Dose-Response: An International Journal

Volume 10
Issue 2 *Special Issue on the Role of Linear and Nonlinera Dose-Response Models in Public Decision-Making*

Article 12

6-2012

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Xiaojie Meng
Beijing Normal University, Beijing, China; Chinese Research Academy of Environmental Sciences, Beijing, China

Yan Zhang
Beijing Normal University, Beijing, China

Yuchao Zhao
Beijing Normal University, Beijing, China

In Chio Lou
University o f Macau, China

Jixi Gao
Chinese Research Academy of Environmental Sciences, Beijing, China

Dose-Response, 10:274–296, 2012
Formerly Nonlinearity in Biology, Toxicology, and Medicine

ISSN: 1559-3258
DOI: 10.2203/dose-response.11-022.Zhang

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www.Dose-Response.org

REVIEW OF CHINESE ENVIRONMENTAL RISK ASSESSMENT REGULATIONS AND CASE STUDIES

Xiaojie Meng □ State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing, China; Chinese Research Academy of Environmental Sciences, Beijing, China

Yan Zhang and Yuchao Zhao □ State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing, China

In Chio Lou □ Department of Civil and Environmental Engineering, University of Macau, Macau SAR, China

Jixi Gao □ Chinese Research Academy of Environmental Sciences, Beijing, China

□ Environmental risk assessment is an essential step in the development of solutions for pollution problems and new environmental regulations. An assessment system for environmental risks has been developed in China in recent decades. However, many of the Chinese technical guidelines, standards, and regulations were directly adapted from those of developed countries, and were not based on the Chinese environmental and socioeconomic context. Although existing environmental regulations for pollutants are usually obtained by extrapolations from high-dose toxicological data to low-dose scenarios using linear-non-threshold (LNT) models, toxicologists have argued that J-shaped or inverse J-shaped curves may dominate the dose–response relationships for environmental pollutants at low doses because low exposures stimulate biological protective mechanisms that are ineffective at higher doses. The costs of regulations based on LNT and J-shaped models could therefore be dramatically different. Since economic factors strongly affect the decision-making process, particularly for developing countries, it is time to strengthen basic research to provide more scientific support for Chinese environmental regulations. In this paper, we summarize current Chinese environmental policies and standards and the application of environmental risk assessment in China, and recommend a more scientific approach to the development of Chinese regulations.

Key words: environmental risk assessment, policy, guideline, threshold value, China

1. INTRODUCTION

Since the State Environmental Protection Administration (SEPA) issued the *Notice of Environmental Risk Assessment for Major Potential Environmental Pollution Accidents* (SEPA 1990), the field of environmental risk assessment in China has developed rapidly. As a result, the laws, guidelines, and standards have gradually improved, gradually making the assessments more standardized. In particular, the *Technical Guidelines for*

Address correspondence to Yan Zhang, Tel/fax: +86 10-5880-7596; E-mail: zhangyanyxy@126.com

Environmental Risk Assessment for Projects (SEPA 2004) that were enacted in 2004 required an environmental risk assessment as part of the environmental impact assessment for any construction project. However, despite several decades of development, the present system and its associated technical framework have some drawbacks and need to be improved. In this paper, we will discuss the components of this system and its drawbacks. In the environmental protection scheme described in the *Environmental Planning of the National 12th Five Year Development Plan* (MEP 2011), environmental risk assessments have been identified as a special focus, and many laws, regulations, guidelines, and standards will be amended. Environmental risk assessment is therefore approaching an important era in China; a review of the present laws and of the technical frameworks for environmental risk assessment are of tremendous significance because they can identify the problems with the current system and help the government to establish a more scientific environmental risk assessment system and technical framework.

2. ENVIRONMENTAL RISK ASSESSMENT POLICIES AND GUIDELINES

In 1990, SEPA (1990) required an environmental risk assessment to account for the possibility of potential environmental accidents. According to these regulations, both new projects and expansions of old projects with a significant chance of accidents (i.g., chemical, petroleum, nuclear and pharmaceutical industries) should be assessed in terms of their environmental risks as part of the project's overall environmental impact assessment. However, before 2004, environmental risk assessments were conducted according to the guidelines and technical documents developed in other countries. The following guidelines have been widely applied in China:

- *A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants* (USNRC 1975) by the United States Nuclear Regulatory Commission.
- *Guidelines for Identifying, Analyzing and Controlling Major Hazard Installations in Developing Countries* (World Bank 1985a).
- *Manual of Industrial Hazard Assessment Techniques* (World Bank 1985b).
- *Awareness and Preparedness for Emergencies at the Local Level*, by the United Nations Environmental Programme (UNEP 1988).
- *Environmental Risk Assessment* (ADB 1990), by the Asian Development Bank.

Based on these guidelines, China's Ministry of Environmental Protection (It replaced the SEPA during the March 2008 National People's Congress sessions in Beijing) issued technical guidelines for environmental risk assessment in projects (SEPA 2004) on 11 December 2004. The guideline, which describes and defines the procedures and technical methods that should be used in environmental risk assessments, is the first Chinese technical document that focuses on environmental risk assessment, and is therefore of great instructional importance. Since this guideline was published, environmental risk assessment has been gradually standardized due to the important role played by this document in the Chinese environmental risk assessment system.

The 20 years of development and improvement that have occurred since 1990 have led to the publication of many policies and guidelines (Table 1), and a basic system of policies for environmental risk assessment and the associated technical framework have been established in China. However, environmental risk assessment is still in its early stages in China. The assessments mainly focus on construction projects and are administered by governmental bureaus. Even though planning for these assessments is becoming an increasing focus of attention, many of the required supporting policies have not yet been issued.

Similarly to the case for Mainland China, the Hong Kong and Macau Special Administrative Regions have no independent environmental risk assessment regulations (FFTI 2008). In these regions, environmental risk assessments are only mentioned in various environmental standards and guidelines for air, noise, waste, water, and environmental assessment and planning. In Hong Kong, the *Environmental Impact Assessment Ordinance* (HKSARG 1998) is meant to avoid, minimize, or control the risk of adverse impacts on the environment created by designated projects. Before the start of a project or subsequent operation of the facility, an environmental impact assessment process must be completed to obtain a permit. The *Hazardous Chemicals Control Ordinance* (HKSARG 2008) regulates the import, export, manufacture, and use of non-pesticide hazardous chemicals that potentially have harmful effects on humans and the environment. Compared to Hong Kong, Macau must still improve its environmental risk assessment laws and regulations. The main legislative regulations currently in existence only focus on air, noise, and water pollution, and environmental impact assessment legislation is still being developed. Macau's law no. 35/97/M (MSARG 1997) controls the disposal of harmful substances in the waters of the administrative area. Despite the lack of a comprehensive risk assessment system, the governments of Hong Kong and Macau are signatories to international conventions such as the Stockholm Convention on Persistent Organic Pollutants and the Rotterdam Convention (FFTI 2008).

An overall system of policies for environmental risk assessments to protect public health and the ecological environment has not yet been established in mainland China or either of the two special administrative regions. Further efforts are therefore needed to let project managers and government officials plan environmental risk assessments, establish a policy framework for these assessments, and promote the development of a comprehensive policy system. Another problem is that, as we noted pre-

TABLE 1. list of the policies and guidelines currently in force in China.

Date effective	Policies	Notes
1988	*Regulations for radiation protection* (SEPA 1988a)	Requires an environmental risk assessment as part of the environmental impact assessment.
August 1988	*Environmental Protection Regulation Guidelines, Standard format and Content of Environmental Impact Reports for Nuclear Facilities* (SEPA 1988b)	Regulates the procedures and methods used for environmental risk assessments fornuclear power plant accidents.
1990	*Notice of Environmental Risk Assessment for Major Potential Environmental Pollution Accidents* (SEPA 1990)	Requires environmental risk assessments for the potential risk of environmental accidents.
1993	*Technical Guidelines for Environmental Impact Assessment General Principles* (SEPA 1993a)	Requires that a risk assessment be conducted for potential accidents
1 April 1994	*Environmental protection regulation guidelines for nuclear facilities, standard format and content of environmental impact reports for research reactors* (SEPA 1993b)	Requires accident analysis and in situ radiation analysis for all accidents related to the nuclear facilities
1 April 1994	*Environmental protection regulation guidelines for nuclear facilities Standard format and content of environmental impact reports for shallow ground disposal of solid radioactive waste* (SEPA 1993c)	Requires accident analysis and *in situ* radiation analysis for all accidents related to the storage and disposal of radioactive solid waste at shallow depth.
April 1996	Provisional Regulations on Environmental Protection in Cases of Waste Importation (SEPA 1996)	States the technical requirements and inspection procedures for an environmental risk assessment for imported wastes.
1997	*Notice on Strengthening the Supervision and Management of the Wastewater of Pesticide Enterprises* (SEPA *et al.* 1997)	Requires that newly constructed, expanded, or reconstructed pesticide manufacturing industries assess the environmental risks created by the possible emission of water pollutants, and especially characteristic pollutants produced during the production processes.
2001	*Guidelines on an Occupational Safety and Health Management System* (SETC 2001a)	States the risk assessment process required for employers.
2001	*Occupational Health and Safety Management System Specifications* (SETC 2001b)	States that the conclusions of a risk assessment should be documented and used as the basis to establish and maintain an occupational health and safety management system.
December 2004	*Technical Guidelines for Environmental Risk Assessment for Projects* (SEPA 2004)	Describes and defines in detail the procedures and technical methods for environmental risk assessment, and is the first technical document that focuses on environmental risk assessments.

continued

TABLE 1. *Continued*

December 2005	*Emergency Notice of Carrying Out Major Investigation of Environmental Security Risks (SEPA 2005a)*	Requires the improvement of environmental risk assessments by an enterprise or project and identification of the security risk.
2005	*Notice of Strengthening the Management of Environmental Impact Assessments to Prevent Environmental Risk* (*SEPA* 2005b)	Requires that environmental risk assessments be added into regional environmental impact assessment reports.
March 2006	*Regulation of the Prevention and Control of Environmental Pollution by Solid Wastes of Zhejiang Province* (ZJG 2006)	Requires environmental risk assessments and remediation for contaminated soils in Zhejiang province.
January 2007	*Technical Guidelines for Environmental Site Assessment (draft)* (BMEPB 2007)	Regulates the procedures and technical methods used for investigation and evaluation of the field environment in Beijing.
May 2007	*Chongqing's Regulation on Environmental Protection* (CQMPG 2007)	Requires that all manufacturing plants remove the leftover poisonous and hazardous materials, and remedy contaminated soil, in Chongqing.
May 2007	*Measures on Environmental Management and Remediation at Contaminated Sites in Shenyang City (trial implementation)* (SYEPB 2007)	Establishes a standard for the evaluation and identification of contaminated sites in Shenyang.
June 2008	*Notice of Strengthening the Management and Remediation of Contaminated Sites Formerly Used by Industry and Enterprises in Chongqing City* (CQMPG 2008)	Requires that risk assessment of contaminated former industrial and business sites be carried out before they can be used for other purposes.
September 2009	*Guidelines for Risk Assessment of Contaminated Sites (draft)* (MEP 2009d)	Regulates the procedures and technical methods for the investigation and evaluation of sites for all of China.
October 2009	*Environmental site assessment guideline*(BBQTS 2009)	Regulates the procedures and technical methods used for investigation and evaluation of the field environment in Beijing. Replaced the *Technical Guidelines for Environmental Site Assessment (draft)* (BMEPB 2007)
November 2009	*Technical Guidelines for Environmental Risk Assessment for Projects (draft)* (MEP 2009c)	Amends the *Technical Guidelines for Environmental Risk Assessment for Projects* (MEP 2009c)
November 2009	*Technical Guidelines for Planning Environmental Impact Assessments. General Principles (draft)* (MEP 2009a).	Requires an assessment of the risks to human health and the environment as part of an environmental impact assessment.
November 2009	*Technical Guidelines for Environmental Impact Assessment. Urban Master Plan (draft)* (MEP 2009b)	Requires an assessment of the risks to human health and the environment as part of an environmental impact assessment for urban planning.
November 2009	*Technical guidelines for Environmental Impact Assessment for Land Use Plans (draft)* (MEP 2009e)	Requires an assessment of the risks to human health and the environment as part of an environmental impact assessment for land use planning.
January 2010	*Technical Guidelines for Environmental Risk Assessment: the Method for Environmental Risk Classification of Chlor-alkali Enterprises* (MEP 2010)	The first guidelines for environmental risk for industry-specific in China.

viously, most of the technical systems and methods are based on foreign research; for example, the technical framework for nuclear plants is based on USNRC (1975), and the *Technical Guidelines for Environmental Site Assessment* issued by the Beijing Municipal Environmental Protection Bureau (BMEPB 2007) and the Ministry of Environmental Protection (MEP 2009e) are based on their United States Environmental Protection Agency counterparts (USEPA, 1996 2002). As a result, these documents do not account for any environmental or socioeconomic differences between China and the country where these documents originated.

In Hong Kong, the *Environmental Impact Assessment Ordinance* (HKSARG 1998) also applies to certain types of construction projects, which are listed as "designated projects" (FFTI 2008). These projects must go through the environmental risk assessment process, but only those listed in Schedule 2 of the ordinance require environmental permits before they can proceed.

3. STANDARDS AND THRESHOLD VALUES

The development of threshold values for a range of pollutants is a fundamental part of environmental risk assessment. Unfortunately, few standards and threshold values have been issued in China. In the current environmental risk assessment framework, the standards and threshold values for risky materials are important references to identify and judge the acceptability of these materials. According to the *Technical Guidelines for Environmental Risk Assessment for Projects* (draft) (MEP 2009c), hazard identification is required as a part of an environmental impact assessment. The guidelines state that the identification of hazardous materials should be based on the threshold values listed in the appendix to the document, and that risk assessment factors must be based on an integrated evaluation of any hazardous, poisonous, flammable, and explosive materials used in the projects. However, these guidelines do not provide guidance or values for physical damage or invasive species. According to the *Technical Guidelines for Environmental Risk Assessment for Projects* (draft) (MEP 2009c), the hazard related to each material must be decided based on the *Classification of Health Hazard Levels for Occupational Exposure to Toxic Substances* (CSBS 1985). To predict the results of accidents with maximum confidence, the guidelines state that the potential dispersion of hazardous materials should be plotted using a distribution graph that shows the maximum concentration, concentrations greater than or equal to the median lethal concentration (LC_{50}), and areas with concentrations greater than or equal to the "immediately dangerous to life or health" concentration (IDLH), as well as information on objects or areas that must be protected within the range of the dispersion.

The regulation demonstrated the importance of the LC_{50} and IDLH parameters as environmental risk threshold values. LC_{50} can be obtained from various reference books, including the *Handbook on Security and Technology of Dangerous Chemicals* (Zhang 2008), whereas IDLH values can be acquired from Appendix B of *Selection, Use and Maintenance of Respiratory Protective Equipment* (GAQSIQ 2002a), which adapts the IDLH concentration from the United States National Institute of Occupational Safety and Health (NIOSH 1990). The regulation also required that risk assessors define the spatial distribution of concentrations of hazardous materials at the study sites within characteristic time periods selected based on the processes that determine concentration changes over time.

Currently, standards related to threshold values in China include the *Classification of Health Hazard Levels for Occupational Exposure to Toxic Substances* (CSBS 1985), the *Environmental Quality Risk Assessment Criteria for Soil at Manufacturing Facilities* (SEPA 1999), the *Selection, Use and Maintenance of Respiratory Protective Equipment* (GAQSIQ 2002a), the *Surface Water Quality Standard* (SEPA 2002), and the *Sea water Quality Standards* (SEPA 1997). The names of the relevant standards and their publication dates are listed in Table 2.

The *Classification of Health Hazard Levels for Occupational Exposure to Toxic Substances* (CSBS 1985) is a set of classification standards based on the acute toxicity, clinical symptoms of acute poisoning, clinical symptoms and consequences of chronic poisoning, carcinogenicity, and highest tolerable concentration of a range of toxic substances. The classification principle is that evaluators should conduct an integrated analysis that balances the classifications in these six categories and then decide on

TABLE 2. The standards used for environmental risk assessment in China.

Name of the standard	Publication date
Classification of Health Hazard Levels from Occupational Exposure to Toxic Substances (CSBS 1985)	Issued by the Standardization Administration of the People's Republic of China on 2 April 1985; implemented on 1 December 1985.
Selection, Use and Maintenance of Respiratory Protective Equipment (GAQSIQ 2002a)	Issued by the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China on 12 March 2002; implemented on 1 October 2002.
Environmental Quality Risk Assessment Criteria for Soil at Manufacturing Facilities (SEPA 1999)	Issued by SEPA on 9 June 1999; implemented on 1 August 1999.
Surface Water Quality Standard (SEPA 2002)	Issued by SEPA and the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China on 26 April 2002; implemented on 1 June 2002.
Sea water Quality Standards (SEPA 1997)	Issued by SEPA on 21 July 1998; implemented on 21 July 1998.
Standards for Drinking Water Quality (MH and SAC 2006)	Issued by the Ministry of Health and the Standardization Administration of the People's Republic of China on 29 December 2006; implemented on 1 July 2007.

the overall level of hazard according to the sub-level identification of the most common items. However, some special toxicants can be categorized according to critical hazards such as their acute effects, chronic effects, and carcinogenicity. Based on the abovementioned principles and methods, the 56 most prevalent toxicants have been grouped into four categories: I (extremely hazardous), II (highly hazardous), III (moderately hazardous), and IV (slightly hazardous). Of these 56 substances, 13 substances, such as mercury and its compounds, benzene, and arsenic and its compounds (excluding non-carcinogenic inorganic arsenic compounds), were assigned to level I; 26 substances, such as trinitrotoluene, lead and its compounds, and carbon disulfide, were assigned to level II; 12 substances, such as styrene, ethanol, and nitric acid, were assigned to level III; and the remaining 5 substances, such as solvent gasoline, were assigned to level IV.

The *Environmental Quality Risk Assessment Criteria for Soil at Manufacturing Facilities* (SEPA 1999) were enacted by the Ministry of Environmental Protection to guarantee the health of employees in various manufacturing enterprises (SEPA 1999). This standard considered intake of toxins during the production activities of factories and skin contact with contaminated soil or drinking contaminated groundwater, and established soil concentration standards for the 89 most common industrial contaminants. The toxicity values given in the appendix of this standard give investigators guidance on how to investigate soil contamination caused by industrial and mining operations. The algorithm for determining these values was adapted from American standards, but the values in the soil standards were much higher than in the United States (USEPA 2002) (Table 3), because they failed to consider respiratory intake; as a result, these guidelines do not make sense in real-world applications (i.e., they are not sufficiently strict), and are thus applied less than they should be.

Due to the lack of threshold values prepared for hazardous and toxic substances emitted into bodies of water, the *Surface Water Quality Standard* (SEPA 2002), the *Sea water Quality Standards* (SEPA 1997), and the *Standards for Drinking Water Quality* (MH and SAC 2006) are used as alternatives. However, because the subjects of assessment in China are pollution accidents, which last relatively short times, and the abovementioned quality standards are designed for long-term concentrations, these alternatives are inadequate. It is noteworthy that these standards were established primarily by referring to the water quality standards in the United States, Japan, the former Soviet Union, and other European countries that control water quality more strictly (Table 4), and therefore these standards are not completely applicable to China.

For example, in 1976, USEPA proposed a maximum contaminant level (MCL) of 0.05 mg/L for arsenic in drinking water as part of the *National Interim Primary Drinking Water Standards.* Then, in 1985, USEPA proposed a

TABLE 3. Comparison of the standard values for some soil pollutants in China and the United States.

Compound	China			U.S.				
	Direct contact (mg/kg)		Migration into groundwater (mg/kg)	Ingestion–dermal (mg/kg)	Inhalation of volatiles (mg/kg)	Inhalation of fugitive particulates (mg/kg)	Migration into groundwater DAF‡ = 20 mg/kg	Migration into groundwater DAF = 1 mg/kg
Benzene	1640	C*	177	12	0.8	—	0.03	0.002
Chlorobenzene	54300	nc†	5860	1600	380	—	1	0.07
Nitrobenzene	1890	nc	147	31	90	—	0.1	0.007
Arsenic	44	c	3.4	0.4	—	770	29	1
Cadmium	3790	nc	147	70	—	1800	8	0.4
Chromium (III)	1000000	nc	293000	120000	—	—	—	—
Cyanide (total)	75800	nc	5860	1600	—	—	40	2

* the benchmark based on carcinogenic risk
† the benchmark based on non-carcinogenic risk
‡Dilution Attenuation Factor

new 4-day mean contaminant level (chronic) of 0.19 mg/L for aquatic life. Based on these values, China has formulated standards for water quality to enhance the safety factor, and has used the protection of human health benchmark of 0.05 mg/L to protect aquatic life. Thus, the class I to class III water standards are all defined based on a threshold of 0.05 mg/L, mainly based on the above considerations rather than based on actual toxicity levels for aquatic life. In addition, in 1976, USEPA developed a crop irrigation water benchmark of 0.1 mg/L; Their study shows that, the arsenic content in brown rice and canola was the same as that in a control treatment when the crops were irrigated with water containing arsenic at 0.05 mg/L. In irrigation water with arsenic levels of 0.10 mg/L, the arsenic content in the brown rice and canola increased slightly compared with levels in the control, but was still within the scope of America's food hygiene standards. Based on these experimental results, China considered an MCL of 0.1 mg/L for arsenic in surface water to be safe for crops.

Mercury is another example. In the *Quality Criteria for Water* (USEPA 1976), 0.05 μg/L of total mercury was recommended as the threshold for the protection of human

TABLE 4. Comparison of water quality indexes in various Chinese standards.

Pollutant	Surface water quality standard (SEPA 2002)	Standards for drinking water quality (MH and SAC 2006)	Standards of other countries or communities	
Arsenic	I to III: 0.05 mg/L IV to V: 0.1 mg/L	0.01 mg/L	Drinking water sources	European Economic Community guidelines: 0.01 mg/L; management value: 0.05 mg/L; Japan: 0.01 mg/L; South Korea: 0.05 mg/L
			Fisheries	Former Soviet Union: 0.05 mg/L
Mercury	I to II: 0.00005 mg/L III: 0.0001 mg/L IV to V: 0.001 mg/L	0.001 mg/L	Drinking water sources	Former West Germany: A grade, 0.0005 mg/L, B grade: 0.01 mg/L England, Switzerland: 0.001 mg/L Canada: 0.001 mg/L
			Fisheries	Japan: <0.04 mg/L Former Soviet Union: 0.001 mg/L
Lead	I to II: 0.01 mg/L III to IV:0.05 mg/L	0.01 mg/L	Drinking water sources	EEC: 0.05 mg/L Canada: 0.01 mg/L
	V: 0.1 mg/L		Fisheries	Japan: <0.1 mg/L
Cyanide	I: 0.005 mg/L II: 0.05 mg/L	0.05 mg/L	Drinking water sources for surface water	EEC, England: 0.05 mg/L Switzerland: 0.01 mg/L
	III to V: 0.2 mg/L		Surface water	Washington State, U.S., target value: 0.005 mg/L, standard value: 0.01 mg/L
			Irrigation water	American farms:0.2 mg/L

health and that of fish-eating wildlife. In the *Chinese Surface Water Quality guidelines*, the standard values were defined as 0.05 μg/L on this basis. An isotope tracing study showed that when the concentration of mercury in irrigation water reaches 5.0 μg/L, the edible parts of cucumber, eggplant, and wheat will show slightly increased mercury levels (Xia *et al.* 2004). Moreover, mercury bioaccumulates in aquatic organisms and is not easily degradable in the water environment. These properties are also important factors that were used to determine the Chinese standard value. The 0.1 μg/L standard value in the *Chinese Surface Water Quality* guidelines and the 1.0 μg/L standard value in the *Chinese Surface Water Quality* guidelines are more stringent than the American standard.

Fish (and especially commercially valuable fish) are also highly sensitive to lead. The toxicity of lead in the water is influenced by the water's pH, hardness, and other factors. USEPA (1976) set a standard value of 50 μg/L to provide guidance to water suppliers that would account for non-health effects such as those on fish. In 1980, USEPA recommended a standard value of 56 μg/L for lead in ambient water because they believed that this standard value would protect humans from the health hazards caused by lead intake (USEPA 1980). Based on the U.S standard, China issued a more stringent standard by defining the standard concentration of lead as 10 μg/L (the analytical detection limit) for class I and II water, 50 μg/L for class III and IV water, and 100 μg/L for class V water.

Chinese standard developers also defined values for cyanide based on the toxicology index of this compound to both guarantee human health and protect aquatic organisms. They used free cyanide in the water as an indicator. Aquatic organisms (and especially salmonids) are much more sensitive than terrestrial organisms to cyanide, and in 1976, USEPA (USEPA 1976) proposed a benchmark of 5 μg/L for the protection of aquatic organisms. In 1985, a 4-d mean cyanide contamination level of 5.2 μg/L was proposed (USEPA 1985). Because these two benchmark values were both about 5 μg/L, the developers of the Chinese standard believed that this benchmark could protect aquatic organisms (including sensitive fish), and defined a cyanide level of 5 μg/L for water class I. In 1999, USEPA set a cyanide level of 700 μg/L as the benchmark for protecting human health (USEPA 1999). Because of the centralized drinking water sources used to supply class II water, the standard developers increased security by choosing 50 μg/L as the standard value for cyanide in water class II areas, which is a lower value than the benchmark used for the protection of human health. In addition, studies showed that 200 μg/L of free cyanide is a lethal concentration for most fish (USEPA 1976). Therefore, standard values for water classes III, IV and V areas were set at 200 μg/L based on the acute toxicity benchmark for the protection of human health and most fish.

However hydrologic and geological conditions in china, and the species and ecosystems affected by these conditions may be significantly different from those in the areas of U.S. for which the USEPA standards were developed. It is therefore evident that risk threshold values for water quality should be studied more intensely in China to confirm that the abovementioned values (and values for other key pollutants) are appropriate. Furthermore, fundamental research on aquatic toxicology is needed in order to develop a set of risk threshold values that are suitable for the aquatic environment and organisms in China.

The guidelines for environmental risk assessments for contaminated land are particularly important guidelines because industries producing large amounts of pollution are increasingly being moved out of populated urban areas, after which the land is reused for other purposes. For example, during the planning that occurred during the development of the *Beijing Olympics Sub-plan for Environmental Protection* (BMEPB 2004), as many as 200 enterprises in the Beijing metro area would be moved out of the city before the 2008 start date of the Olympics, and the industrial real estate along the 4th Ring Road would be converted into business and residential land. However, because these industrial lands had been contaminated by the previous industrial activities, it was necessary to assess the contaminant levels to protect the safety of future land users and (if necessary) to remediate these lands before they were converted to their new functions. To guarantee that these measures would be taken, the Beijing Municipal Environmental Protection Bureau issued the *Environmental Site Assessment Guideline (draft)* (BMEPB 2007) in January 2007, and then Beijing Bureau of Quality and Technical Supervision issued a formal draft in October 2009 (BBQTS 2009); these documents used American sources as the framework and modes for these guidelines (MEP 2009e).

The compilation of the national *Guidelines for Risk Assessment of Contaminated Sites (draft)* (MEP 2009d) was initiated by China's Ministry of Environmental Protection in 2009, with the draft guidelines published in September 2009. The guidelines divided environmental risk assessment for contaminated land into damage identification, exposure assessment, toxicity assessment, risk characterization, and the expected values of soil remediation. The methods used were those developed by ASTM (2002) and USEPA (1996, 2002). Some methods or models were directly adapted from those that were used abroad and then adjusted to make them more suitable for the Chinese situation (Table 5). For example, based on the American guidelines, China adopted an adult exposure frequency of 365 days per year for the use of residential lands. For the use of business and industrial lands, the exposure frequency was set to 250 days by assuming 5 working days per week and 52 weeks per year, and then eliminating 10 national holidays. The recommended exposure duration was set to 24 days for adult use of residential lands, and 25 days for adult use of business and

TABLE 5. Comparison between China and the United States of exposure parameters for soil risk assessment.

	China		U.S.				
			Residential land	Non-residential land (commercial/industrial)		Construction sites	
Parameter	Residential and public land	Land for commercial and industrial use	Resident	Outdoor worker	Indoor worker	Construction worker	Off-site resident
Exposure frequency (d/yr)	365 for child or adult	none for child, 250 for adult	350	225	250	Site-specific	Site-specific
Exposure duration (yr)	6 for child, 24 for adult	none for child, 25 for adult	30 [6 for children for non-cancer effects]	25	25	Site-specific	Site-specific
Soil ingestion rate (mg/d)	200 for child, 100 for adult	none for child, 100 for adult	200 for child, 100 for adult	100	50	330	NA
Inhalation rate (m^3/d)	7.5 for child, 15 for adult	7.5 for child, 15 for adult	20	20	20	20	20
Surface area exposed (cm^2)	2291 for child, 4860 for adult	none for child, 2734 for adult	2800 for child, 5700 for adult	3300	NA	3300	NA
Adherence factor (mg/cm^2)	0.2 for child, 0.07 for adult	none for child, 0.2 for adult	0.2 for child, 0.07 for adult	0.2	NA	0.3	NA
Body weight (kg)	14.4 for child, 53.1 for adult	14.4 for child, 53.1 for adult	15 for child, 70 for adult	70	70	70	70

industrial lands. The recommended values were set based on federal and state regulations in the United States, and other variables such as heights and weights were determined according to data on Chinese adults obtained from the China Statistical Yearbook (MEP 2009e).

As a special risk factor, ionizing radiation has received much attention from the Chinese government. Many standards have been developed for common radiation sources and certain sites where radioactive materials are used, except nuclear facilities such as power plants, for which the only standard is *Specifications for Monitoring of Occupational Exposure at Nuclear Power Plants* (MH 2010), which came into force on 1 December 2010. After developing the standard *International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources,* the International Atomic Energy Agency (IAEA), the United Nations' International Labor Organization (ILO) and Food and Agriculture Organization (FAO), the Organisation for Economic Co-operation and Development's Nuclear Energy Agency, the Pan American Health Organization, and the World Health Organization also published radiation safety guidelines with "RS-G-1X" number. Many of these standards have been converted into Chinese radiation protection standards. For example, the *Basic Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources* (GAQSIQ 2002b), which were implemented on 1 April 2003, were developed based on the *International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety Of Radiation Sources* (IAEA 1996). The two documents are equivalent in their technical content. In addition, the *Basic Principles for Radiological Protection During Medical Exposure* (MH 2006) and the *Specifications of Individual Monitoring for Occupational External Exposure* (MH 2002a), and other relevant standards resemble their international counterparts.

Because of the large number of references used in the standards development process, most of the standard values developed by international authorities such as the International Commission on Radiological Protection (ICRP) and IAEA were adopted in many Chinese standards. For example, the *Regulations for Radiation Protection* (SEPA 1988a) require that the annual effective dose equivalent for a member of the general public should be below 1 mSv (0.1 rem); based on the requirement that the lifetime dose be maintained below the prescribed total exposure, the annual effective dose can be increased to 5 mSv (0.5 rem) in some years. To determine these limits, the main references were ICRP Publication No. 26 and the statement from Paris Conference of 1985(ICRP 1977; ICRP 1985). In addition, when infants and children are included in the critical group, the exposure value should be set at 1% of the annual limit of intake (ALI) according to the *Regulations for Radiation Protection* (SEPA 1988a).

For historical reasons, Hong Kong and Macau have their own separate systems of environmental standards, in which the values were adopted directly from European standards. For example, the drinking water quality standards used by the Hong Kong Government follow the WHO standard, whereas Macau's government follows the European standard. However, there are few legislative standards and threshold values for environmental risk assessment.

4. CASE STUDIES

Recently, a number of environmental risk assessment studies have been conducted for Chinese construction projects; the fields include the petrochemical industry, fossil fuel–based power generation, and pipeline transportation. The properties of these projects were analyzed while determining the scope of the effects of each project, and specific thresholds were decided accordingly for each project (Fang *et al.* 2009; Cai 2010; Dong 2010). Fang *et al.* (2009) evaluated the environmental risk assessment in a project in which coal chemical industry proposed the production of 1.5 Mt methanol as an example. The main steps were project engineering analysis, identification of materials that posed an environmental risk, identification of major hazards, prediction of environmental risks, assessment of the risks that would be created by accidents, precautionary measures to reduce the environmental risk, and the preparation of contingency plans. The lethal concentration of methanol was set at 86 000 mg/m^3, and the upper limit for the concentration in the environment was set at 260 mg/m^3 (OSHAPEL-TWA). (Zhang 2008).

As another example, X.Q. Zhang *et al.* (2009) predicted the consequences of the maximum credible accident for a proposed petrochemical project that would produce propylene by means of catalytic pyrolysis of residues. To do so, they used the environmental risk assessment procedure recommended in *Technical Guidelines for Environmental Risk Assessment for Projects* (SEPA 2004). In this procedure, these authors applied the TNO (proposed by the Netherlands Organization for Applied Scientific Research) explosion equations recommended by the World Bank (World Bank 1990), and considered related accidents including an explosion caused by fire and the leakage of acidic H_2S solution. They selected an LC_{50} of 618 mg/L (based on inhalation by adult rats) and a maximum tolerable concentration of 10 mg/m^3 based on the *Occupational Exposure Limit for Hazardous Agents in the Workplace* (MH 2002b) to determine the effect scale of an H_2S accident.

Relatively few studies have assessed the environmental risks created by fossil fuel–based power plants. Zhang (2009) analyzed the impact of extensive emissions of SO_2 on the surrounding vegetation caused by a malfunction in the plant's dust removal efficiency. He defined an SO_2 concentration that would produce 5% visible leaf damage on crops as the threshold value. The environmental risk assessments for other projects used China's national standards to define the concentration thresholds. For example, Yu *et al.* (2008) studied a delayed coking project with an annual production of 1 Mt. Based on the procedure in the recommended environmental risk assessment guideline (SEPA 2004), fire was selected as the accident with the maximum likelihood of occurrence, and the "Large Outdoor Fire Plume Trajectory Model-Flat Terrain" was used to predict the plume and the distribution of combustion products downwind. In this study, the carbon monoxide concentration threshold regulated by the *Ambient Air Quality Standard* (SEPA 1996) served as a reference standard.

In some other cases, the LC_{50} values from relevant Chinese standards such as the *Sanitary Standard for the Design of Industrial Enterprises* (MH 1979) were used to define the threshold of environmental risk (Sun *et al.* 2007; Yue *et al.* 2008). In summary, no common standards have been developed to determine the threshold values that should be used in environmental risk assessments. Due to a lack of basic data, the toxicological parameter LC_{50} and the corresponding foreign standards have been most commonly used. In some cases, data from animal experiments were directly applied to assessments of the impacts on humans, which leads to a conservative approach and problems related to whether the animal studies are applicable to human subjects. To address these problems, China's government must develop an amount-reaction-conversion method and conduct fundamental research to clarify the actual safe levels for humans.

Because of the current lack of consistent guidelines, regional environmental risk assessments are still being studied. Chen *et al.* (2006) selected the LC_{50} and the 100% lethal concentration of a leaking gas as the threshold for determining the risk rating. Yang *et al.* (2006) studied a development area along the Yangtze River (the Jiangsu section) and applied a framework with four subsystems (risk sources, elementary control mechanisms, secondary control mechanisms, and receptors) in their case studies. They developed index systems and a formula to compute the "system partial value" for the whole area in which development was occurring:

$$M = \sum_{j=1}^{n} K_j M_j \tag{1}$$

where M is the system partial value (which represents the level of the regional environment risk); K_j is a weighting factor for subsystem j, which is determined using expert evaluation based on the analytical hierarchy process; M_j is the partial value for the jth subsystem; and n is the number of subsystems. Based on this model, they performed a comprehensive analysis and classified the integrated risk index into four categories.

Qu *et al.* (2010) developed an environmental risk assessment index system with two groups of indexes that represented the hazard posed by the cumulative hazard posed by all potentially dangerous substances and the fragility of the ecosystem to assess the environmental risk status in each Chinese province. The study used time-ordered weighted averaging to determine a time vector that would permit a dynamic integrated assessment for all Chinese provinces; based on the resulting 5-year environmental risk status, the provinces were divided into regions with high, medium, and low risk.

Xu and Liu (2009) proposed an environmental risk assessment method based on the use of gridded information dispersion. This method is based on fuzzy set theory, and their model effectively disperses each individual source of environmental risk. By conducting the information dispersion, they were able to group and analyze the acquired regional environmental risk index under specific regional environmental risk classification standards, and produced a distribution map for the environmental risk. Case studies using this method included studies of Huangge Town and Nansha Town in the Nansha Area of Guangzhou City. Each risk source was grouped into four categories (i.e., lethal zone, heavy injury zone, light injury zone, and inhalation reaction zone), and they obtained the environmental risk distribution for hazardous gases using a simplified calculation according to fuzzy set theory.

Xu *et al.* (2004) assessed the ecological risk for the Yellow River Delta region by defining and analyzing the target area, analyzing receptors and risk sources, analyzing the hazard exposure, and performing an integrated risk assessment. The risk sources were identified as flooding, drought, storm surges, oil spills, and disruption of the Yellow River's flow. The ecological loss for each ecosystem in the study area was quantified using a species conservation index, biological diversity index, perturbation intensity, degree of the natural state, fragility index, and ecological loss index. Since the risk sources differed in their intensity of effects on the corresponding receptors, Xu *et al.* (2004) used the analytical hierarchy process to assess the dominant ecological risk sources. Based on the integrated risk probability, the integrated ecological loss, and the integrated ecological risk index, they calculated a risk index for each sub-region within the study area and classified the results into five categories.

The abovementioned studies demonstrate that the use of integrated indexes is still the dominant approach to regional environmental risk assessment in China. However as these examples show, each researcher used a different approach, and there has been no standardization of methods that would provide a consistent framework for these evaluations.

Because there are no shared technical guidelines for health risk assessment in China, this kind of assessment is still being studied. Zheng *et al.* (2010) evaluated the health risk of Urumqi's drinking water resource using a method recommended by USEPA (1992), in which organochlorine pesticides enter the human body primarily through drinking water. They concluded that the carcinogenic and non-carcinogenic risks acquired from each monitoring section were lower than the maximum acceptable risk recommended by USEPA (2004). The formulas used in the calculation and the selection of parameters, such as the carcinogenic slope factor and non-carcinogenic reference dose, were adapted from USEPA (2004).

Zhang *et al.* (2010) applied an improved Monte-Carlo method to conduct a health risk assessment based on the quality of the effluent from a wastewater treatment plant in Xi'an. The reference dose and carcinogenic intensity coefficient in the formula were determined using rules proposed by international cancer research institutes, WHO, and USEPA.

A number of other studies applied methods developed in the United States to conduct health risk assessments, such as growing rice in a polluted field and measuring pollutant concentrations in the grains (Lei *et al.* 2010), and analyzing concentrations in surface water (Ji *et al.* 2010a; Kai *et al.* 2010) and groundwater (Ji *et al.* 2010b). The American methods are still the dominant approach used in China. In many cases, methods have been adapted from American environmental health risk assessment guides and the threshold values were from the United States or other countries. Thus, environmental health risk assessments in China still rely almost exclusively on methods and applications developed in other countries, and China lacks techniques that are focused on the Chinese context and effective support for these guidelines based on fundamental research data in that context.

5. CONCLUSIONS AND RECOMMENDATIONS

Environmental risk assessment in China has entered a critical period. After several decades of development, this field has made great progress in the establishment of policies and standards, as well as in their application. However, the situation remains imperfect because a complete and consistent system has not yet been established. The development of environmental risk assessment methods and standards for accidents, contaminated sites, and human health has just started in China. In particular, basic research to develop standard values and thresholds is weak, with most of the guidelines, standards, and thresholds directly adopted from values in other countries. Most of the applications also follow the methodologies used in developed countries. Unfortunately, during the decision-making process related to assessing environmental risks, neither the suitability of foreign regulations to the Chinese context nor the reliability of the assessment process used to determine the threshold values has been evaluated.

In most developed countries, there are differences of opinion about the risk assessment process that should be used for developing regulations. For example, in the United States, regulatory agencies assume that cancer risk follows a linear increase at low doses, but hormesis phenomena (i.e., beneficial effects at low doses) that result in J-shaped dose–response curves have been widely reported, independent of the biological model, measured endpoint, and chemical class or physical stressor that were studied (Calabrese and Baldwin 2003; Calabrese 2010). This is believed to occur because low exposure levels may stimulate biological protective mechanisms that are ineffective at higher doses. Obviously, predictions of adverse effects based on a J-shaped dose–response model and a linear non-threshold model would produce quite different results in the low-dose region, and this would result in the selection of different threshold numbers. Figure 1 conceptually compares the predictions of adverse effects using these two conceptual models. In an extreme case, if the J-shaped model is true and the acceptable upper bound of the cancer risk for a given dose is below the turning point on the J-shaped curve, it is not necessary to reduce the dose; in contrast, a linear non-threshold model would suggest the need for measures to reduce the dose, leading to higher regulatory costs. Since economic factors are an important consideration when making regulatory decisions in developing countries, where budget constraints can be significant, it is critical to establish a more scientifically based risk assessment system at the current stage of

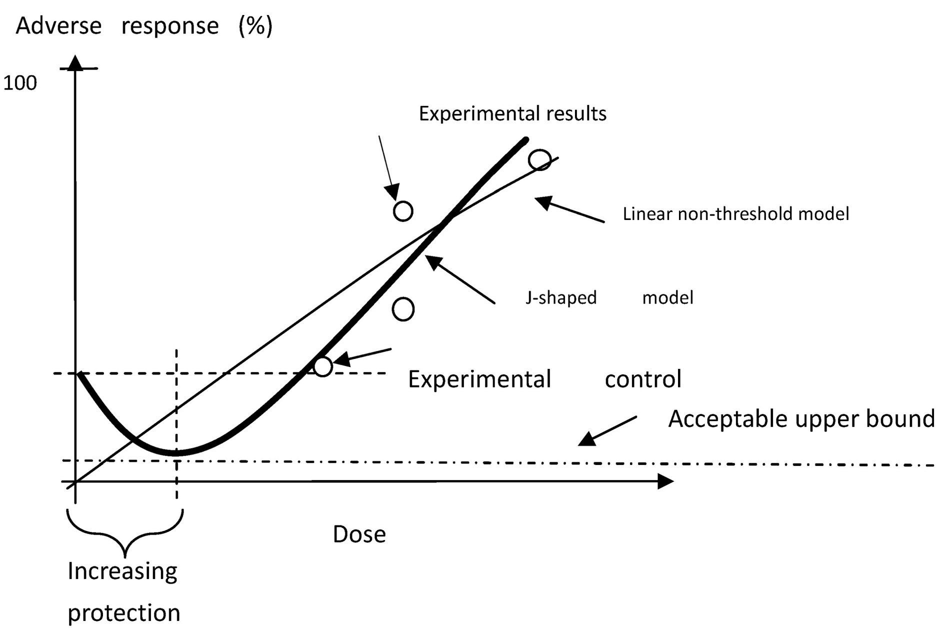

FIGURE 1. Comparisons of the predictions of adverse effects using a J-shaped (hormetic) dose–response model and a linear non-threshold model.

China's development. Therefore, it will be important to strengthen basic research on environmental risk assessment so that China can develop a more suitable and scientific approach to the determination of risk thresholds—one that is optimal for the Chinese context.

ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China (No. 40701004), the Program for Changjiang Scholars and Innovative Research Team in University (No. IRT0809), the National High Technology Research and Development Program (No. 2008AA06A404) and the Fundamental Research Funds for the Central Universities.

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