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Research Progress on Parameter of Health Risk Assessment in Soil

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Abstract: *With the development of human society, the problem of environmental pollution caused by human factors is becoming more and more serious, and the resulting human health risks are becoming increasingly prominent. Based on the English literature on health risk assessment published in recent years, this paper summarizes the value of health risk assessment parameters for heavy metal pollutants, organic pollutants, and other indicators in soil. On this basis, the shortcomings of current health risk assessment and possible future research directions are discussed.*

Keywords*: Environmental Pollution; Health Risk Assessment; Research Progress*

1. Introduction

Human health has always been closely related to the environment, but with the rapid development of society, human development, and utilization of the environment gradually increased, resulting in a large number of various pollutants entering the environment for human survival. These pollutants pose a great risk to human health. Heavy metals (such as cadmium, copper, chromium, etc.) can cause various diseases such as cancer, hypertension, and renal insufficiency; chemical pollutants (such as polycyclic aromatic hydrocarbons) are carcinogenic and mutagenic. Therefore, for the sake of human health, many experts at home and abroad have conducted relevant research on the health risk assessment of pollutants. However, most of the papers have only conducted in-depth research on a certain environment or a certain type of pollutant and provide a less comprehensive summary. Based on the literature research on health risk assessment at home and abroad, this paper systematically summarizes the research progress of soil environmental health risk assessment and lays a foundation for the comprehensive study of soil environmental health risk assessment.

2. Method of Health Risk Assessment

2.1 Concepts related to health risk assessment

Health Risk Assessment (HRA) was proposed by the National Research Council of the National Academy of Sciences (NAS) in 1983. It uses risk as an evaluation index, links environmental pollution with human health, and quantitatively describes the risk of adverse health effects after human exposure to environmental hazards.

The health risk assessment of environmental pollutants is divided into four steps: hazard identification, dose-response relationship assessment, exposure assessment, and risk characteristics analysis.

Hazard identification is the first step of health risk assessment, which is a qualitative evaluation stage. The purpose is to determine whether the chemical has a harmful effect on the health of the body

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and whether this effect is due to the inherent toxicity characteristics and types of the substance. Hazard identification mainly comes from toxicology and epidemiological data collection.

Dose-response assessment is defined as 'describing the possibility and severity of adverse health effects under a certain exposure dose and exposure conditions of a chemical substance'. Dose-response assessment provides a mathematical basis for converting exposure information to assess health risks.

Exposure assessment is a process of measuring, estimating, or predicting the intensity, frequency, time, and ways of exposure to harmful factors in environmental media. It is a quantitative basis for risk assessment. The identification of the characteristics of the exposed population and the determination of the concentration and distribution of the evaluated substances in the environmental media are two related and inseparable components of the exposure assessment.

The analysis of risk characteristics is the last step in health risk assessment. The nature and size of human risk were estimated by combining the analysis and conclusions of hazard identification, dose-response relationship assessment, and exposure assessment. The uncertain factors in each stage of evaluation and the advantages and disadvantages of various evidences were explained and discussed, which provided the basis for the management department to carry out the risk management of exogenous chemicals.

2.2 Formulas used for health risk assessment

For heavy metals in soil, the average daily doses of potentially toxic metals by ingestion (ADD_{ing}), dermal contact (ADD_{derm}), and inhalation (ADD_{inh}) were calculated using equations (1)–(3).

$$ADD_{\mathrm{ing}} = \frac{C_{soil}\times \mathrm{IngR}\times \mathrm{ED}\times EF}{BW\times AT}\times 10^{-6} \tag{1}$$

$$ADD_{inh} = \frac{C_{soil}\times \mathrm{InhR}\times \mathrm{ED}\times EF}{PEF\times BW\times AT} \tag{2}$$

$$ADD_{\mathrm{dermal}} = \frac{C_{soil}\times SA\times AF\times ABS\times \mathrm{ED}\times EF}{BW\times AT}\times 10^{-6} \tag{3}$$

Among them, ADD represents the average daily dose (mg/kg), C_{soil} is the metal concentration in the soil (mg/L), IngR and InhR are the intake and inhalation rate of heavy metals (mg/day), EF and ED are exposure frequency (days/year) and duration (years), BW is body weight (kg), AT is the average time (days), SA is the exposed skin surface area (m2), ABS is the gastrointestinal absorption coefficient, and AF is the skin adhesion factor.

For polycyclic aromatic hydrocarbons in the soil environment, the ILCR formulas for direct ingestion, dermal contact, and inhalation in the soil are (4)–(6).

$$ILCR_{\mathrm{Dermal}} = \frac{CS\times\left(CFS_{Dermal}\times\sqrt[3]{BW/70}\right)\times SA\times AF\times ABS\times EF\times ED}{BW\times AT\times 10^{6}} \tag{4}$$

$$ILCR_{\mathrm{Ingestion}} = \frac{CS\times\left(CFS_{\mathrm{Ingestion}}\times\sqrt[3]{BW/70}\right)\times IR_{soil}\times EF\times ED}{BW\times AT\times 10^{6}} \tag{5}$$

$$ILCR_{\mathrm{Inhalation}} = \frac{CS\times\left(CFS_{\mathrm{Inhalation}}\times\sqrt[3]{BW/70}\right)\times IR_{air}\times EF\times ED}{BW\times AT\times PEF} \tag{6}$$

CS is the concentration of PAH in soil (mg/kg), CSF is the carcinogenic slope factor, BW is the body weight (kg), SA is the skin surface exposure (cm^2), AF is the skin adhesion factor (mg/cm^2), PEF is the soil particulate matter emission factor (m^3/kg), and 10^6 is the conversion coefficient of PAH concentration.

The total hazard index (THI) was calculated as (7) (8).

$$HI = \sum HQ = \sum \frac{ADD}{RfD} \tag{7}$$

$$THI = \sum HI \tag{8}$$

The total carcinogenic risk index (TCRI) was described in Equations (9) and (10).

$$CR = \sum ADD \times SF \tag{9}$$

$$TCRI = \sum CR \tag{10}$$

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SF is the cancer slope factor, RfD is the reference dose, and ADD refers to the average daily dose of different pollutants calculated in the above formula.

3. Health risk assessment parameters of soil environment

3.1 Parameter of heavy metals

Heavy metals in soil not only reduce the quality of soil and food crops but also pose considerable risks to human health. On the one hand, the accumulation of heavy metals in soil will lead to the loss of soil nutrients and the destruction of soil structure and function, thus affecting the quality and yield of crops; on the other hand, heavy metals in soil mainly enter the human body through three exposure pathways: ingestion, inhalation, and skin contact, thus posing a threat to human health.

Table 1: Health risk assessment parameter table of heavy metals in soil

Factor	Value		Unit	Reference
	Teens	Adults		
$IR_{vegetable}$		372	g/day	Zhuang et al,2009a,2009
		345		
IR_{rice}		274		
BW		65	kg	
		70		USEPA,1991
		55.9		National Bureau of Statistics, 2009
	15	55.9		Environmental site assessment guideline,2009
EF		365	days/year	Zhuang et al,2009a,2009b
		365		USEPA, 2011
		365		National Bureau of Statistics, 2009
	350	350		Environmental site assessment guideline,2009
ED		70	years	National Bureau of Statistics, 2009
	6	24		USEPA,2001
ET		4	h/day	UDOE,2011
AT		25550	days	National Bureau of Statistics of China, 1994-2012;Plant Management Division in Ministry of Agriculture,2009
	2190	8760		USEPA,2001
IngR		100	mg/day	Zhuang et al,2009a,2009b
	200	100		USEPA,2001
InhR	7.63	12.8	m^3/kg	LI et al,2010
SA		5700	cm^2	USEPA,2011
		3300		National Bureau of Statistics of China, 1994-2012;Plant Management Division in Ministry of Agriculture,2009
	1600	4350		Environmental site assessment guideline,2009
AF		0.07	$mg\cdot cm^{-2}$	USEPA,2011
		0.2		National Bureau of Statistics of China, 1994-2012;Plant Management Division in Ministry of Agriculture,2009
	0.2	0.7		USEPA,1993
ABS		0.001		USEPA,2011
		0.001		National Bureau of Statistics of China, 1994-2012;Plant Management Division in Ministry of Agriculture,2009
	0.001	0.001		Chabukdhara and Nema,2013
PEF		1.36×10^9	m^3/kg	USEPA,2002
		1.36×10^9		National Bureau of Statistics of China, 1994-2012;Plant Management Division in Ministry of Agriculture,2009
	1.36×10^9	1.36×10^9		USEPA,2001
CF		10^{-6}	kg/mg	USEPA,2002
RfD_{ingest}		1	μg/day	USEPA,1985;WHO,1972
RfD_{dermal}		0.025		

Note: (1) For the population, the parameter blank indicates that the literature has not been studied or given specific parameter values. (2) The data sources in the table are the ones mentioned in the cited data in the literature cited in the article and other documents not directly cited in the article. (3) The main way for the human body to ingest heavy metals in soil is through the intake of food containing heavy metals, so the intake of food is used to replace the intake of heavy metals.

In 2012, Huarong Zhao used the sequential index simulation method to delineate the spatial pattern of soil data. The multiple linear regression model of heavy metal absorption by crops was fitted to predict the concentration of heavy metals in crops from the pH value and soil heavy metal concentration. The land use is explained according to the remote sensing image, and the spatial pattern, absorption model, and land use are included in the dose-response model of heavy metals to human health risk, and the health risk assessment is carried out on the basis of considering the land use in the Dabaoshan mining area [1]. In 2015, Xiao Qing et al. divided heavy metals into two categories: industrial sources and natural sources, through principal component analysis (PCA) and matrix cluster analysis (matrix cluster analysis), and evaluated the health risk of heavy metal pollution in Liaoning Iron and Steel Industrial City [2]. In 2019, Hui-Hao Jiang et al. used geostatistics and positive matrix factorization (PMF) methods to identify and quantify the sources of heavy metals in soil. The potential ecological risk index (RI), human health risk assessment model, and PMF model were combined to study the ecological and human health risks of different soil heavy metal sources [3]. In 2020, Hasan Baltas et al. used heavy metal pollution parameters such as heavy metal enrichment factor (EF), soil accumulation index (Igeo), pollution factor (CF), pollution load index (PLI), and soil spatial distribution pattern to explain and evaluate the pollution status and distribution of heavy metals in the soil around Sinop, Turkey, and used the health risk assessment model of the US Environmental Protection Agency for health risk assessment [4]. In 2021, Yuqi Zhang et al. used the absolute principal component score multiple linear regression model (APCS-MLR) to identify and quantify the sources of heavy metals in the soil of the Shihe River Basin and adopted a variety of heavy metal evaluation methods, such as the fuzzy comprehensive evaluation method, index method, and health risk assessment method [5]. The health risk assessment parameters of heavy metals in soil are shown in Table 1 [6–20].

3.2 Parameter of organic pollutants

Polycyclic aromatic hydrocarbons are not easy to dissolve, easy to adsorb on soil particles, and difficult to degrade. Therefore, they tend to accumulate in the soil, which is the most important sink for these pollutants. In recent years, the problem of PAH soil pollution has attracted people's attention, especially in China. The rapid development in the past few decades has led to large-scale industrialization and urbanization, and PAHs are mainly derived from anthropogenic sources related to urban development, such as vehicle emissions, fossil fuel combustion, chemical manufacturing, and oil spills.

Table 2: Health risk assessment parameter table of organic polycyclic aromatic hydrocarbons in soil

Factor	Value		Unit	Reference
	Teens	Adults		
IR_{air}	5.65	13.04	m^3/day	Z.S. Wang et al.,2009
IR_{soil}	200	100		Duan et al.,2011
BW	6.94	58.55	kg	Z.S. Wang et al.,2009
EF		350	days/year	Ying Zhu et al,2019
	350	350		Duan et al.,2011
ED	6	24	years	Chun hui Wang et al.,2015
AT		25550	days	Ying Zhu et al,2019
	29200	29200		NSB,2014
IngR	400	100	mg/day	Williams et al,2013
SA	2800	5700	cm^2	Duan et al.,2011
AF	0.2	0.07	$mg\cdot cm^{-2}$	
ABS	0.13	0.13		USEPA,2011
PEF	1.36×10^9	1.36×10^9	m^3/kg	
SF_{oral}		2.9	kg·day/mg	OEHHA,2010
$SF_{inhalation}$		3.9		
CSF_{dermal}	25	25		Peng et al.,2011
$CSF_{Ingestion}$	7.3	7.3		
$CSF_{Inhalation}$	3.85	3.85		

In 2013, Diego Badern et al. evaluated the toxicity of soil organic extracts in a semi-rural area in northern Italy, focusing on polycyclic aromatic hydrocarbons, which have potential toxicity and carcinogenic effects. According to the guidelines provided by Health Canada (2004), the health risks of human receptors were assessed, and accidental soil intake was selected as the route of exposure to soil contaminants, with young children (6 months to 4 years old), adolescents (12–19 years old), and adults as health risk assessment receptors [21]. In 2018, Chunhui Wang et al. used the positive matrix factorization (PMF) method to determine the possible sources of polycyclic aromatic hydrocarbons and the Kriging interpolation method to analyze the spatial distribution of PAHs and evaluate the risk of PAHs in Nanjing soil to human health [22]. The health risk assessment parameters of organic polycyclic aromatic hydrocarbons in soil are shown in Table 2 [22–31].

4. Conclusion and discussion

The health risk assessment of heavy metals mainly focuses on heavy metals in soil and groundwater. At present, the conventional practice in the health risk assessment of heavy metals in soil is to evaluate the level of soil pollution by calculating the soil geological accumulation index (Igeo), pollution index (PI) and potential ecological risk index (PER). Hazard index (HI) and carcinogenic risk (RI) were used to evaluate the risk of heavy metals to human health. For the health risk assessment of heavy metals, the method proposed by American scientists and the model published by the United States Environmental Protection Agency are still used to calculate the health risk, and the population is divided into children and adults.

The research on the health risk assessment of organic pollutants is mainly focused on the study of polycyclic aromatic hydrocarbons and polybrominated diphenyl ethers. In the process of calculating the health risk of each age group, there are a variety of age division methods: children and adults; children (6 months to 4 years old); adolescents (12–19 years old); and adults; infants (< 1 year); young children (1-2 years); children (3–11 years); adolescents (12–17 years); and adults (18–75 years).

Although there are many health risk assessments for various pollutants, there are still some directions for follow-up research.

(1) At present, the health risk assessment of pollutants is still calculated using the method proposed by American scientists and the model issued by the United States Environmental Protection Agency. However, due to the differences in geography, ethnicity, and environment, whether the parameters of the corresponding model are consistent with the characteristics of the study area needs further verification. Therefore, each country and region should make appropriate changes to the parameters of the model according to the local climate characteristics and customs, so as to make the health risk more accurate in the evaluation results.

(2) In the health risk assessment of the population, there is ambiguity in the classification according to age. For example, there are at least three classification schemes in the health assessment of polycyclic aromatic hydrocarbons, and different schemes will inevitably lead to different results, which will make the evaluation unable to be unified. Therefore, if an accurate but not cumbersome classification method can be confirmed, it is beneficial to the development of health risk assessment.

(3) Due to the different uses of land, the content of various pollutants in the soil has a certain impact. Studying the health risks of different land uses is beneficial to the development of health risk assessment and may become a good research direction.

(4) Before the health risk assessment of pollutants in soil, it is very important to determine the source and status of pollutants. Most scholars have used multiple linear regression models, principal component analysis, and positive matrix factorization to analyze the sources and status of pollutants. Therefore, in order to better carry out health risk assessment, the analysis method of the source and status of pollutants in soil is also important research.

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References

[1] Zhao Huarong, Xia Beicheng, Fan Chen, et al. Human health risk from soil heavy metal contamination under different land uses near Dabaoshan Mine, Southern China. Science of the Total Environment, 2012, 16(1): 45–54.
[2] Xiao Qing, Zong Yutong, Lu Shenggao. Assessment of heavy metal pollution and human health risk in urban soils of steel Industrial city (Anshan), Liaoning, Northeast China. Ecotoxicology and Environmental Safety, 2015, 6(10): 377–385.
[3] Jiang Huihao, Cai Limei, Wen Hanhui, et al. An integrated approach to quantifying ecological and human health risks from different sources of soil heavy metals. Science of the Total Environment, 2019, 20(1): 134466.
[4] Hasan Baltas, Murat Sirin, Emre Gökbayrak, et al. A case study on pollution and a human health risk assessment of heavy metals in agricultural soils around Sinop province, Turkey. Chemosphere, 2020, 02: 125015.
[5] Zhang Yuqi, Wang Songtao, Gao Zongjun, et al. Contamination characteristics, source analysis and health risk assessment of heavy metals in the soil in Shi River Basin in China based on high density sampling. Ecotoxicology and Environmental Safety, 2021, 21(10): 112926.
[6] Zhuang Ping, Murray B. McBride, Xia Hanping, et al. Health risk from heavy metals via consumption of food crops in the vicinity of Dabaoshan mine, South China. Science of the Total Environment, 2009a, 15(2): 1551-1561.
[7] Zhuang Ping, et al. Heavy metal contamination in soils and food crops around Dabaoshan mine in Guangdong, China: implication for human health. Environmental Geochem Health, 2009b, 13(2) 707-715.
[8] UDOE. Best practices laboratories for the 21st century: modeling exhaust dispersion for specifying. Acceptable Exhaust/ Intake Designs; 2011.
[9] USEPA. Risk Assessment Guidance for Superfund (RAGS), volume I: Human Health Evaluation Manual (HHEM) supplemental guidance. Washington DC: Office of emergency and remedial response; 1991 [EPA/540/R-92/003].
[10] USEPA. Supplemental guidance for developing soil screening levels for superfund sites. Washington, DC: Office of soild waste and emergency response; 2002 [OSWER9355.4-24].
[11] USEPA. Exposure Factors Handbook 2011 Edition (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/052F, 2011.
[12] Wang Xilong, T. Sato, Xing Baoshan, et al. Health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish. Science of the Total Environment, 2005, 28(1): 28-37.
[13] National Bureau of Statistics. Communique on Major Data of The Second National Economic Census of China. Beijing: China Statistics Press. 2009.
[14] National Bureau of Statistics of China. (1994-2012). China City Statistical Yearbook. Beijing: China Statistics Press.
[15] Plant Management Division in Ministry of Agriculture. National Vegetable Key Regional Development Plan (2009-2015). Chinese vegetables, 2009, (11): 1-8.
[16] Environmental site assessment guideline, 2009. DB1 1/T 656-2009. (In Chinese).
[17] USEPA (United States Environmental Protection Agency), 1993. Reference Dose (RfD): Description and Use in Health Risk Assessments. Background Document1A. Integrated risk information system (IRIS). 1993, 15(3).
[18] Mayuri Chabukdhara. Arvind K. Nema. Heavy metals assessment in urban soil around industrial clusters in Ghaziabad, India: probabilistic health risk approach. Ecotoxicology and Environment Safety. 2013, 1(1): 57-64.
[19] USEPA. Drinking-Water Criteria Document for Cadmium (final draft). Final draft report. United States: N. p., 1986.
[20] WHO. Evaluation of certain food additives and the contaminants mercury, lead, and cadmium: sixteenth report of the Joint FAO/WHO Expert Committee on Food Additives, Geneva, 1972, (4): 4-12.
[21] Diego Baderna, Andrea Colombo, Giorgia Amodei, et al. Chemical-based risk assessment and in vitro models of human health effects induced by organic pollutants in soils from the Olona valley. Science of the Total Environment, 2013, 01(10): 790-801.
[22] Wang Chunhui, Zhou Shenglu, Song Jing, Wu Shaohua. Human health risks of polycyclic aromatic hydrocarbons in the urban soils of Nanjing, China. Science of the Total Environment, 2018, 15(1): 750-757.
[23] Zhu Ying, Tao Shu, Sun Jianteng, et al. Multimedia modeling of the PAH concentration and distribution in the Yangtze River Delta and human health risk assessment. Science of the Total

ISSN 2616-5872 Vol.5, Issue 10: 1-7, DOI: 10.25236/AJEE.2023.051001

Environment, 2019, 10(1): 962-972.
[24] Wang Jing, Yan Zhenguang, Zheng Xin, et al. Health risk assessment and development of human health ambient water quality criteria for PBDEs in China. science of the Total Environment, 2021, 10(12): 149353.
[25] E. Spencer Williams, Barbara J. Mahler, and Peter C. Van Metre. Cancer risk from incidental ingestion exposures to PAHs associated with coal-tar-sealed pavement. Environmental Science & Technology, 2013, 47(2): 1101-1109.
[26] OEHHA. Cancer Potency Information of Benzo[a]pyrene. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, US, 2021,09.
[27] Wang Zongshuang, Duan Xiaoli, Liu Ping, et al. Human exposure factors of Chinese people in environmental health risk assessment. Research of Environmental Sciences, 2009, 22(10): 1164-1170.
[28] Duan, X.L., Tao, S., Xu, D.Q., Jiang, Q.J. Exposure Measurement and Health Risk Assessment of Human Exposure to Polycyclic Aromatic Hydrocarbons. Chinese Environment Science Press, 2011.
[29] NSB (Nanjing Statistics Bureau). Statistic Yearbook of Nanjing. China Statistics Press, 2014.
[30] Wang Chunhui, Wu Shaohua, Zhou Shenglu, et al. Polycyclic aromatic hydrocarbons in soils from urban to rural areas in Nanjing: Concentration, source, spatial distribution, and potential human health risk. Science of the Total Environment. 2015, 15(9): 375-383.
[31] Peng Chi, Chen Weiping, Liao Xiaolan, et al. Polycyclic aromatic hydrocarbons in urban soils of Beijing: status, sources, distribution and potential risk. Environmental Pollution. 2011, 03: 802-808.