork, main structural construction, and secondary structure and indoor decoration stages. In this study, the earthwork stage was monitored from May 1, 2018 to July 23, 2018. By analyzing data gained from in-situ monitoring of construction sites, the distribution situations and pattern of dust concentration in the earthwork stage were summarized. Finally, health loss caused by dust pollution in the earthwork construction stage was calculated.

RESULT ANALYSIS

Classification of Construction Workers

Unlike the direct monitoring of dust concentration in the construction environment, this study evaluated health loss of employees in the construction industry, including construction workers and site managers. On the basis of early preliminary analysis of dust monitoring data, dust concentrations in different regions of different stages were analyzed, and the environmental concentration in different regions of a construction site was obtained. The worker groups in these regions might suffer different health losses from exposure to dust due to the remarkable differences in dust concentration among the different regions in a construction site. Accordingly, Table 1 lists the evaluation objects in the earthwork stage in different regions.

Estimation of Dust Exposure Dosage

In this case, the residential community in Zhengzhou City is in the earthwork stage. A deep and large foundation exists,

Table 1: Health loss evaluation objects in the earthwork stage.

Objects	Number	Activity range
mManagers	28	Office building in the construction site
Road cleaners	17	Two sides of the road
Cementer	18	Cement processing region
Rebar processing staff	16	Rebar processing region
Foundation operators	49	Foundation operation region

and the total earth volume is over 450,000 m^3. The two types of dust involved in the earthwork stage are siliceous and cement dust. The former comes from soil and is diffused into the air by passing vehicles or natural wind. The latter is from the dry cement used in construction and is diffused during machinery processing and dumping. The dust data in the earthwork stage were monitored throughout the entire stage. Table 2 presents the monitoring results in the different regions.

Table 2 shows that the average dust concentration at different points is higher than the national standards in the earthwork stage. Moreover, a certain difference exists in terms of dust concentration at the different regions of the construction site. Hence, different workers in the construction site may suffer from different health costs from dust pollution. The construction worker group is the closest to the direct emission source of dust pollution in the construction site, and they suffer the most serious health loss from dust pollution. Foundation excavation is not the main source of dust in the construction site. Thus, the dust pollution it creates leads to small health losses among construction workers. In the earthwork site, dust comes from cement processing and passing vehicles. Cementers and road cleaners at both sides of the roads suffer the most serious health loss from dust pollution. Dust from cement processing falls under high-intensity emission in a short period. Although the emission peak of dust is high, it disperses rapidly. Relevant workers shall adopt relevant protective measures from dust pollution.

According to monitoring data and Eq. (1), the exposure dosage of different groups to dust in the earthwork stage is calculated. Table 3 lists the results.

Table 3 shows that cement dust emission generally occurs in the machinery processing of cement. Cementers must directly pour abundant dry cement into a machine. The vibration of the machine and wind pressure produced during operation cause a considerable amount of cement particles to fly in the air and produce high-concentration dust emission. Consequently, the dust exposure dosage of cementers is substantially higher than those of other worker groups. Road cleaners are the second major group exposed to dust pollution. Cleaners are required to clean the surface in the earthwork stage, which results in dust flying into the air. Therefore, the dust exposure dosage of road cleaners is also maintained at a relatively high level.

WTP Value of Health Cost

Based on previous calculation, the WTP values of health costs of different groups were calculated using Eqs. (2)-(4). Fig. 2 illustrates the results.

Dust-induced health risk and health cost of different worker groups are compared (Fig. 2). Foundation operators and managers suffer relatively small dust-induced health costs. In the earthwork stage, road cleaners and cementers suffer the highest health risks and costs caused by dust pollution. In this case study, the total number of construction workers was around 65. Construction workers are the principal victims of dust-induced health costs. Health costs of cementers and road cleaners reached RMB 19,342.74 and RMB 14,532.36, respectively. This finding is explained by the high-intensity emission the dust production has in a short

Table 2: Dust concentration and number of affected people at different points.

Points	Type of dust	Test time	Concentration range (mg/m^3)	Average concentration (mg/m^3)
Office building	Siliceous dust	12	0.63–0.98	0.76
Rest area of workers	Siliceous dust	16	0.38–1.84	1.35
Rebar processing region	Siliceous dust	8	0.54–1.20	0.98
Foundation operation region	Silicious dust	9	0.12–1.65	1.03
Two sides of the road	Silicious dust	15	1.39–7.83	5.39
Cement processing region	Silicious dust	23	1.98–29.49	12.56

Table 3: Exposure dosage of different groups to dust in the earthwork stage (ADD).

No.	Staff composition	C (mg/m^3)	IR (m^3/h)	EF (d/a)	ET (h/d)	ED (a)	BW (kg)	AT (a)	ADD (mg/kg.d)
1	Managers	0.76	0.48	308	8	0.15	63.83	73	0.03
2	Rebar processing staff	0.98	0.48	308	8	0.15	63.83	73	0.04
3	Foundation operators	1.03	0.48	308	8	0.15	63.83	73	0.04
4	Road cleaners	5.39	0.48	308	8	0.15	63.83	73	0.21
5	Cementer	12.56	0.48	308	8	0.15	63.83	73	0.48

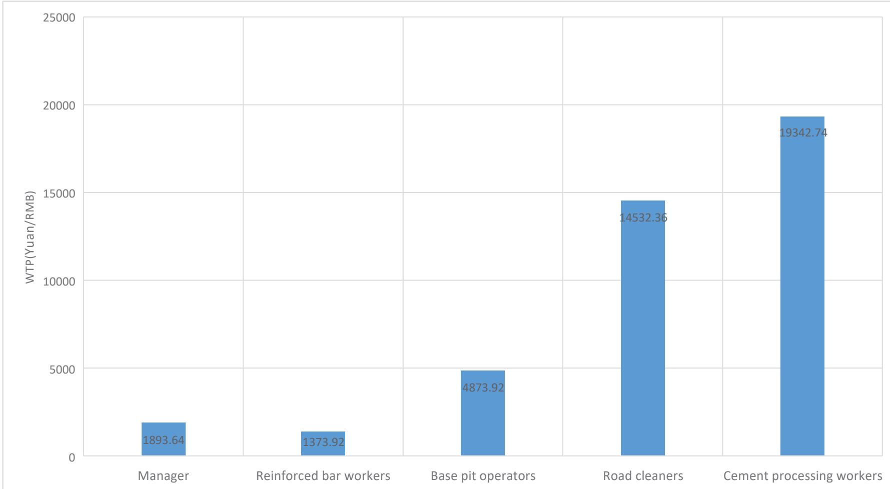

Fig. 2: WTP value of health costs of different worker groups.

period via cement processing. Although the dust emission peak is high, it disperses rapidly. Therefore, cementers need targeted protection. The hardening pavement combined with watering is an effective method of controlling dust on the road. Notably, watering can effectively decrease dust concentration and has high cost performance. However, pavement hardening can considerably reduce cumulative dust. The combination of watering and pavement hardening can control dust concentration within a standard range.

POLICY SUGGESTIONS

Strengthening the monitoring of the different construction worker groups' level of exposure to dust pollution: Following the spatial distribution of workers in the construction site and construction activity characteristics of different groups, this study formulated a set of overall construction monitoring scheme covering earthwork, the main structural construction, and indoor decoration. This scheme could realize dust monitoring in a specific region of the construction site. The research conclusions could provide a theoretical foundation for investigating the direct source of dust pollution in the construction site and analysing the distribution pattern of dust.

Apart from the earthwork stage, high-concentration dust in the two other stages is produced in a closed operation space. Therefore, the protection of involved workers and indoor ventilation conditions can be improved. Moreover, strengthening the supervision of managers in key-closed working areas is suggested to protect the occupational health of relevant workers.

Setting up a health management system for construction workers: A scientific and authoritative dust-induced health cost database was formed by recording and collecting the above health cost data to further supplement the environmental dust concentration data in practical projects. Accordingly, a series of standard regulations and management methods, such as dust concentration and health management standards of construction workers in the construction region, could be formulated further to provide practical management guarantee to the occupational health of construction workers. The research mode of monitoring, calculation, and analysis on dust supervision and assessment in construction sites can be further promoted. This research mode closely related to management can be applied to other contexts involved in the exposure parameter method, such as monitoring of a specific toxic substance and health cost assessment in the decoration stage. The results can provide references for implementing specific monitoring and management mechanisms to identify similar factors causing occupational health risks.

Focus on the environmental monitoring system: After trials and practices in China, the environmental supervision organization cooperates with the construction unit on the basis of a contract and offers construction unit technological services as the social third party. The environmental supervision organization and construction unit have a common goal to promote the environmentally friendly completion and acceptance of projects. The construction unit shall change its view regarding the environmental supervision organization from an administrative unit into a cooperative partner. Moreover, the construction unit shall make full use of the environmental supervision organization not only in the construction process but also in employee training to increase the consciousness and operation level of workers in terms of dust pollution control. The construction unit shall focus on the role of the environmental supervision organization in dust pollution control and exploit its cooperative power rather than limit its function to supervision and management.

Standardizing the emission of dust pollution in the construction site: Dust pollution control in the construction site requires corresponding supervision and emission standards. The installation of an advanced dust tester is suggested in core areas of the construction site to test the content of particulates. Then, the test data shall be uniformly uploaded into the detection platform, and the dust supervision system will immediately send alarms upon exceeding the standards. The majority of construction sites have installed online dust supervision devices according to the requirements of relevant departments. Additional enterprises of supervision device manufacturing are increasingly participating in dust pollution control in construction sites with the development of dust online monitoring in construction and demolishing sites. On the basis of the scientific charging standard and method for dust emission, other administrative sanctions (e.g., punishment per day) shall be adopted to penalize enterprises with exceeding emission of dust pollution.

CONCLUSIONS

Dust pollution is a major atmospheric pollution in the architectural construction stage that causes serious health costs to the human body. Dust pollution will cause serious health losses to workers and managers in the construction site and to the people living and conducting activities in surrounding areas.

Accordingly, this study carried out a case study on the basis of the earthwork stage of a construction site in Zhengzhou City, Henan Province, China. Environmental health risk was assessed by using the exposure parameter method, and health costs to different construction workers in the study area were estimated. The results demonstrated that the dust exposure dosage of cementers and road cleaners reached 0.48 and 0.21 mg/kg·d, and their health costs amounted to RMB 19,342.74 and RMB 14,532.36, respectively. This study further provided some policy suggestions, including strengthening the monitoring of different construction worker groups' level of exposure to dust pollution, setting up a health management system of construction workers, focusing on the environmental monitoring system, and standardizing the emission of dust pollution in the construction site. Finally, it suggests further currency value estimation of dust-induced health costs throughout the construction period of a project, a big data analysis concerning health costs throughout the construction period, analysis on the relationship between different construction management modes and dust emissions, and implementation of the specific toxic substance monitoring and health-cost assessment in a specific construction stage.

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