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Chapter 19

Heavy Metal in Urban Soil: Health Risk Assessment and Management

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Additional information is available at the end of the chapter

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Abstract

With the rapid development of industrialization and urbanization in the developing country, quite a few pollutants produced by anthropological activities enter into urban soil. A large area of urban soil was polluted by different kinds of pollutants. There have been many pollution events like itai-itai disease in the whole world, and many people suffered from urban soil pollution. As the place where people are highly concentrated, urban soil has a great deal with human health. Research has shown that the current soil environmental management and control system may be unable to adapt to changes of the current complex environment. In order to protect urban residents' health, the scientific and reasonable environmental health risk assessment and management system of environmental pollutants in urban soil have strong scientific, realistic, and strategic significances. Soil pollution including its characteristics, resources, and pollutant types were introduced. The definition of urban soil, current situation of urban soil pollutant, and assessment methods of urban soil were also introduced. Also, this chapter introduces main contents of health risk assessment and management on heavy metals in urban soil, and pointed out existing issues and possible research directions in this field, with the aim of offering references.

Keywords: urban soil, soil pollution, heavy metal, health risk assessment, risk management

1. Introduction

World Urbanization Prospects 2014 Revision published by United Nations Population Division showed that from 1950 to 2014, the global urban population increased from 746 million to 3.9 billion, accounting for 54% of the world's total population [1]. Despite the low urbanization rate in Asia, it is still the most populous city in the world due to its large population base,

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accounting for 53% of the total urban population in the world [2]. Urban is the place where human activities are highly concentrated. The population in urban is dense and unevenly distributed, which consumes a large amount of natural resources and produces a large amount of pollutants [3]. When the pollutants exceed the load of the urban environment, the urban environment would be polluted or even destroyed. With rapid urbanization and industrialization in developing country, relatively short-term and intensive human activities will bring a large number of organic pollutants (such as polycyclic aromatic hydrocarbons and phenols) and inorganic pollutants (such as heavy metals, arsenic compounds, and so on) into the urban environment. These pollutants will be accumulated in the urban environment, and may migrate or transform directly through the soil, water, atmosphere, and other environmental multi-media, directly or indirectly causing risk to human health and ecological security in urban [4–6]. Urban soil is an important part of urban ecological environment, and it is closely related to urban water, atmosphere, groundwater, and other environmental factors [7]. Urban soil is located in the central position of urban ecological environment, which is not only the sink of various pollutants, but also the source of various pollutants; so it is often used as an important indicator of comprehensive environmental quality of urban [8, 9]. Heavy metals are a kind of toxic pollutants, which are difficult to degrade in the environment. Heavy metal pollution in urban soils is difficult to control because of its wide sources, many forms, and complex migration [10]. The three wastes, traffic exhaust, sewage irrigation, improper fertilizer, and pesticide application have become the main sources of heavy metals in urban soils [4, 8, 11]. The land use type, the disturbance time, and degree of human activities are the important factors affecting heavy metal pollution in urban soil [8, 12]. In recent years, with the acceleration of urbanization and the occurrence of environmental public hazards related to heavy metal pollution in urban, the research, and practice of the characteristics, mechanism, assessment, and management of heavy metal pollution in urban soil have become major issues that all countries must be faced with. The research results will be of great significance to the sustainable development of urban economy and society, the maintenance of regional environmental equity, and the construction of ecological civilization in urban.

The Chinese National "12th five-year plan" for Environmental Protection and *National Environment and Health Action Plans (2007–2015)* pointed out that "With the rapid development of industrialization and urbanization in China, problems of environmental pollution affecting people's health and safety have become prominent. Protecting environment and ensuring human health have become the most pressing need of the people". Urban residents may directly or indirectly be exposed to heavy metals in urban soil through the ingestion of soil, skin contact, and inhalation, causing short-term harm or long-term risks [13]. By 2050, the global urban population will increase by 2.5 billion, and the proportion of global urban population will reach 66%, nearly 90% of which is concentrated in Asia and Africa. Countries with the largest increase in urban population will be India, China, and Nigeria in the future. From 2014 to 2050, these three countries will increase by 404, 292, and 212 million of the urban population, totally accounting for 37% of the global new urban population. In developing countries such as China, its urbanization rate has reached 53.73% and the total exceeding standard rate of soil was 16.1% [14]. The research on the relationship between heavy metals in urban soil and urban population health is in line with the actual needs of the country and people. According

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to the soil census data of 2005–2013 in China, the spatial distribution of the total noncarcinogenic risk factors of heavy metals (including cadmium, mercury, lead, chromium, arsenic, copper, zinc, and nickel) in three pathways of oral intake, skin contact, and respiratory inhalation was obtained, which can be seen from **Figure 1**. For children, 45% of 29 provinces, autonomous regions and municipalities in the mainland of China have a moderate potential noncarcinogenic risk, which did not exceed the acceptable noncarcinogenic risk limits [15]. Moreover, research and practice have shown that the current soil environmental management and control system based on *Soil Environmental Quality Standard (GB15618-1995)* has been unable to adapt to changes of the current complex environment and requirements of "green" socio-economic development. In 2016, the State Council promulgated *Action Plan for Soil Pollution Prevention and Control*. It indicates that the health risk of urban people exposure to heavy metal pollution in urban soil cannot be ignored.

Therefore, hopes are placed on the health risk assessment and management technology, which has been vigorously promoted and developed by the United States Environmental Protection Agency (USEPA) and the International Program on Chemical Safety (IPCS) in the past 20 years. A mature framework for health risk assessment and management of contaminated sites has been developed both at home and abroad. However, there is a big difference in land area, function, and characteristics between soil in contaminated sites and urban soil;

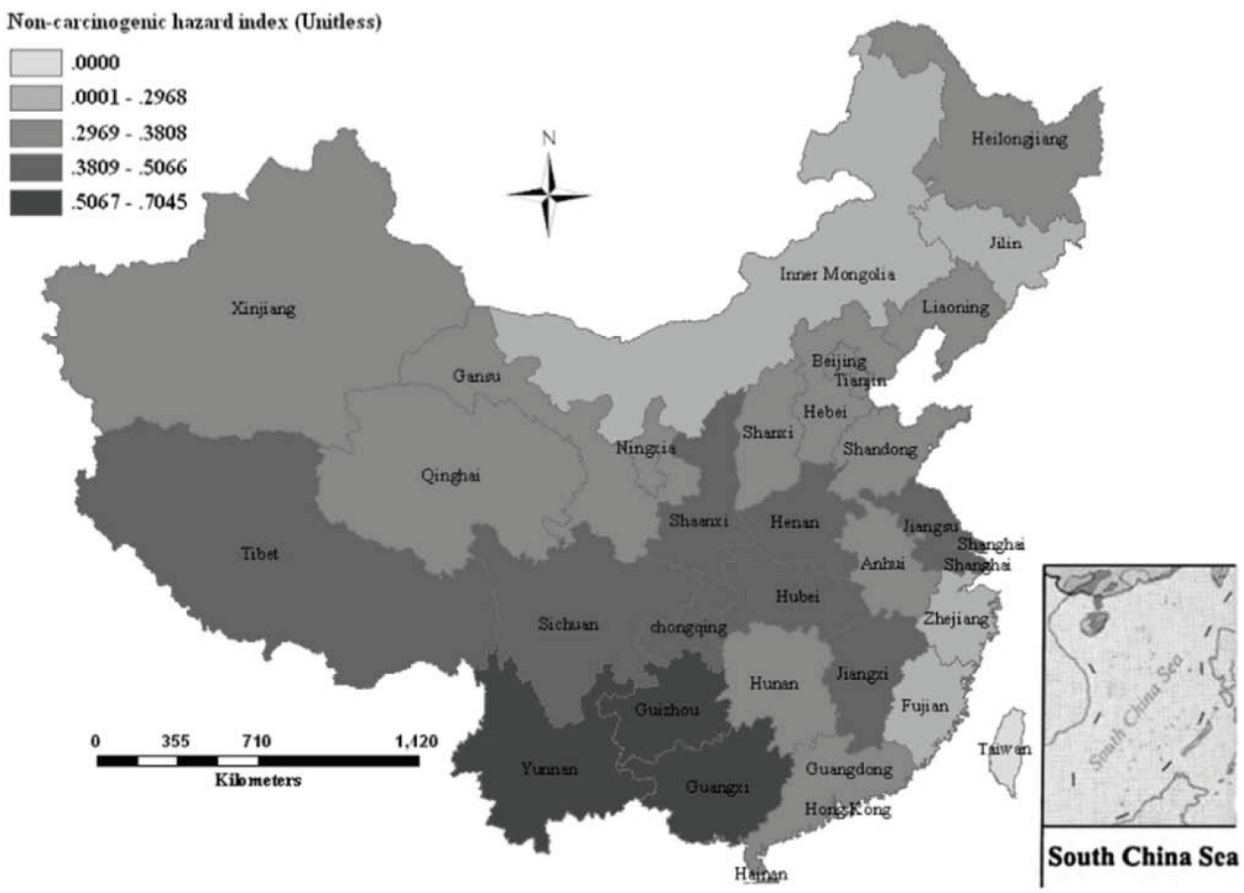

Figure 1. Spatial distribution of total noncarcinogenic risk factors of heavy metals [15].

mechanism of urban soil heavy metal pollution is more complex and involved more factors, so there is still no formation of a scientific and efficient urban soil environmental health risk assessment and management system in China. The World Bank Overview of the Current Situation on Brownfield Remediation and Redevelopment in China points out that at present, China has a large area of Brownfield and a limited amount of restoration funds, and a highly efficient and prioritized Brownfield risk rating system should be established according to the actual situation on Brownfield in China. Considering the latest researches on soil science and the significant differences in land use status, receptor spatial distribution, exposure characteristics, risk assessment and management, and economic input degree between different countries, the key technologies of health risk assessment, risk source analysis and risk quantification management of heavy metal in soil should be further improved, integrated, and developed.

In summary, with the aim of protecting urban residents' health, the scientific and reasonable environmental health risk assessment and management of heavy metal pollution in urban soil have strong scientific, realistic, and strategic significances. It helps to decision-making of regional soil remediation, establishment of regional soil standard value and action value, and establishment and improvement of relevant policies and regulations. Taking scientific health risk assessment and China's national situation as the starting point, how to construct a health risk assessment and management system of environmental pollutants in urban soil with Chinese characteristics and easy to be popularized, has becoming the basic research subject that needs to be explored. The State Council promulgated *Action Plan for Soil Pollution Prevention and Control* in 2016, so the market scale of health risk assessment and remediation of pollutants in urban soil in China will be more than 1000 billion Chinese yuan. It is undoubtedly a huge push to promote the development of related research projects, which obviously makes this study to have strong social and economic prospects.

2. Heavy metal pollution in urban soils

2.1. Introduction of soil pollution

2.1.1. Characteristics of soil pollution

Soil is a historical natural body. It is a loose and heterogeneous aggregate layer with vitality and productivity, which is located on the earth's surface and in the bottom of phreatic area. It is a component of the earth system and a key element of environmental quality control [12]. Soil environment is a complex system, which contains solid phase, liquid phase, and gas phase, and its components change greatly. Moreover, the interaction between the soil environment system and the plant system that grows in soil constitutes the soil-plant ecosystem [12, 16].

However, soil pollution becomes a common thing with the development of industry, and it happens mainly due to human factors. Substances or preparations that are harmful to

human beings and other organisms are applied to the soil intentionally or unintentionally, and the content of the new component will be increased or a component becomes significantly higher than its original content, finally results in the existing or potential deterioration of soil environment.

According to soil science, soil pollution has three types of characteristics [12, 16, 17]:

I. Concealed and latent. Water or air pollution is intuitive. It could be easily found by people when water or air pollution is heavy. On the contrary, soil pollution has characters of concealment and latency. It commonly reflected the growth status of crops including grain, vegetables, fruits, and grass and health status of related human or animals, and there is a gradual cumulative process from happening pollution to causing harm.

II. Irreversible and long-term effects. Once the soil is contaminated, it is difficult to recover. The process of soil pollution by heavy metals is irreversible.

III. Consequences are serious. Once the soil is polluted, biodiversity, biological cycles, and water cycles (including water quality and water cycle processes) are bound to be affected accordingly. Besides, because of the concealment and irreversibility of soil pollution, health of animals and human beings often suffer from soil pollution via food chain.

2.1.2. Sources of soil pollution

Soil pollution sources can be divided into natural sources and anthropogenic sources. Natural sources of soil pollution relate to natural disasters such as volcano eruption that will produce harmful substances. These harmful substances will be discharged into the natural environment and result in soil pollution. Anthropogenic sources refer to the pollution produced by anthropogenic activities such as sewage irrigation, utilization of solid waste, use of pesticides and chemical fertilizers, atmospheric deposition and so on, which are the main objects of scientific research.

I. Sewage irrigation. Domestic sewage and industrial wastewater contain nutrient elements that plants growth needed, such as nitrogen, phosphorus and potassium. Therefore, using sewage probably to irrigate farmland can gradually increase production. However, the sewage also contains heavy metals, phenols, cyanide, and many other toxic and harmful substances. If the sewage is used for agricultural irrigation directly without pretreatment, toxic and harmful substances in the sewage will enter into the farmland and pollute the soil.

II. Utilization of solid waste. Industrial waste and municipal solid waste are solid pollutants in soil. For example, a variety of agricultural plastic film is widely used as in greenhouse and plastic mulching. If the management and recovery are not good, a large number of pieces of plastic film will scatter in the field and cause white pollution. Such solid pollutants are not easily evaporated, volatilized, or decomposed by microorganisms, which will remain in the soil for a long time.

III. Use of pesticides and chemical fertilizers. The application of chemical fertilizer is an important measure to increase agricultural yields, but unreasonable use of chemical fertilizer will result in soil pollution. Long-term use of nitrogen fertilizer will destroy soil structure, result in soil compaction, deteriorate biological properties, and finally affect the yields and quality of crops. Part of the pesticide sprayed on the object absorbed by plants escapes into the atmosphere. About half of pesticide for object spraying are scattered on farmland, and this part of pesticide and pesticide directly applied to the farmland constitute the basic sources of pesticides in soil.

IV. Atmospheric deposition. The harmful gases in the atmosphere are mainly poisonous waste gases discharged from industry. Its pollution surface is big, which will cause serious pollution to the soil. Industrial waste gas pollutions include gas pollution and aerosol pollution. Gas pollution is usually caused by sulfur dioxide, fluoride, ozone, nitrogen oxides, and hydrocarbons. The reason for causing aerosol pollution is that solid particles (such as dust, soot, and smoke) and liquid particles (such as mist) enter into soil via deposition and precipitation.

2.1.3. Types of soil pollution

There is no strict classification of soil pollution. Considering from the material properties, soil pollution can be divided into organic pollution, inorganic pollution, microbial pollution, and radioactive pollution.

I. Organic pollution. Natural organic pollutants and synthetic organic pollutants can cause organic pollution. Synthetic organic pollutants include organic wastes and pesticides. Organic pollutants in soil have adverse effects on the growth of crops and the survival of soil organisms. After people contacted with polluted soil, red rash appears on their hands with the feeling of nausea and dizziness. The application of pesticide in agricultural production has received good results, but its residues have contaminated the soil and corresponding food chain.

II. Inorganic pollution. Some inorganic pollutants come into the soil with the natural processes such as crustal change, volcanic eruption and rock weathering, while some enter into the soil with the human production and consumption activities. Human production activities such as mining, smelting, machinery manufacturing, building, and chemical producing produce a great number of inorganic pollutants including harmful heavy metals and their compounds, acids, alkalis, and salts.

III. Microbial pollution. Soil biological pollution means that one or more harmful microbial populations invade the soil from the outside, and multiply in a sharply speed, destroy the original ecological balance, and cause adverse effects on soil ecosystem and human health. The main sources of soil biological pollution are untreated feces, garbage, municipal sewage, and waste of feed yard and slaughterhouse. Soil organisms may do harm to human health, and some plant pathogens that survive in the soil for a long time will seriously harm plants, and resulting in agricultural yield reduction.

IV. Radioactive pollution. Radioactive pollution refers to that radioactive materials emitted by human activities entering into soil makes the radioactivity of soil become higher than its background level. Radioactive pollutants refer to various radionuclides, radioactivity of which has nothing with their chemical states. Radionuclides can pollute soils in many ways. Radioactive wastewater to the ground, radioactive solid waste buried in the underground, and radioactive emission accident in nuclear power plant will cause serious soil pollution in some areas. Deposition of radioactive substances in the atmosphere, application of phosphate fertilizer containing uranium, radium and other radionuclides, and irrigation of water with radioactive river water will also cause soil radioactive pollution. Although the pollution is generally mild, its scope is relatively large. Polluted by radioactive materials, soil can produce alpha, beta, and gamma rays by radioactive decay. These rays can penetrate human tissues, damage cells, cause external radiation damage, and enter the human body through respiratory system or food chain, causing internal radiation damage.

2.2. Overview of urban soil

2.2.1. Definition of urban soil

Bockheim, the first man used the word of "urban soil", believed that urban soil is a kind of urban or suburban soil with thickness of 50 cm formed by the man-made mixture, landfill, or pollution of land [18]. De Kimpe and Morel [19] generalizes urban soil as the soil in urban and suburban areas that are strongly disturbed by human activity. The mainstream explanation of urban soil according to Chinese scholars is that urban soil developed under long-term disturbance or direct assembly of human activities and under the special environmental background of the urban [20]. Comparing with the natural soil and agricultural soil, urban soil not only inherits some characteristics of natural soil, but also has its unique soil environment and forming process. Urban soil has special physical and chemical properties, nutrient cycling and soil biological characteristics. Urban soil is widely distributed in residential areas, urban rivers, roads, parks, suburban areas, stadiums, landfill sites, abandoned factories, and so on. In view of the fact that heavy metals in urban soil under all land use types are likely to be exposed to nearby receptor populations and cause health risks, urban soil defined in this study include urban soil, forest soil, agricultural soil, and potentially contaminated soil [21].

2.2.2. Current situation of urban soil pollution

The earliest cases of heavy metal pollution in foreign was the copper poisoning caused by drainage from the Ashio Copper Mine in Tochigi prefecture, beginning as early as 1878. It was found that the extremely painful itai-itai disease and Minamata disease were caused by mercury and cadmium pollution. Heavy metal pollution caused by the food chain has begun to be much concerned. In the early 1970s, British have carried out studies on heavy metals in soil and dust in London and other big city. It was found that heavy metal pollution in urban soil is closely related to industrial activities and emission of automobile exhaust, and heavy metals in urban surface soil and road dust can be used as indicators of urban air pollution. In 1990s, urban soil research has gradually become new hot topic in the field of soil research all over the world. Heavy metal pollution in

urban soil in cities such as major cities in British, major cities in America, Naples and Sicily in Italy, Seville in Spain, Munich in Germany, Hanoi in Vietnam, and Bangkok in Thailand have been studied by many a scholar. Pb, Zn, and Hg were the main pollution factors in Sicily City of Italy, and the enrichment coefficient of Pb was 5–10, and Hg was 35. The correlation between soil heavy metal content and soil properties was determined, and the heavy metal pollution's relationships with urban scale, population density, traffic flow, land use types, and history were discussed. Therefore, the International Union of Soil Sciences established the Soils in Urban and Industrial, Traffic and Mining Areas (SUITMA) working group. Up to now, three international academic conferences had been held, of which heavy metal pollution in urban soils was the main topic.

In 2014, the Ministry of Land and Resources and the Ministry of Environmental Protection jointly released the National Soil Survey Report. The results showed that the soil environment in the whole country was not optimistic and the soil pollution was terribly serious in some areas. The soil environment quality of cultivated land was worth serious consideration while the soil environment problems of abandoned mining industry were prominent [14]. Compared with standard values, the total exceeding rate of soil sampling sites in China was 16.1%, and the proportions of slight pollution, mild pollution, moderate pollution, and severe pollution were 11.2, 2.3, 1.5 and 1.1%, respectively. For exceeding sampling sites, the main type of pollution was nonorganic pollution (82.8%), the second was organic pollution, and the least compound pollution. The problem of heavy metal pollution in urban soil in China is outstanding. Liao et al. [22] studied on distribution characteristics and pollution sources of heavy metals in soils of Jiangsu Province. It was found that contents of Cd and Hg in soil in the South of Jiangsu were generally higher while the soil in Northern Jiangsu was rich of As. Pollution degrees of heavy metals in soil in Suzhou and Wuxi were relatively serious, mainly due to the human activities in the process of industrialization and urbanization. Guo et al. [23] studied on the characteristics of heavy metal pollution in soil under different functional zones of Hohhot and it showed that average contents of Cu and Zn were 2.33 times and 1.85 times than their background values, respectively. Soil heavy metal pollution near the business district and urban roads was more serious, which mainly comes from traffic pollution and living waste dumps.

The population in urban is much more intensive, heavy metals in the soil are easily enter into bodies of human beings via various exposure pathways directly or indirectly. Those heavy metals can interact strongly with proteins and enzymes, and then make proteins and enzymes lose activity. Heavy metals can also be accumulated in organs of human body. Once the accumulated content of heavy metals exceed the limit of the human body can be tolerated, the human body will cause great harm or risk, it will lead to acute poisoning, subacute poisoning, chronic poisoning, and so on [24, 25].

2.3. Assessment methods of heavy metal pollution

2.3.1. Geo-accumulation index

To assess the enrichment degree of heavy metals in the soils, the geo-accumulation index (I_{geo}) was used. I_{geo} can be calculated by the following formula [26–29]:

$$I_{geo} = log_2(k\, C_i / B_i) \tag{1}$$

where C_i is the actually measured concentration of the heavy metal in the samples. k is corrected coefficient, which take account of variation of background value caused by anthropogenic influences or litho logic variations in the soil (in general $k = 1.5$). B_i is the reference value of heavy metal concentration in soil. I_{geo} is classified into seven levels and its corresponding contamination degrees of heavy metal are shown in **Table 1**.

2.3.2. Potential ecological index

In order to evaluate the potential ecological risk caused by heavy metals in soil, the potential ecological risk index (PEI) was utilized. The PEI was established by Hanson to assess the characteristics of heavy metal contaminants on the basis of sedimentary theory [30, 31].

$$RI = \sum_{i=1}^{n} E_r^i, E_r^i = T_r^i \cdot C_r^i = C_D^i \cdot C_B^i \tag{2}$$

where RI is the sum of the potential risk of individual heavy metal, E_r^i is the potential risk of individual heavy metal, T_r^i is the toxic-response factor for a given heavy metal, value of T_r^i for Cd, Ni, Zn, Cu, and Cr are 30, 5, 1, 5, and 2, respectively [30, 32, 33]. C_r^i is the contamination factor,C_D^i is the present concentration of heavy metals in soil, and C_B^i is the reference value of heavy metal concentration in soil. Hanson defined five categories of E_r^i, and four categories of RI, as listed in **Table 2**.

Level	Value	Extent of pollution
I	$I_{geo} \leq 0$	Uncontaminated
II	$0 < I_{geo} \leq 1$	Uncontaminated to moderately contaminated
III	$1 < I_{geo} \leq 2$	Moderately contaminated
IV	$2 < I_{geo} \leq 3$	Moderately contaminated to heavily contaminated
V	$3 < I_{geo} \leq 4$	Heavily contaminated
VI	$4 < I_{geo} \leq 5$	Heavily to extremely contaminated
VII	$I_{geo} > 5$	Extremely contaminated

Table 1. Seven levels and its corresponding contamination degrees.

E_r^ivalue	Grades of eco-risk of single metal	RI value	Grades of potential eco-risk of the environmental
$E_r^i < 40$	Low risk	$RI < 150$	Low risk
$40 \leq E_r^i < 80$	Moderate risk	$150 \leq RI < 300$	Moderate risk
$80 \leq E_r^i < 160$	Considerable risk	$300 \leq RI < 600$	Considerable risk
$160 \leq E_r^i < 320$	High risk	$RI \geq 600$	Very high risk
$E_r^i \geq 320$	Very high risk		

Table 2. Indices and corresponding grades of potential eco-risk of heavy metals.

3. Health risk assessment of heavy metals in urban soils

3.1. Health risk assessment

Current soil environmental management system can control soil heavy metal pollution to some degree, but it is obviously the lack of consideration on the relationship between soil heavy metal and urban human health. There is no complete set of related laws and regulations, so its efficiency of quantitative control is low. In the past 20 years, driven by Organization for Economic Co-operation and Development (OECD), World Health Organization (WHO), especially the United States Environmental Protection Agency (USEPA), the International Program on Chemical Safety (IPCS), and European Center for Ecotoxicology and Toxicology of Chemicals (ECETOC), the health risk assessment management has developed rapidly [13]. The European Union, the United States, Canada, and Japan have issued relevant laws and regulations, and health risk assessment has become an important basis and scientific reference at national even international level for dealing with the problem of chemical pollution risk management [34]. It provides important references for the establishment of health risk assessment and management system of urban soil.

Health risk refers to the possibility of human exposure to environmental substances causing injury, disease, or death. In 1983, the United States National Academy of Sciences (NAS) published the "Red Book" named *Risk Assessment in the Federal Government: Managing the Process*, which primarily proposed the definition of health risk assessment. It is defined as a characteristic description of the potential adverse health effects of human exposure to environmental hazards. Health risk assessment includes several elements [13, 35, 36]: an assessment of potential adverse health effects based on epidemiological, clinical, toxicological, and environmental studies, extrapolations from assessment results to predict and estimate types and extent of human health effects under certain exposure conditions, determination of the number and characteristics of human exposed to different intensities and times, and summarization of existence and overall level of public health problems. Therefore, risk assessment has the following four steps: hazard identification, dose-response assessment, Exposure assessment, and risk characterization. Then, subsequent risk management is carried out based on risk assessment results. The basic contents of health risk assessment and management are shown as in **Figure 2**.

3.1.1. Hazard identification

Hazard identification is the first step of a human health risk assessment, which aims to identify the character and intensity of risk sources. The NAS defines it as "*Hazard Identification is the process of determining whether exposure to a stressor can cause an increase in the incidence of specific adverse health effects (e.g., cancer, birth defects).*" The types of hazard can be physical, chemical, or biological, and when human has enough exposure dose, it can cause injury, disease, or death. Scientists assess the effects of harmful substances on human and laboratory animal health, understand the characteristics of the substance, identify its potential health

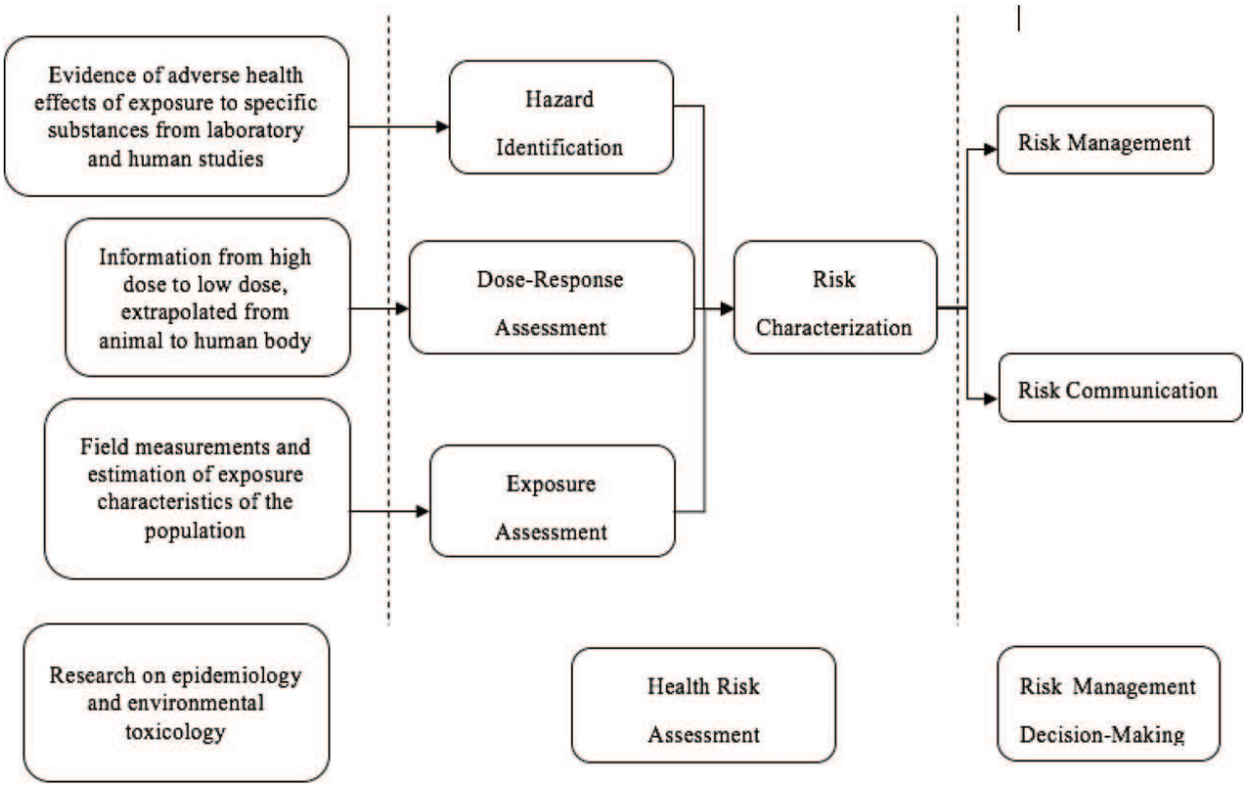

Figure 2. Risk assessment and management of environmental health.

problems, and clearly demonstrate its statistically or biologically significant toxicity [13, 37]. Study on the human directly exposed to hazardous substances can provide the best evidence, but because there are few human clinical trials data, animal experiments, in vitro experiments and activity relationship of chemical structure are often used to estimate the possible health hazards of human exposure to chemicals.

3.1.2. Dose-response assessment

Dose-response assessment is a process of quantitative estimation on the relationship between the exposure level of harmful factors and the incidence of health hazard effect of exposed humans, which is the cornerstone of quantization of health risk assessment [13, 37]. Dose-response assessment belongs to the category of toxicology research, and it has an important creed, that is "Dose makes the poison". For example, the level of clinical dose can determine whether the drug is a therapeutic drug or a potentially lethal drug. Dose-response relationship can be broadly divided into two categories. The first one is the relationship between the dose of exposure to hazardous pollutants and the biological intensity response of individual. The second one is the relationship dose of hazardous pollutants and the proportion of individuals who respond to a particular response in a group like mortality and tumor incidence. Each chemical substance has different dose response relationship according to its toxicity.

3.1.3. Exposure assessment

Exposure assessment refers to quantitative or qualitative methods for estimating or calculating exposure dose, exposure frequency, exposure time, and exposure path [38]. The main exposure pathways include ingestion, derma contact, and inhalation. However, it must be pointed out that no matter how dangerous the pollutant is, "*No exposure, no health risk*" [13]. Exposure assessment often requires exposure factors (including body height, weight, inhalation rate, exposure frequency, and so on) of the local receptor population, and factors related to the transport of pollutants in the environmental media under the local environmental conditions. The United States, Japan, South Korea, and other countries have established a national exposure factors database. Due to China's vast territory, large population and the great differences in life habit, it is necessary to establish our own database of exposure factors gradually. The Ministry of environmental protection published *Exposure Factors Handbook of Chinese Population (adults)* in 2013, which filled the gaps in the national exposure factor manual in China. However, it is clear that the more systematic national exposure factor database is still in the stage of data accumulation, which also brings some uncertainty to the health risk assessment in China [39].

3.1.4. Risk characterization

As the last step of risk assessment, risk characterization based on the data and analysis results of the three steps mentioned above. Finally, the probability of the occurrence of harmful results, the acceptable risk level and the uncertainty of the evaluation results are quantified [13]. Risk characterization is a bridge linking risk assessment and risk management, and risk managers can use risk characterization results to formulate strategies of risk control and pollution remediation. Risk communicators can use risk characterization conclusions to inform the types, sizes, and possibilities of adverse health effects among stakeholders, and disseminate knowledge about risk prevention.

3.1.5. Risk management

Health risk assessment requires collaboration among multiple scientific teams. Similarly, risk management is also a multidisciplinary process. Risk management is a decision-making process base on health risk assessment. It is necessary to balance the political, social, economic and technical information and other related information, to develop, analyze and compare management methods, and ultimately choose appropriate management methods for health risks. That is, to reduce the risk to acceptable levels with acceptable costs [13].

3.2. Researches and issues on health risk assessment and management

3.2.1. Hazard identification

With the development of industrial technology and social economy, the types of materials that people produce and discharge into the environment are increasing rapidly, and the amount of harmful substances that can be analyzed and detected is also increasing. Although

people pay more and more attention to the environmental pollution and its health damage, it is impossible to carry out comprehensive management of the pollutants in the environment because of the limit of manpower, material resources, financial resources, and science and technology. At the same time, researches on chemical toxicology have shown that not all of the pollutants have the same harm to human health. Therefore, targeted research and treatment of pollutants with high health hazard effect have gradually become an effective environmental management strategy. Since the mid-twentieth century, many countries, regions and international organizations have developed their own screening methods for pollutants, and compiled their own list of environmental priority pollutants, and applied them to the management of environmental pollutants in practice [13, 40]. The European community, the United States, Japan, Germany, Holland, and other countries have published list of environmental hazardous substances one after another, which plays an important role in promoting environmental protection and governance.

With a short period of about 30 years, China has achieved development, which can catch up with the development of developed countries for 100 years, and achieved brilliant economic achievements. However, due to the extensive development mode and many other reasons, the ecological environment of our country has suffered serious damage, which leads to the environmental problems that should occur at different stages are reflected and erupted in a short time. In view of this, the State Environmental Protection Administration of China presided over research and proposed "Black list of pollution substance for preferential control in water" in the period of seventh five-year. However, over time, the characteristics of China's environmental problems have undergone profound changes, the existing list obviously not able to fully reflect the current situation of environmental risk and research level, and failed to cover the comprehensive environment system of water, soil, and atmosphere [40, 41]. In view of the new changes in the national and world environmental issues, with the reference of the developed countries' catalog making methods, the State Environmental Protection Administration (SEPA) published the *National catalog of Pollutants' Environmental Health Risk* in 2007. It represents the significant progress in the field of hazard identification in China, and provides the basis and method for the decision-making of government, monitoring of environment, formulation of environmental emergency plans, and emergency treatment of environmental pollution accidents.

However, after more than half a century of development, directory management has gradually exposed its limitations. Most of the early catalogs are static, which are balancing results of environmental pollution status, understanding level and management objectives at the beginning of the catalog editing. It cannot reflect the long-term dynamic changes of various factors, making many catalogs cannot effectively support the current environmental management work. Besides, the early catalogs commonly compiled by a single country or region. With the deepening understanding of transboundary migration of pollutants, people have realized that it is necessary to take the joint action of river basin and region to effectively cope with the common environmental problems. Therefore, the hot research spots in the field of hazard identification are mainly [13, 40, 42]: (a) new screening methods of priority pollutants considering pollutants migration and transformation characteristics, (b) construction of dynamic risk list updating mechanism in regional environment, (c) and risk identification of non-occupational long-term exposure with low dose.

3.2.2. Dose-response assessment

I. No threshold effect (carcinogenic effect) [13]. In view of humanitarian considerations, most carcinogenic chemicals are based on low dose extrapolation models to assess the risk probability of human exposure. Varieties of evidences have been applied to dose-response assessment of carcinogens, including human epidemiological data, which should be regarded as primary basis. In the absence of appropriate human clinical studies, data on animal species that close to humans should be used, and in the long-term animal studies, the most sensitive and biologically acceptable data should be given to the greatest extent of attention.

II. Threshold effect (noncarcinogenic effects) [13]. The reference dose (RfD) is an important basic factor, which means that when the dose is below this level, the risk of harmful effects will not be expected. At present, the following methods are used to evaluate the dose-response effect of threshold dose: firstly, determine the key toxic effects (the initial deleterious effects at this dose) and the highest dose that does not occur harmful effects (no observed adverse effect level, NOAEL) through reading literatures. Then, the NOAEL is divided by the uncertainty factor to obtain the safety limit value, and the uncertainty factor range from 10 to 1000. The uncertainty factor expresses a variety of internal uncertainties related to the existing data.

The focus of toxicity testing of environmental chemicals is to determine the safety level of human exposure to toxic chemicals. At present, the test has been extended from simple acute and subacute tests to full consideration of various toxicity data, including acute, subacute and chronic toxicity, and some specific toxicities, such as carcinogenicity, mutagenicity, reproductive toxicity, immune toxicity, neurotoxicity, skin toxicity, and other organ tests. In addition to these studies, the toxic dynamics of chemicals and their related mechanisms in the tissues, cells, subcellular, and receptor levels are also expected to further elucidate the toxic mechanisms of environmental chemicals and provide scientific references for potential hazard assessment of human bodies. In recent years, the main research focuses of dose-response assessment are [42, 43]: (a) dose-response relationship of chemical mixture interaction, (b) study on biological dynamics characteristics and establishment of bio dynamic model, (c) study on toxicity mechanism and toxicity kinetics, (d) and study on toxicity mechanism of cellular and subcellular.

3.2.3. Exposure assessment

Humans may expose to a variety of pollutants through different kinds of exposure pathways, which can be broadly divided into external exposure and internal exposure [39]. External exposure refers to the concentration of a substance in contact with the receptor, which can be understood as the gastrointestinal epithelium, the lung epithelium during respiration, and the epidermis in contact with the skin [37]. Internal exposure refers to the amount that a substance has been absorbed, that is, the amount that has entered the systemic circulation of the receptor. Bioavailability is defined as the proportion of absorbed in external dose.

Exposure assessment research mainly includes the following aspects [39, 44–47]: (a) analysis and characterization of exposure environment. That is, to describe characteristics of common environmental physics and population. The climate, vegetation, groundwater literature, and surface water in regional need to be determined, and the target receptor population also should be determined, and characteristics of exposure population like the location of the source of pollution and the activity characteristics of the population should be described. Moreover, it is necessary to take into account characteristics of both the current exposure population and future exposure population. (b) Analysis of exposure pathways. According to the location and release of pollution sources, the migration and transformation process of possible chemical substances in multi-media environment and the potential exposure position and activities of people, to analyze and determine exposure points and approaches via each exposure pathway (such as direct skin absorption, ingestion, and so on). (c) Quantification of exposure. To quantify the exposure size, exposure frequency, and exposure duration of each pathway, step of exposure quantification including estimating exposure concentration and calculating intake. (d) Estimation of exposure concentration. To determine concentrations of chemical pollutants in the exposure period, and the exposure concentration is generally estimated by monitoring data or chemical environmental fate model. (e) Calculation of intake. To determine specific chemical exposure dose via each exposure route, and exposure dose is expressed in terms of unit weight per unit time, and the mass of body exposure to chemicals. In recent years, hot research spots in field of exposure assessment mainly include: (a) investigation on regional epidemiology or occupational exposure factors, (b) study on the mechanism and mass model of chemical migration in atmosphere, (c) study on migration mechanism and model of chemicals in water and sediment, (d) study on migration mechanism and model of chemicals in soil, (e) and study on chemo taxis mechanism and corresponding integrated exposure model of chemicals in multi-media environment.

3.2.4. Risk characterization

Risk characterization includes qualitative risk characterization and quantitative risk characterization [13]. The qualitative risk characterization use semi quantitative words such as "negligible", "slight", "medium", or "serious" to describe the degree of risk. Quantitative risk characterization can quantify the degree of risk by digital expression, which can more intuitively and effectively describe the degree of risk, and facilitate the screening and ranking of the risk of pollution factors, providing scientific reference for decision makers. The risk characterization methods both at home and abroad are established based on the framework of risk assessment system of USEPA. The quantitative risk characterization can be divided into the carcinogenic risk characterization and noncarcinogenic risk characterization. The conclusion of environmental risk characterization will provide a scientific basis for the formulation of environmental standards or environmental management strategies at the national, local, and organizational levels. And the formulation and implementation of environmental standards is the starting point of environmental administration and an important basis for environmental management.

3.2.5. Risk management

The risk management process is triggered by the concerns of risk of specific uses or special scenarios of chemicals. Environmental risk assessment and risk management are closely related, but their process is different. The characteristics of the risk management decision affect the breadth and depth of risk assessment, while risk assessment provides a scientific basis for risk management. The last game between risk assessment and legal, political, social, and economic and technology based on the present situation and put forward reasonable control measures. Risk management is based on the relationship of risk assessment with law, politics, society, economy, and technology, and puts forward reasonable control measures. Risk management includes the following tasks: classification of risks, determination of risk reduction measures and benefit analysis of risk management, risk reduction, and monitoring and review. In recent years, the new development of risk management research mainly includes [13, 48, 49]: (a) focus on risk reduction and responsibility concerns, that is, the establishment of appropriate laws and regulations, and the responsibility of the original competent authorities transferred to the manufacturing risk industry (manufacturers and importers and its users), (b) risk communication and stakeholder participation. Risk communication is the link between environmental risk assessment and risk management, and the active participation of stakeholders will help to ensure that the assessment results and management practices are better understood and implemented, (c) the integrated framework of information platform for environmental risk assessment and management system. To analyze human health comprehensively, environment, ecological security and socio-economic factors has been one of the main trends in this field, (d) risk cognition. Because the risk (or interest) cognitions of individuals, public, enterprises or employees are different, which will change with time as well, it is of great significance to explore different groups for their own risk assessment or cognitive inertia.

3.2.6. Uncertainty analysis of system

The controversies about risk assessment often revolve around some differences, which aim at the assessment of incomplete and uncertain data and the nature, explanation and demonstration of the methods and assessment models. When science is used for management purposes, decision makers need to know not only the existing scientific knowledge, but also to understand the uncertainty part and blank part of these knowledge, and to distinguish between uncertainty and variability. In view of risk assessment, inaccurate and incorrect parameters, parameter variability, imperfect or unreasonable simplified model theory, and unreasonable establishment of receptor exposure scenarios may lead to uncertainty [13, 34]. In 1999, Cullen and Frey divided the uncertainty in risk assessment into parameter uncertainty, model uncertainty and variability. Because parameter uncertainty is easier to quantify, most of the uncertainty research focus on parameter uncertainty. Zhang Yinghua, Liang Jie, and Babendreier, respectively applied Monte-Carlo algorithm, Bayesian Monte-Carlo neural network method, Monte-Carlo method, and fuzzy mathematics method to effectively control and quantify the parameter uncertainty in assessment to a certain extent, ignoring uncertainty and variability of the model in the evaluation process. Wang Yongjie, Moschander,s and Karuchit found that the influence of model uncertainty and variability on the credibility of assessment results is

much higher than that of parameter uncertainty, and made a qualitative/semi-quantitative analysis. Nevertheless, because model uncertainty and variability are not so easy to quantify, related researches tend to move along at a slow.

To sum up, on the basis of risk assessment system in the United States, the European Union, Australia, Canada, Japan and other countries, referring to a large number of literature, the deficiency and difficulty of in the field of soil environmental pollutants health risk research are mainly concentrated in the following aspects:

I. The urban is the center of the crowd gathering, which is easy to occur environmental public hazards. Present researches on the urban soil environment and population health is not deep enough at home and abroad.

II. In the practice of risk assessment and management, how to obtain the regional characteristics of risk assessment and management more efficiently under limited economic budget still needs further exploration.

III. In the field sampling analysis of health risk assessment, it is often used to monitor the distribution of sites, which requires a large amount of human and material input. In view of the significant temporal and spatial variability of soil environment, it is necessary to find out more efficient sampling methods.

IV. A large number of studies show that the chemical fractions of heavy metals in soil can more accurately characterize soil metal bioavailability and mobility, so how to embed heavy metal fraction parameters into the classical model of heavy metal content evaluation needs further study and verification in practice.

V. For health risk assessment, the scientific identification of exposure pathways of different receptor populations is the key to determine the credibility of risk assessment. Most of the existing studies base on questionnaire surveys or theoretical analysis hypotheses. However, these two methods have high cost and high uncertainty, so it is a new research direction to find a low cost and high credibility exposure path analysis and determination method.

VI. In the risk assessment systems implemented in China and abroad, most of them only make the relevant regulations on the uncertainty control of the parameters in the assessment process ignoring model uncertainty and variability. Researches show that influences of model uncertainty and variability on the credibility of assessment results is much higher than that of parameter uncertainty. Because model uncertainty and variability are not so easy to quantify, related researches tend to move along at a slow.

VII. In most of the current studies, the pollutant source analysis is only multivariate statistical analysis of regional pollutant content data. But considering the complexity of urban pollution, single pollution data statistical analysis is limited by the amount and quality of pollution data, which cannot fully reflect the problem obviously. Therefore, it is necessary to take into account ecological environment, human health and social economy and further study the correlation of risk sources, so as to help decision makers make more reasonable and accurate risk management decisions.

VIII. In the process of current health risk assessment, the participation rights and discourse rights of stakeholders are obviously unequal. How to embed the concept of environmental equity into environmental risk assessment system and further develop feasible technical methods has become a new direction of research.

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