Review

Air Pollution Health Impact Monitoring and Health Risk Assessment Technology and Its Application — China, 2006–2019

Jingxiu Han[1]; Dongqun Xu[1,#]; Donggang Xu[2]; Xu Yang[3]; Qin Wang[1]; Mingqing Chen[3]; Wenrong Xia[2]; Weiwei Xing[2]; Chunyu Xu[1]; Yue Liu[1]; Junrui Chang[1]; Wenliang Fu[2]; Shuxin Hao[1]; Na Li[1]; Xiaoyan Dong[1]; Yunpu Li[1]; Congshen Meng[1]; Jingyi Liu[1]

ABSTRACT

Air pollution is a significant risk factor contributing to the burden of disease in China. Health risk assessment and management are important to reduce the impact of air pollution on public health. To help formulate standardized health risk assessment techniques, a series of studies were conducted from 2006 to 2019. Through systematic review, study of molecular mechanisms, epidemiological investigation, and health effect monitoring, the overall project established a monitoring and evaluation indicator system, a comprehensive information platform, software for automatic data cleaning, and standardized health risk assessment techniques. Technical specifications have been issued by the National Health Commission for promoting health risk assessments across China. This paper introduces the project, the research approach, its main research accomplishments, innovations, and public health significance, and describes directions for further research.

BACKGROUND

Air pollution is one of the most important public health problems in China. The Global Burden of Disease Study found that ambient and household air pollution were the fourth and fifth most significant risk factors contributing to the nation's age-standardized disability-adjusted life-years rating (*1*). To reduce the impact of air pollution on health, China enacted laws requiring the establishment and improvement of environment and health monitoring, investigations, and risk assessment systems. Establishing a comprehensive air pollution and health monitoring system and health risk assessment technology involved three major technical problems. First, a population-wide indicator system for monitoring and evaluating the health effects of air pollution that spanned the life cycle and range of severity, from sub-clinical health effects to death, needed to be established. Second, a comprehensive information platform that incorporated multi-source data integration and data quality control was required. Third, a health risk assessment technology needed to be established based on the mechanisms of action of air pollution on health.

After 14 years of hard work, a multi-disciplinary collaborative research program was finished ,which was funded by the National Health Commission (NHC), the Ministry of Science and Technology, and the National Natural Science Foundation of China. Through a series of studies (systematic reviews, molecular mechanisms studies, epidemiological investigations, and health effect monitoring), the three major technical problems were solved, and specifications were formulated. The project identified the major health impacts and potential health risks of urban air pollution and is working to reduce disease burden by integrating health into air pollution prevention and control policies.

OVERALL RESEARCH APPROACH

Figure 1 shows the studies used to establish a monitoring and evaluation indicator system (MEIS), a comprehensive information platform, and health risk assessment technology. First, MEIS indicators (i.e., air pollution, and health influencing factors) were established through systematic literature review, mechanistic studies of respiratory system damage and cardiovascular disease, and analyses of existing air pollution and health monitoring systems.

Second, air quality, meteorological, toxicological, and health data were collected in selected cities with smog. After analyzing the data, evaluating data quality, and defining a data dictionary, an information

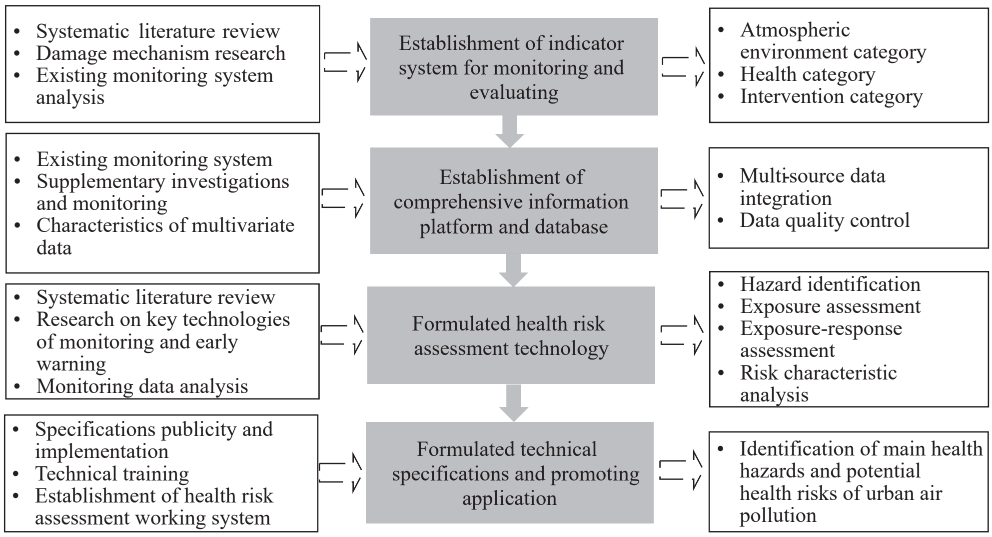

FIGURE 1. Overall research approach of air pollution health impact monitoring and health risk assessment technology and its application.

platform and database for integrated monitoring of air pollution on health was established.

Third, data application rules were clarified by studying relevant technologies, after which accurate exposure assessment models, exposure-response assessment models, public health risk assessment models, and health risk assessment techniques for air pollution were established. Finally, the indicator system, a comprehensive information platform, and health risk assessment technology were promoted to provide technical support for establishing and improving the health risk assessment system and implementing health risk management.

RESEARCH ACCOMPLISHMENTS

Figure 2 shows the research milestones leading to the indicator system, the information platforms and database, and health risk assessment technology.

Indicator System

In accordance with the World Health Organization (WHO) Driving Force-Pressure-State-Exposure-Effect-Action (DPSEEA) framework and the American hazard, exposure, health effects, and intervention (HEHI) framework, air pollution and health indicators were divided into basic, atmospheric environment, health, and intervention categories (*2*). Indicators with clear and probable causal evidence for health effects were stratified into core indicators. Research clarified the health impact of indicators that are closely related to or possibly have causal effects on health.

A guiding principle was that the indicator set should make full use of existing monitoring data in China. Studies were conducted in eight cities to determine the relationship between smog pollutant characteristics and health. Disease and death data were obtained from existing monitoring or registration systems, and data characteristics, quality, accessibility, and availability were evaluated. Ultimately, an atmospheric pollution environmental health indicator system was established based on existing literature, mechanism studies, and data from existing monitoring systems (*2*).

Information Platform and Database

Data from existing monitoring systems and supplementary investigations were used to establish a comprehensive information platform and database in selected cities with smog. Relevant data included air pollutant and fine particulate matter ($PM_{2.5}$) composition, meteorological factors, and multi-sourced data on physiological and functional indicators for entire populations and sub-groups — morbidity and symptoms, hospital outpatient services, emergencies, and hospitalizations, and causes of death. Multivariate analyses were conducted, and a data dictionary was defined. A basic database on health impact of smog was established, and data rules were defined. Data quality was evaluated by assessing repeatability, completeness, validity, and standardization. An object-oriented methodology was used to design the software, and the resulting Comprehensive Information Platform for Health Impact of Smog (HIS platform) was developed in Java with middleware technology and centralized

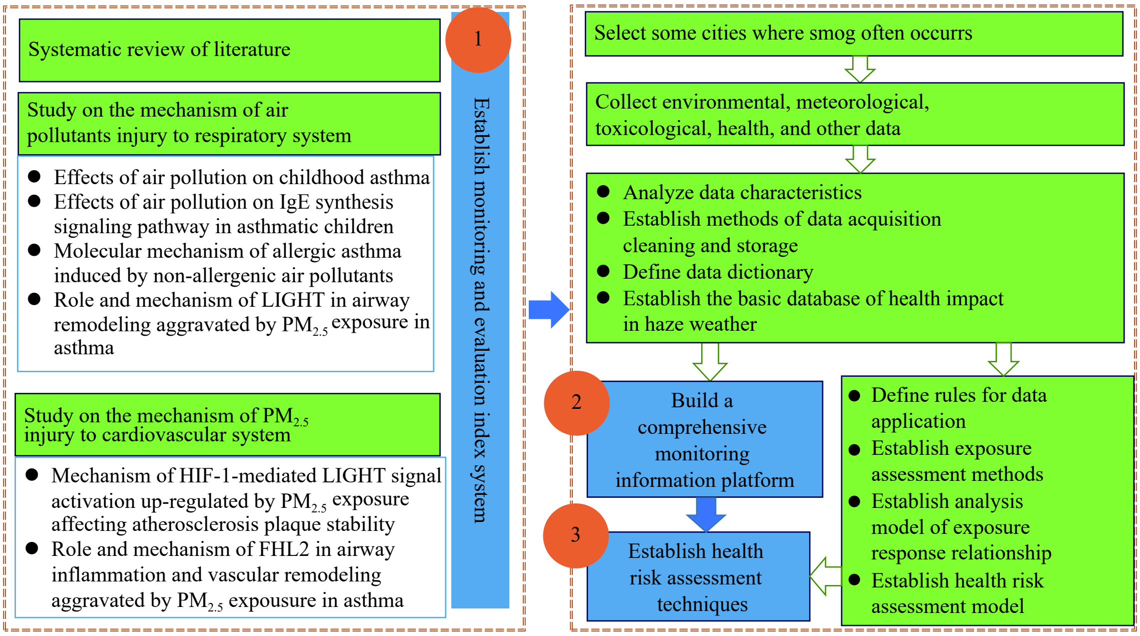

FIGURE 2. Research milestones of air pollution health impact monitoring and health risk assessment technology and its application.

Abbreviation: LIGHT=Tumor necrosis factor ligand superfamily member 14, a tumor necrosis factor (TNF) superfamily ligand; IgE=Immunoglobulin E; HIF-1= hypoxia inducible factor-1; FHL2=four and a half LIM domain protein 2.

data management. This approach allowed for multi-source data collection, data quality assessment, statistical analyses, data management, and visual display of analytic results.

Automated Data Cleaning Tools

Java was used to develop the Toolkit Software for Cleaning Monitoring Data of Air Pollutants and Health (CMDAPH software) in a structured query language database. The resulting software is a secure tool without requiring installation. It is easy to operate, allowing for intuitive data import, automatic auditing, cleaning, export, and visual display. A professional book was published: "*Methods for Data Cleaning and Public Health Impact Evaluation of Air Pollutant.*"

Health Risk Assessment and Technical Specifications

Health hazards were identified through a systematic literature review and the findings of molecular mechanism studies of airway and blood vessel damage due to typical air pollutants. An accurate assessment model of individual exposure to $PM_{2.5}$ was established by integrating air pollution data, building characteristics, permeability coefficients, 24-hour population activity patterns, and concentrations of air pollutants in microenvironments. Exposure-response evaluation models suitable for long-term or short-term exposure were formulated using public health, air pollution, and meteorological data. Based on sensitivity analyses, the influence of other air pollutants, meteorological factors, day of the week, time, and seasonal trends were adjusted to evaluate the relation between smog exposure and outcomes in several pilot cities in China. This model became a key method for population-based and toxicity-based health risk assessments. These technologies were integrated to develop comprehensive, mechanistic health risk assessments. Major project outputs included the publication of the *Methods and Application for Health Risk Assessment of Air Pollution*, and formulation of *Technical Specifications for Health Risk Assessment of Ambient Air Pollution* (HRAAAP specification, WS/T 666–2019).

INNOVATIONS

This project brought about several technical innovations in systems integration. Based on molecular mechanism study results, monitoring data analyses, and DPSEEA and HEHI frameworks, an end-to-end technology system was established. This system, in turn, led to the establishment of a monitoring and evaluation indicator system, a comprehensive information platform with multi-source data integration and data quality control, and comprehensive health risk assessment technology.

The molecular mechanism studies yielded six major findings or outputs. First, non-allergenic air pollutants such as formaldehyde, phthalate, and $PM_{2.5}$, may cause allergies and asthma. Second, two phthalates (i.e., diisononyl phthalate, Di 2-Ethyl Hexyl Phthalate (DEHP)] increase blood pressure by activating angiotensin converting enzyme and inhibiting the nitric oxide (NO) pathway. DEHP with high molecular weight and dibutyl phthalate with low molecular weight had different effects on blood pressure due to their differential effects on the renin-angiotensin-aldosterone system or estrogen levels (*3*–*6*). Third, $PM_{2.5}$ exposure can induce the expression of nitric oxide synthase 2 (NOS2) and production of NO to cause high levels of autophagy. Conversely, blocking the NOS2 signaling pathway can inhibit autophagosome formation and subsequent cell death. NO plays a key role in the lung oxidative stress response earlier than in inflammatory responses (*7*). Fourth, four and a half LIM domain protein 2 (FHL2) and autophagy play an important role in the vascular inflammatory response and vascular remodeling induced by $PM_{2.5}$ exposure (*8*). Fifth and sixth, two markers and primers developed in this project were converted to patents — a marker for the detection of asthma in children (Grant No. ZL 201110060515.7) and a marker and primer for the detection of asthma in children (Grant No. ZL 201310299330.0).

Another innovative development is obtaining software copyrights by the project's HIS platform and CMDAPH software.

The $PM_{2.5}$ individual exposure assessment model became more accurate and comprehensive, as it considered building characteristics, indoor and outdoor $PM_{2.5}$ concentrations, permeability coefficients, 24-hour population activity characteristics, and the concentrations of air pollutants in residential, office, supermarket, outdoor exercise, or transportation settings (*9*–*10*).

Finally, the HRAAAP specification represented the first health risk assessment standard of environmental exposure for China's health industry (*11*).

PUBLIC HEALTH SIGNIFICANCE

The key air pollution health risk assessment technologies established by the project expanded the understanding of health impacts and health risks caused by typical air pollutants and provided technical support for establishing an environmental health risk assessment and risk management system.

Promoting Monitoring and Health Risk Assessment Across the Country

Due to severe smog and concerns about its health impact, NHC launched the national air pollution (smog) health impact monitoring program in 2013. The establishment of a timely indicator system provided a top-level design and monitoring scheme. The HIS platform and CMDAPH software have also been widely used in monitoring projects since 2017, including in applications in all 31 provincial-level administrative divisions (PLADs), 87 monitoring cities, and 167 monitoring sites by 2021.

The HRAAAP specification was promulgated by NHC in 2019 and officially implemented on January 1, 2020. By implementing standardized technical training in the monitoring program, monitoring staff in the 31 PLADs improved their skills in data review, clearing, statistical analysis, and health risk assessment. Air pollution health risk assessment has been widely implemented in monitoring cities. Identification of major health impacts and potential health risks of urban air pollution based on local conditions provides evidence and a scientific basis for the formulation of air pollution prevention and control policies and the development of targeted health protection measures.

Decision-making Basis for National Environmental Health Actions

Promulgation and implementation of the HRAAAP specification enabled the establishment of relevant standards for environmental and health risk assessment and laid a foundation for establishing a risk assessment system. It also supported decision-making related to air pollution health risk management and public health protection in China. Relevant results provided a scientific basis for formulating the Three-year Action Plan for Resolutely Fighting the Battle Against Pollution, Comprehensively Strengthening Environmental and Health Work, and the Healthy China Action (2019–2030): Action to Promote a Healthy Environment.

Enhancing Public Health Protection Awareness

The popular science books *Smog and Health Knowledge Q&A* and *Abnormal Weather and*

Environmental Pollution Events Cognition and Response were published as part of this project. The content was translated into various publicity materials including web pages, posters, and leaflets. Targeted health protection suggestions were promoted through display boards, websites, and news media. In a national survey, 430,000 parents received information about the prevention and control of childhood asthma. These efforts enhance the public's awareness of the health impact of air pollution and protective behaviours that can be adopted, thus playing an important role in reducing the health impact of air pollution.

NEXT RESEARCH DIRECTIONS

The atmosphere has a complex composition, and with the widespread application of new chemicals, people are exposed to an increasing number of novel air pollutants. Many studies have shown that health effects differ by air pollutant composition. It is still not clear how to accurately assess the health impact and health risk of single pollutants in mixed pollutant exposures. With the progress of science and the emergence of new air pollutants, future research should focus on several topics. First, health impact and mechanisms of action of new air pollutants and key components of particulate matter should be investigated to provide more evidence for causal health effects of air pollutants. Second, exposure characteristics and quantitative evaluation methods should be established for new air pollutants and air pollutant mixtures. This will provide accurate exposure data for the assessment of the health impact of pollutants. Third, a quantitative health risk assessment technology needs to be established to improve health protection intervention measures by assessing combined exposures of various air pollutants and the comprehensive influence of geographical, meteorological, population, and economic factors. Finally, the impact of continuous air quality improvement or deterioration on public health requires further investigation to support the establishment of a sustainable development path between economic development and ecological balance.

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[#] Corresponding author: Dongqun Xu, xudq@chinacdc.cn.

[1] China CDC Key Laboratory of Environment and Population Health, National Institute of Environmental Health, Chinese Center for Disease Control and Prevention, Beijing, China; [2] Academy of Military Medical Sciences, Academy of Military Sciences, Beijing, China; [3] Hubei Key Laboratory of Genetic Regulation and Integrative Biology, College of Life Sciences, Central China Normal University, Wuhan City, Hubei Province, China.

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