Guidebook on the Management and Financing of Soil Rehabilitation Projects in China

International Institute for Sustainable Development

Norwegian Institute for Water Research

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International Institute for Sustainable Development

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Cover design is based on soil symbols used in mapping soil types.

About This Report

This is a part of a series of outputs of a five-year project, Financing Models for Soil Remediation with support from the Norwegian Ministry of Foreign Affairs. The project aims to support the implementation of China's priorities and its policy development process through institutional partnerships; mutual learning and exchange; strengthening of capacity, especially in government institutions; and the effective demonstration of results on the ground in the implementation of China's environmental priorities. The overall objective of the project is to harness the full range of green finance approaches and vehicles in the task of funding and managing the associated risks in the remediation of contaminated soils in China. This series of reports focuses on the financial vehicles available to attract investment to the environmental rehabilitation of degraded land and the financial reforms needed to make these vehicles viable and desirable means of investing in land rehabilitation. We draw on best practices worldwide in funding environmental rehabilitation, with a special focus on the design and use of financial mechanisms to attract private investors, share the risks, and offer a clear benefit for the rehabilitated land.

Table of Contents

List of Figures

List of Tables

List of Boxes

1.0 Introduction

Maintaining healthy soil is crucial to every aspect of human and planetary life. It provides ecosystem services for filtering water, providing a habitat for billions of organisms, supporting the growth of plants, recycling raw materials, and mitigating climate change. Healthy soil is vital for food and feed production. But human activities have seriously damaged and contaminated soil, and often the level and extent of contamination remains unknown, coming to light years after the contaminating activity has taken place. Around the world, large amounts of contaminants have been found in the soil, from mining, waste disposal, intensive agricultural activities, and industrial activities, among others.

One of the biggest challenges for soil remediation remains its financing. Currently, soil remediation efforts around the world still mainly rely on public funding. Although some jurisdictions have started to employ a variety of financing instruments, such as grants, concessional loans, green bonds proceeds, or climate fund investments, these are not enough. Furthermore, the COVID-19 pandemic is erasing years of development progress and causing major setbacks to all sources of finance for sustainable development. At the same time, there are also some equally important bottlenecks such as governance structure and technical capacity.

This guidebook is intended to advise the relevant stakeholders in any soil remediation project on the principles of initiating an investigation, conducting a risk assessment, and evaluating potential financial measures. The main focus of the proposed guidebook will be on best practices, governance models, and financial models for soil remediation in order to overcome the obstacles that may get in the way of the remediation project.

This guidebook will first address the technical aspects of soil remediation, which include how to identify potentially contaminated sites, conduct a risk assessment, and select remediation measures. These technical processes are similar across the world and follow up-to-date international guidance on soil remediation. The guidebook will later dive into a more China-specific stakeholder analysis examining the special characteristics of the Chinese legal system, especially regarding ownership. Section 3 of the guidebook will focus on the financing aspect of soil remediation projects, exploring a wide variety of financing modalities available to tackle this issue.

2.0 International Practices for Contaminated Sites Management

In this report, we will use the latest international progress on the management of contaminated sites proposed by the Minamata Convention (MC) on Mercury (Hg) (2019) to illustrate how to manage contaminated sites. The MC adopted the official *Guidance on the Management of Contaminated Sites* (Secretariat of the MC on Hg, 2019; UN Environment Programme, 2019) at the 3rd Conference of the Parties to the MC on Hg on November 29, 2019. This decision allows the convention parties to implement measures to identify and remediate Hg-contaminated sites in a coordinated way. Article 12 of the guidance, for example, contains provisions on contaminated sites, including the identification and assessment of sites, an explanation of their risks to human and environmental health, and the financial aspects of remediation (Secretariat of the Minamata Convention on Mercury, 2019). Section 2 will demonstrate, by using selected cases, how a contaminated site management plan can be developed.

2.1 Site Identification and Characterization

The first step in contaminated site management is to identify possible contaminated sites. Some provinces and cities, along with the Ministry of Environment and Ecology of China (MEE), have issued simple screening values to identify possible contaminated sites, such as *Screening Levels for Soil Environmental Risk Assessment of Sites*, issued by Beijing Quality and Technical Supervision (2011), and *Risk Screening Guidelines for Soil Contamination of Development Lands* (MEE, 2018b). In this report, we selected Hg as the target contaminant: 14 mg/kg was used as the screening level for soil contamination. When the average Hg content of soil in the site is higher than this value, it can be preliminarily determined as an Hg-contaminated site, and further risk assessment is needed. The potentially Hg-contaminated sites in China can be divided into the following categories:

1. **Hg-mining areas**
   China is rich in Hg mineral sources, and Hg deposits are widely distributed: there are 127 ore deposits, which belong to 13 provinces and autonomous regions around the country. Most of them are located in the southwest region, especially in Guizhou Province. China's major Hg-mining areas are listed in Table 1.

Table 1. List of China's Hg-mining areas*

Location		No.	Mines	Reserves / tonnes	Grade /%
Hubei		M001	Zhongguwan	1,280	0.43
Hunan		M002	Chatian	4,990	0.15–0.33
		M003	Xinhuang	3,606	0.186
Guangxi		M004	Yulan	1,981	1.1
Chongqing		M005	Xiushan	11,760	0.2
		M006	Youyang	1,195	0.1
Guizhou	Wuchuan	M007	Muyouchang	16,312	0.15–0.134
			Laowuji	973	0.14
			Bojiyan	588	0.132
			Houdong	528	0.115
	Tongren	M008	Lulachang	5, 499	0.165
			Shaluoxi-Huilongxi	12,140	0.15–0.36
			Baiyabi	3,109	0.149
			Luanyantang	2,490	0.364
	Songtao	M009	Shuiyinchang	741	0.1
			Dayuan	599	0.13
	Wanshan	M010	Heidongzi	2,395	0.123
			Daping	1,117	0.361
			Lengfengdong	2,691	0.161
			Zhangjiawan	6,226	0.136
			Sanmudong	13,908	0.137–0.275
			Yanwuping	3,337	0.168
			Chongkezhai	3,318	0.658
			Tianba	771	0.58
			Meizixi	623	0.130–0.252

Location		No.	Mines	Reserves / tonnes	Grade /%
Guizhou	Xinren	M011	Lanmuchang	3,140	0.191
	Kaiyang	M012	Baimadong	2,683	0.15
	Sandu	M013	Jiaoli	1,899	-
	Danzhai	M014	Hongfachang	5,862	0.298
			Sixiangchang	5,768	0.52
Yunnan	Qiubei	M015	Ximatang	920	0.39
	Shidian	M016	Maocaopo	971	0.39
	Baoshan	M017	Shuiyinchang	2,098	0.26
			Jinjiashan	885	0.26
Shaanxi	Xunyang**	M018	Gongguan	14,791	0.32–0.35
			Qingtonggou	7,257	0.35
Gansu		M019	Majiashan	513	0.5
Qinghai		M020	Muhei	1,294	0.25
		M021	Kuhai	2,009	0.19
Shaanxi		A001	Qiantongshan	1,069	-
Guangdong		A002	Fankou	3,000	-

*The information on each Hg deposit comes from China's mineral reserve statistics (1996); part of it comes from the discovery history of deposits in China (Guizhou Volume) and the discovery history of deposits in China (Yunnan Volume). Source: Sino-Norwegian Cooperation Project on Reducing Hg Pollution, Phase 3, 2016.

**Xunyang Hg and antimony mine is usually regarded as an Hg mine.

2. **Chemical plants using an Hg cathode to produce caustic soda**
The chlor-alkali industry uses Hg as a cathode to produce caustic soda in the process of the electrolysis of a sodium chloride solution. In China, the chlor-alkali industry, which uses Hg, began in the 1950s, and in the 1960s and 1970s, there was rapid development. Today, China has eliminated caustic soda production processes that use Hg; however, there are a lot of brownfields that are potentially contaminated sites. Table 2 shows the chemical plants that used the Hg cathode technique in China.

Table 2. Chemical plants using the Hg cathode technique in China

Province	Plant	Year of decommissioning
Tianjin	Tianjin Chemical Plant	1998
Liaoning	Jinxi Chemical Plant	1998
	Jincheng Paper Mill	2001
Heilongjiang	Qiqihar Electrochemical Plant	1987
Jiangxi	Xinghuo Silicone Plant	1990
Yunnan	Hongyun Chemical Plant	1991
Shaanxi	Shaanxi Chemical Plant	1990
Qinghai	Qinghai Liming Chemical Plant	1990
	Qinghai Electrochemical Plant	1998
Gansu	Yanguoxia Chemical Plant	1989
Guizhou	Guizhou Organic Chemical Plant	1997
Beijing	Beijing Second Chemical Plant	-

Source: Sino-Norwegian Cooperation Project on Reducing Hg Pollution, Phase 3, 2016.

3. **Other typical Hg-polluted sites**
Besides the Hg-mining areas and chemical plants, other industrial brownfields are also potentially Hg-contaminated sites; these include gold-mining areas, coal-fired power plants, non-ferrous metal-smelting areas, landfill and incineration plants, and Hg-containing products plants (which make fluorescent lamps, thermometers, and batteries).

Gold-Mining Areas
Gold amalgamation mining is one of the important anthropogenic Hg sources: according to conservative estimates, it accounts for about one tenth of the anthropogenic sources and is considered second only to the artificial source of non-ferrous metal smelting. Gold amalgamation mining has been used in Tongguan, Shaanxi, and Lingbao in Henan; Dexing in Jiangxi; Jiapigou in Jilin; and other main gold deposits.

The Coal-Fired Power Plants
In China, the Hg content in most coal ranges from 0.01 to 1 mg/kg, with an average of 0.15 mg/kg (Belkin et al., 2006). Because of the strong volatility of Hg, after coal's combustion process, all the Hg is turned to gaseous form and emitted into the atmosphere. Due to the huge number of emissions from coal-fired power plants, the migration and transformation of Hg in the coal combustion process has become one of the important components in the Hg cycle in the biosphere; at the same time, it also causes pollution in the soil surrounding coal-fired power plants.

Non-Ferrous Metal-Smelting Areas

Non-ferrous metal smelting is one of the main anthropogenic sources of atmospheric Hg. Mainly the Huludao zinc plant, the Zhuzhou smelter, Zhejiang district, and Hezhang Fuyang copper zinc-smelting areas were reported in the literature. The Zhuzhou zinc plant is located in Zhuzhou City. Z. Li et al. (2011) investigated the soil around the factory, and the Hg content was 0.15–2.89 (mean value of 0.9) mg/kg. F. Liu et al. (2013) determined that the soil around the Zhuzhou smelter had an Hg content of 0.04–3.83 mg/kg, and the Hg content in local vegetables was 0.10–4.16 mg/kg. Affected by zinc smelting and a chlor-alkali plant, the soil Hg content in the surface layer of the zinc smelting and chlor-alkali production area near the Huludao zinc plant was 0.055–14.575 (mean value of 1.435) mg/kg, and the soil Hg content in that area was 4.602 mg/kg (Zheng et al., 2007). In addition, some work was done to study the zinc plant in Hezhang (Z. Li et al., 2011) and its copper-smelting factory (Yin et al., 2009).

The Landfill and Incineration Plant

There is Hg pollution around the landfill and incineration plants that have been studied. Tang et al. (2005) investigated Pudong's power plant that is driven by refuse in Shanghai and found the Hg value in the soil around the plant was 0.126 mg/kg, but after 1–2 years of operation, the average value increased to 0.139 and 0.137 mg/kg, and the atmospheric Hg around the plant was 4.9–11.2 ng/m^3. X. Wang et al. (2013) obtained amounts for the total Hg and methyl Hg in the soil around the plant, and those levels were 56.0–103.2 ng/g and 0.146–0.978 ng/g, respectively (mean of 0.079) mg/kg. In addition, Z. G. Li et al. (2006) found the soil Hg content in and around the three landfill sites was 0.130–8.3 mg/kg.

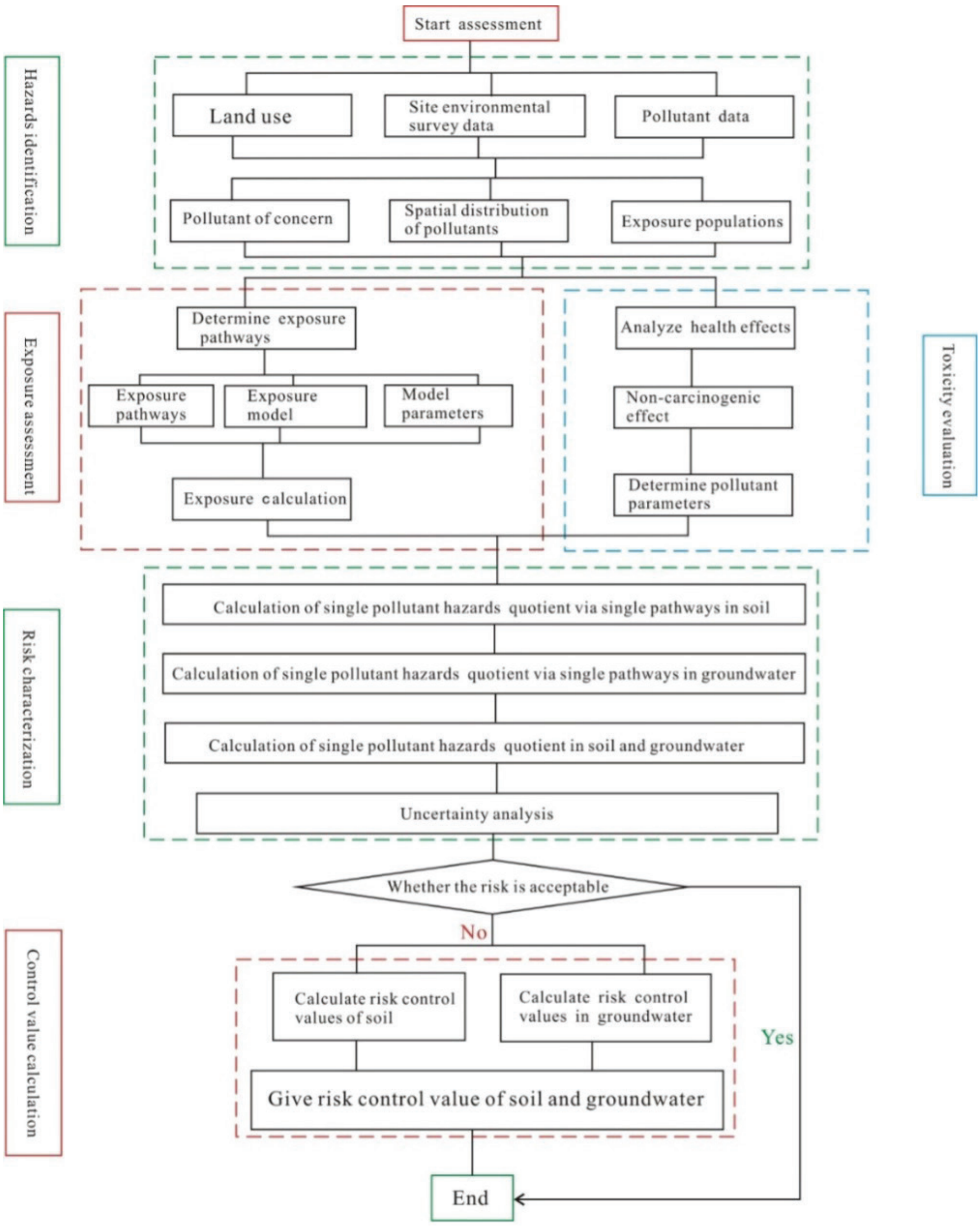
Hg-Containing Products Plant (Fluorescent Lamps, Thermometers, and Batteries)

Hg is widely used in the manufacture of all kinds of fluorescent lamps (including other energy-saving lamps), thermometers, blood pressure meters, and batteries, among other products. Statistics show that in 2013, China's fluorescent lamp output reached as high as 4.4 billion lamps. Due to the low boiling point of Hg, it can be volatile at room temperature, and when discarded, the broken tubes of energy-saving lamps can emit Hg into air that could cause the ambient Hg concentration to be elevated by a hundred times in a short period of time. Over the long term, Hg from the fluorescent and energy-saving lamp production process seriously polluted the production environment and the area surrounding the plant.

2.2 Contaminated Site Risk Assessment

Health-related and environmental risk assessments are essential steps in determining the populations (human and biota) that are at risk from contamination and will be the foundation for making a remediation plan. In this report, the assessment process covers five parts: hazard identification, exposure evaluation, toxicity evaluation, risk characterization, and calculation of remediation target values. The assessment will be conducted following the requirements of the *Technical Guidelines for Risk Assessment of Contaminated Sites* (MEE, 2019b). Figure 1 shows the technical flow chart of risk assessment from this source.

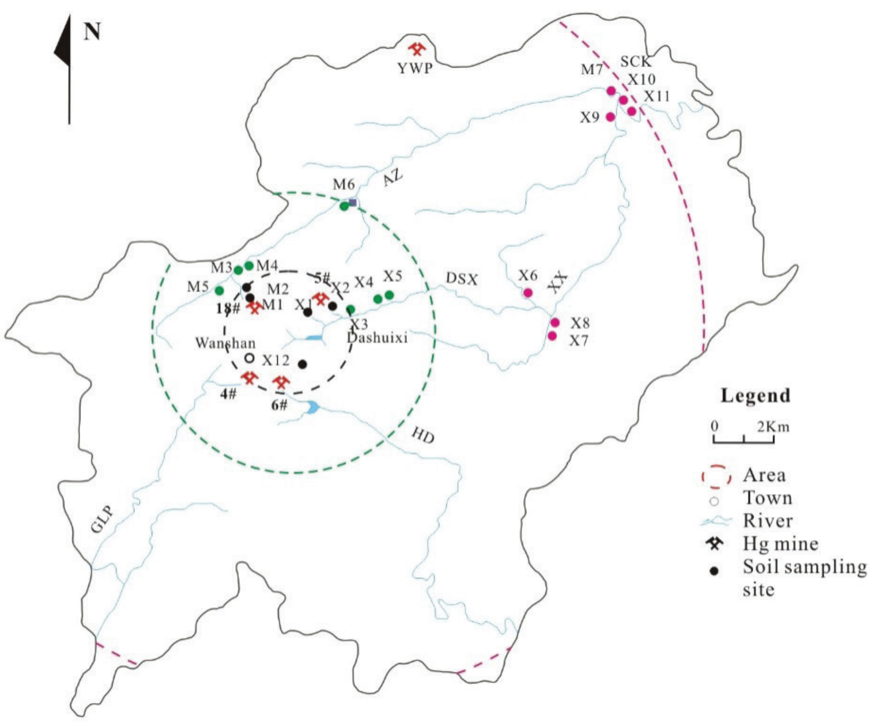
Figure 1. Technical flow chart of contaminated sites' risk assessment



2.2.1 Hazard Identification

Hazard identification refers to the process of determining the presence of pollutants of concern at the sites, the spatial distribution of pollutants, and possible sensitive receptors. In this guidebook, the Wanshan Hg-mining area (WMMA) is selected as the case study area, and the following steps will use the data from Wanshan to illustrate how to conduct a comprehensive risk assessment. Wanshan is located in Tongren City, in the eastern part of Guizhou Province. Wanshan Hg mine is the largest Hg mine in China; the area it covers is 45 km^2, and large-scale Hg-mining and smelting activities went on there for more than 630 years, until the mine was closed in 2002. In this area, the main pollution pathways are drainage water from tailings, retort calcines, and Hg-polluted ambient air. The main Hg-mining and smelting sites—Yikeng, Sikeng, Wukeng, Liukeng, and Shibakeng—are distributed around Wanshan Township within the circle marked with black dashes in Figure 2. The rivers that drain the mine tailings once carried Hg-rich sediments to downstream areas (in the circle outlined in green dashes and the area marked with the red dashed line). The study area has widely distributed rice paddy fields. The crops are corn and rice. Residents usually drink tap water; only a few people drink well water. The main pollutants of concern are Hg and its compounds. The study area is approximately divided into three distance gradients, including WMMA (0–1 km from the mine tailings), Baiguoshu (2–3 km from the mine tailings), and Shengchongkou (7–8 km from the mine tailings). Figure 2 shows the distance gradients and the distribution of sampling points, and Table 3 shows the Hg concentrations found in the study area.

Figure 2. Distance gradients and the distribution of soil sampling points in WMMA



Source: Sino-Norwegian Cooperation Project on Reducing Hg Pollution Phase 3, 2016. (Black circle: WMMA; green circle: Baiguoshu; red line: Shengchongkou; green dots: sampling locations within a 2–3 km radius, red dots: sampling locations within a 7–8 km radius)

Table 3. Hg concentration in WMMA

Sites	Gradients km	Hg in Soil		Air ng/m³	Hg in Rice	
		THg mg/kg	MeHg ng/g		THg ng/g	MeHg ng/g
WSZ	0–1	7.6–790 (109.33)	0.17–4 (1.93)	110	110	4.5
BGS	2–3	1.1–270 (92.7)	0.13–15 (3.70)	110	110	4.5
SCK	7-8	0.1–89 (15.45)	0.1–1.5 (0.52)	110	110	4.5

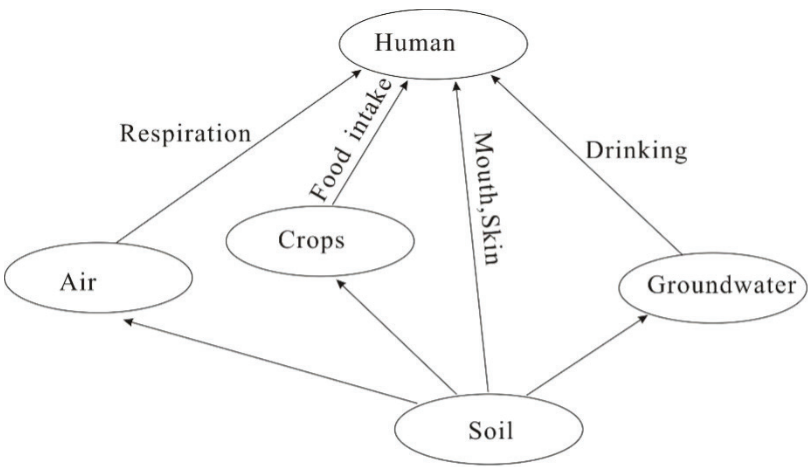
Source: Sino-Norwegian Cooperation Project on Reducing Hg Pollution Phase 3, 2016.

2.2.2 Exposure Assessment

Exposure assessment consists of several steps: identify the hazard; analyze the scene where soil pollutants are likely to be and where they might endanger sensitive receptors; determine exposure pathways of soil pollutants to sensitive populations; determine the migration model and sensitive population exposure model of pollutants in the environmental medium; determine model parameter values related to pollution status, soil properties, groundwater characteristics, sensitive populations, and types of harm of target pollutants (e.g. IQ loss, defects in growth or motor skills); and calculate the exposure of soil and groundwater to contaminants that sensitive populations might take in. At this last stage, the main activities are analyzing exposure scenarios, determining exposure pathways, and calculating soil and groundwater exposure.

According to the technical guidelines (MEE, 2019b), the population in WMMA can be exposed to pollutants by oral ingestion, such as when they drink the groundwater, and direct skin contact with contaminated soil. See Figure 3.

Figure 3. The conceptual model of the exposure pathways of contaminated sites



Source: Sino-Norwegian Cooperation Project on Reducing Hg Pollution, Phase 3, 2016.

2.2.3 Toxicity Assessment

Toxicity assessment refers to analyzing the hazardous effects (including carcinogenic and non-carcinogenic effects) posed to human health and determining the toxicity parameters (including the reference dose, reference concentration, carcinogenic slope factor, and unit carcinogenic factor) of pollutants of concern.

Hg is regarded as a non-carcinogen substance; the related toxicity parameters, including respiratory inhalation reference concentration (*RfC*), respiratory inhalation reference dose (*RfDi*), oral intake reference dose (*RfDo*), and skin contact reference dose (*RfDd*) in Table 4 were quoted from the technical guidelines (MEE, 2019b).

Table 4. Toxicity parameters of Hg (non-carcinogenic effects)

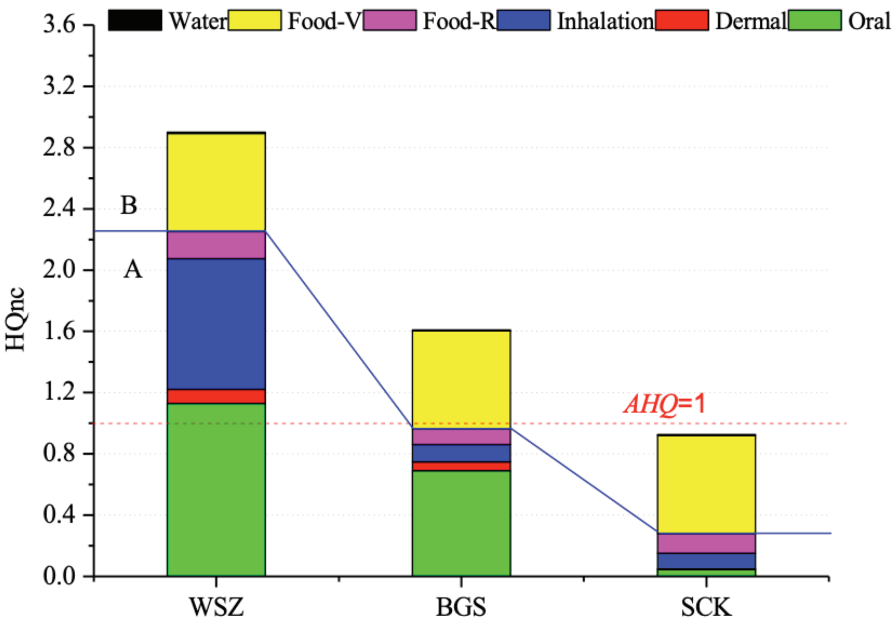
Oral intake reference dose *RfDo*	**Respiratory inhalation reference dose** *RfDi*	**Reference dose absorbed by skin contact** *RfDd*	**Respiratory inhalation reference concentration** *RfC*	**Skin contact absorption efficiency factor** *ABSd*	**Gastro-intestinal absorption efficiency factor** *ABSgi*	**Oral ingestion absorption factor** *ABSo*	**Breath absorption factor** *ABSair*
mg kg^{-1} d^{-1}	mg kg^{-1} d^{-1}	mg kg^{-1} d^{-1}	mg m^{-3}				
3.00E-04[a] 1.00E-4[b]	8.57E-05	2.10E-05	3.0E-04	1.00E-03	7.00E-02	0.07[a] 1[b]	0.7

Note: a: inorganic or elemental Hg; b: methyl Hg

2.2.4 Risk Characterization

Risk characterization refers to calculating risk values of contaminants via all exposure pathways. The final hazard quotient results are shown in Figure 4. According to the results, it can be concluded that the risk of exposure to Hg in Wanshan Township (WSZ) is the highest, followed by the Baiguoshu area (BGS) and the Shenchongkou area, shown by the Hg concentration gradient. The non-carcinogenic risk hazard quotients at WSZ and BGS are higher than the acceptable level (AHQ = 1), which indicates that the populations within these areas are at risk. Especially in WSZ, where the Hg mines are concentrated due to the long-term influence of Hg-mining activities, the areas near the mining pits and those downstream of tailing piles experienced significant adverse effects on residents' health.

Figure 4. Non-carcinogenic risk hazard quotient (HQnc) of different exposure pathways in different regions

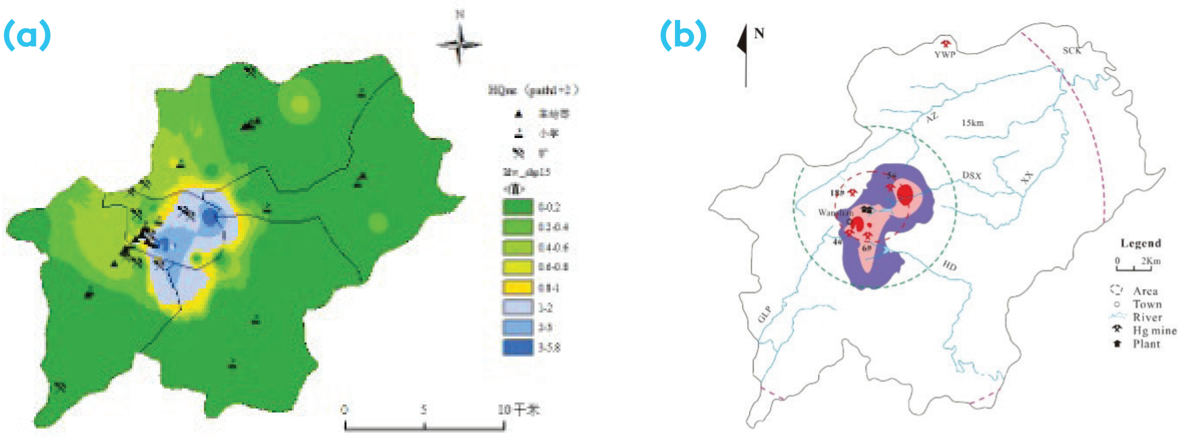


Note: A = actual data; B = estimated data

Source: Sino-Norwegian Cooperation Project on Reducing Hg Pollution, Phase 3, 2016.

According to the results, food and oral intake are the main Hg exposure pathways for all residents in WSZ; furthermore, the inhalation of atmospheric Hg is also significant for residents in WZS (close to mines) where atmospheric Hg concentrations are high.

Figure 5. Classification of contaminated areas in WSZ based on HQnc



Source: Sino-Norwegian Cooperation Project on Reducing Hg Pollution, Phase 3, 2016.

Notes: In b, in the purple area 2 > HQnc > 1; in the pink area 3 > HQnc > 2; and in the red area HQnc > 3.

2.2.5 Calculation of Remediation Target Values

In order to lower the risk related to oral and food intake, measures need to be taken to bring the hazard quotient below 1. The exposure pathways, including oral and food intake, are taken into consideration to back-calculate the remediation target value. The calculated target value in soil is 46 mg/kg.

2.3 Options for Managing the Risks Posed by Contaminated Sites

2.3.1 Risk Management Options

To avoid exposure through oral intake and respiration, local residents should try to stay away from the mines and tailings. Residents should pay attention to the sanitation of their hands, local vegetables, and cooking utensils, and should try to wash them thoroughly to reduce the number of attached soil particles. To reduce exposure through food intake, rice cultivation in seriously contaminated red and pink zones (Figure 5b) should be avoided. For other food sources, low Hg-accumulating vegetables or fruits should be promoted. At the same time, the relocation of the Zhangjiawan Hg chemical industrial park, which used to be a contamination source of Hg, was carried out and completed in 2015. This measure also effectively reduced the adverse health impacts of industrial production activities involving Hg on local residents.

2.3.2 Remediation Measures

For seriously contaminated soil, remediation activities should be carried out. The available soil remediation technologies are explained in more detail in the *Catalogue of Contaminated Site Remediation Technologies (Batch 1)* (Ministry of Environmental Protection [MEP], 2014); much of the information below is taken directly from this source. Table 5 lists most of the soil remediation techniques available.

1. **Stabilization/Solidification**

   Stabilization/solidification involves physically binding or enclosing contaminants within a stabilized mass (solidification) or inducing chemical reactions between the stabilizing agent and the contaminants to reduce their mobility (stabilization). Soil can be treated both in situ and ex situ. The binders, such as Portland cement, sulphur polymer cement, sulphide and phosphate binders, cement kiln dust, polyester resins, polysiloxane, powder reactivated carbon, and thiol-functionalized zeolite, were used to stabilize Hg.

2. **Soil Washing**

   Soil washing refers to ex situ techniques that employ physical and/or chemical procedures to extract metals contaminants from soils. The process includes 1) physical separation; 2) chemical extraction; 3) a combination of both. The main advantage of the technique is that it takes a shorter time for a treatment cycle, and the treated soil can backfill contaminated sites. The process uses diluted acid, thiosulfate, Ethylenediaminetetraacetic acid, iodide, and nitric acid (HNO_3) for extracting Hg from soils.

3. **Thermal Desorption**

   Thermal treatment usually involves the application of heat and reduced pressure to volatilize Hg from the contaminated medium, followed by conversion of the Hg vapours into liquid elemental Hg by condensation. The soil types, organic concentrations, particle size, moisture concentration, amount of Hg in the waste, and operating temperature and pressure are the main factors that can affect the performance and capital cost of the technology. As one might expect, the high-efficiency removals of Hg are obtained with the operating conditions at a relatively high temperature.

4. **Electro Remediation**

   The goal of electrokinetic remediation is to affect the migration of subsurface contaminants in an imposed electric field via electro-osmosis, electro-migration, and/or electrophoresis processes. During electrokinetic soil treatment, hydrogen ions (H^+) are generated at the anode due to water electrolysis and migrate into the bulk of the soil. A low pH develops through the soil (except at the cathode where hydroxide [OH^-] is generated), causing desorption of metallic contaminants from the soil in solid form. The dissolved metallic ions are then removed from the soil solution by ionic migration and precipitation at the cathode.

5. **Vitrification**

   Vitrification is a high-temperature treatment technique designed to fix contaminants by adding them to a vitrified end product with chemical durability and leaching resistance. An array of electrodes that generate electrical currents are inserted vertically into the surface of the contaminated soil. The conductivity of the soil is enhanced by adding a conductive glass material containing graphite. Soils can be treated in situ or ex situ. In situ vitrification is generally used to treat contaminated soil to a depth of 20 feet. Contaminated soil needs to be transferred to a controlled area for ex situ vitrification. For mercury-concentrated sludge, dewatering should be conducted prior to treatment.

6. **Nanotechnology**

   Nanotechnology involves using particles with dimensions in the range of 1–100 nm to affect the mobility, toxicity, and/or bioavailability of contaminants in soils. Nano-sized particles are characterized by a large surface area to volume ratio, which speeds up sorption kinetics.

7. **Phytoremediation**

   In phytoextraction, a plant absorbs Hg in its root system and transfers it to aerial parts through its growth metabolism, and Hg in soil is removed through harvesting the aerial parts of the plant. Generally, Hg mainly bonds to sulphur or organic matter, causing low bioavailability. Based on this information, scientists mix a chemical chelator into the soil to increase Hg bioavailability, thus promoting the absorption of Hg by plants. Currently, chemical chelators used in practice include potassium iodide, ammonium thiosulfate, Ethylenediaminetetraacetic acid, and ammonium thiocyanate

(Moreno, Anderson, Stewart, Robinson, Ghomshei et al., 2005; Moreno, Anderson, Stewart, Robinson, Nomuro et al., 2005; Smolińska & Cedzyńska, 2007; Wang & Greger, 2006). It is not reported that hyper-accumulative plants for Hg exist, thus phytoextraction efficiency is comparatively low.

8. **Landfill**

Landfill technology consists of placing the contaminated soil or after-treated soil in the landfill sites with an anti-seepage and separation device, or blocking the migration and diffusion of contaminants in the soil by laying barrier layers to isolate the contaminated soil from the surrounding environment, in order to avoid the contaminants coming into contact with the human body and migration with precipitation or groundwater, which can have hazardous effects on human health and the ecological environment (MEE, 2019b).

9. **(9) Soil/Biological Air Stripping**

By supplying air or oxygen to the contaminated soil, the degradation of contaminants can be promoted via biodegradation of aerobic microorganisms. At the same time, the pressure gradient in the soil is increased to promote the volatile organic compounds and degradation products flowing to the pumping well, where they can be extracted and removed. The removal rate of contaminants can be enhanced by injecting hot air, a nutrient solution, and exogenous high-efficiency degradation bacteria (MEE, 2019b).

10. **Microbial Remediation**

Microbial soil remediation technology refers to the use of microorganisms in the original soil or the addition of artificial domesticated microorganisms with specific functions into the target contaminated soil in an appropriate environment so that microorganisms can metabolize contaminants and reduce the activity of toxic contaminants or degrade them into non-toxic substances. This technology has many advantages, such as improving the soil quality, having a low cost, and producing little impact on the environment, so it is used most often for the remediation of contaminated soil. According to studies done at different remediation sites, microbial remediation technology can use both in situ and ex situ remediation technology (N.-N. Wu et al., 2020).

11. **Chemical Extraction**

Chemical extraction is a technology that uses extractants to separate or desorb contaminants from soil particles into an extraction solution by chemical and physical methods. The extraction solution interacts with heavy metals in the soil to form soluble heavy-metal ions or heavy-metal reagent complexes. Finally, heavy metals are recovered from the extraction solution and recycled. There are many extractants used to extract heavy metals in soil, which are usually divided into three types: a chelating agent; acid, alkali, and salt; a surfactant (Ding et al., 2018).

12. Low-Temperature Thermal Desorption

Low-temperature pyrolysis technology is a remediation method that uses physical heating to remove contaminants from soil. At room temperature, the boiling point of Hg is 356.73°C, the melting point is -38.87°C, and the vaporization heat is 13.905 kcal/mol. Therefore, Hg in soil can be evaporated by heating. In theory, the required temperature for Hg removal from soil is about 600°C. When there is no mercury oxide (HgO), the theoretical temperature can be much lower. Compared with high-temperature pyrolysis, the physical and chemical properties and natural fertility of the soil treated by low-temperature pyrolysis are less damaged, so it can be used to backfill and restore agricultural production. Especially for the seriously Hg-contaminated soil, such as soil with a high content of volatile Hg compounds (elemental Hg or methyl Hg), the remediation effectiveness is significant (Lai, 2015).

13. Chemical Oxidation/Reduction

By injecting oxidants or reductants into the soil- or groundwater-contaminated area, the contaminants in soil or groundwater can be transformed into non-toxic or relatively less-toxic substances through oxidation or reduction reaction. Common oxidants include permanganate, hydrogen peroxide, Fenton reagent, persulfate, and ozone. Common reductants include hydrogen sulphide, sodium dithionite, sodium bisulphite, ferrous sulphate, calcium polysulfide, ferrous iron, and zero-valent iron, among others (MEE, 2019b).

14. Cement Kiln Co-processing Technology

The characteristics featured in this process include high temperatures, the long residence time of gas, a large thermal capacity, great thermal stability, an alkaline environment, and no waste residue discharge in the cement rotary kiln; the contaminated soil is incinerated and solidified while producing a cement clinker (MEE, 2019b).

15. Soil Replacement Method

According to Shi et al. (2018), the soil replacement method consists of replacing contaminated soil with new, clean soil, which dilutes the concentration of toxins and thereby reduces the levels of pollutants. One advantage of this method is that it takes place over a comparatively short time. However, the polluted soil that has been removed still has to be treated, so the process involves other remediation methods, as well. Further, a careful disposal plan is needed for the transferred contaminated soil, to prevent secondary pollution to the environment (Fu et al., 2012).

16. Cement Solidification and Stabilization Technology

In this method, the contaminated soil is mixed with cement and other cementing materials. Through physical and chemical methods, the leaching characteristics of contaminants can be reduced in order to meet the corresponding environmental requirements (Zhai et al., 2014).

Table 5. Comparison of remediation techniques

*Assuming that the density of soil is 1.8 t/m3, the cost is calculated after conversion.

Methods	Properties	Description	Cost	In situ/ ex situ	Advantages and disadvantages
Stabilization/ encapsulation	Physical/ chemical	This technique involves physically binding or containing contaminants within a stabilized mass (encapsulation) or inducing chemical reactions between the stabilizing agent and the contaminants to reduce their mobility (stabilization).	The cost of in situ encapsulation / stabilization technology is about USD 50–80/m^3 for shallow contaminated sites and USD 195–330/m^3 for deep contaminated sites; for ex situ solidification/ stabilization technology, the cost is about USD 160–245/m^3 for small sites and USD 90–190/m^3 for large sites (H. Wang, 2019).	In situ/ ex situ	Advantages: 1) it can treat multiple heavy metals wastes; 2) low cost; 3) facilities can be easily transported; 4) the formed and stabilized materials are stable and less toxic; 5) the microorganism has difficulty growing in coagulated material. Disadvantages: 1) the metals are not removed from contaminated media; 2) questionable longevity of the solidified/stabilized materials; 3) the need for future monitoring of heavy metals on site.

Methods	Properties	Description	Cost	In situ/ ex situ	Advantages and disadvantages
Soil washing	Physical/ chemical	Soil washing refers to ex situ techniques that employ physical and/ or chemical procedures to extract metals contaminants from soils.	USD 53–420/m^3 (T. Li, 2018).	ex situ	Advantages: (1) the processed soil can be returned to the site; (2) the process duration is typically short to medium term compared to other metal extraction methods. Disadvantages: (1) the vast consumption of water required for making up the washing solution, and of clean water for the removal of the mobilized metallic species that have been retained in the soil after the remedial treatment; (2) the washing solution is rich with metal–chelant complexes and must subsequently be treated before it can be safely discharged.
Thermal desorption	Chemical	Thermal treatment usually involves application of heat and reduced pressure to volatilize Hg from the contaminated medium, followed by conversion of the Hg vapours into liquid elemental Hg by condensation.	The cost is about USD 100–300/m^3 for small and medium-sized sites and USD 50/m^3 for large-scale sites (H. Wang, 2019).	In situ/ ex situ	There are many advantages of this method, such as safety and less emission of the treating substance as compared with other processes. However, the major disadvantages are high energy costs and effectiveness only at rather high Hg concentrations.

Methods	Properties	Description	Cost	In situ/ ex situ	Advantages and disadvantages
Electrolysis	Chemical	The goal of electrokinetic remediation is to affect the migration of subsurface contaminants in an imposed electric field via electro-osmosis, electro-migration, and/or electrophoresis processes.	USD 115–400/m^3 (Athmer, 2009).	In situ/ ex situ	Advantages: 1) low disturbance to the environments; 2) low damage to soil fabric. Disadvantages: 1) the performance of the method is affected by the solubility of pollutants and the desorption of pollutants from a soil colloid, as well as soil physical-chemical properties; 2) the remediation efficiency is affected when the soil moisture concentration exceeds 10%.
Nano-technology	Physical/ chemical	Nanotechnology involves using particles with dimensions in the range of 1–100 nm, to affect the mobility, toxicity, and/or bioavailability of contaminants in soils.	<USD 400/m^3 (United States Environmental Protection Agency, 2008).	In situ	The major advantages of this method are safety, low cost, environmental friendliness, low energy demand, stability, as well as the ability to treat soil on site. However, the effect of nanoparticles on soil microorganisms has yet to be investigated, and the method should be tested in field conditions.
Vitrification	Physical/ chemical	Vitrification is a high-temperature treatment technique designed to fix contaminants by adding them to a vitrified end product with chemical durability and leaching resistance.	USD 650–1,350/m^3 (Beijing University, 2019).	In situ/ ex situ	The major disadvantages of the technology are 1) the remediation efficiency is affected when the gravel content exceeds 10%; 2) the pollutants move to the clean soil when the soil is heated; 3) the exploitation and utilization of soil may be affected by the solidified wastes; 4) if the contaminated soil is below the underground water level, steps should be taken to prevent underground water refill to the sites; 5) the high moisture concentration will influence the cost of the method.

Methods	Properties	Description	Cost	In situ/ ex situ	Advantages and disadvantages
Phytoremediation	Biological	Phytoremediation is a method that utilizes the plant's ability to uptake concentrate contaminants from soil. The pollutants are removed from the contaminated soil by harvesting the aboveground tissues.	<USD 11.1/m^3 (CHYXX, 2014) .	In situ	The major advantages of this method are safety, low cost, environmental friendliness, and ease of operation, as well as the ability to spread in a large area. However, the major disadvantages are low accumulation efficiency of Hg by plants, long times needed for remediation, and the residuals of the plants needing to be treated.
Landfill	Physical	Landfill uses the contaminated soil or the after-treatment soil in the anti-seepage landfill sites, which are lined with a high-density polyethylene membrane and other anti-seepage materials. Although this technology cannot reduce the toxicity and volume of contaminants in soil, it can reduce the exposure and migration of contaminants on the surface and underground (L. L. Wu, et al., 2017).	The treatment cost in China is CNY 300–800/m^3 (MEE, 2014b).	In situ/ ex situ	Advantages: It is suitable for heavy-metal contamination, organic contamination, a combination of these two, and other types of soil contamination (MEE, 2014b). The treatment cycle is comparatively short, and it can be a more economical treatment method. The landfill surface can support vegetation or be used for other purposes. Disadvantages: it is not suitable for contaminated soil with strong water solubility or a high permeability of contaminants, and it is also not suitable for areas with frequent geologic activity and high groundwater levels (CHYXX, 2014; T. Li, 2018).

Methods	Properties	Description	Cost	In situ/ ex situ	Advantages and disadvantages
Soil/biological air stripping	Biological	Soil/biological air stripping refers to promoting the growth of indigenous or exogenous microorganisms that can degrade target contaminants in the soil by supplying air, oxygen, and nutrient solution to the soil, so that the contaminants in the soil can be degraded into non-toxic or less-toxic substances (B.Liu et al., 2012; H. Wang, 2019).	The price of in situ remediation technology is USD 13–27/m^3; The price of ex situ remediation technology is USD 130–260/m^3 (H. Wang, 2019).	In situ/ ex situ	Advantages: soil/biological air stripping technology is a very popular remediation method in many countries outside of China. It improves the degradation rate of contaminants by enhancing the aerobic metabolism of microorganisms. This technology is economical and efficient and causes little secondary pollution. Disadvantages: The remediation process is limited by soil structure and indigenous microorganism species, and the operation time is relatively longer than other soil remediation technologies. (Duan et al., 2004; B. Liu et al., 2012).
Microbial remediation	Biological	Microbial remediation is mainly used with indigenous microorganisms or alien microorganisms with higher degradation efficiency and relatively strong resistance to contaminants in order to restore contaminated soil (Chen & Lu, 2019).	USD 27.8-77.8/m^3 (CHYXX, 2014).	In situ/ ex situ	Advantages: compared with traditional treatment technologies, microbial remediation has the advantages of convenient implementation, low cost, and high transferability. It also causes less damage to the environment. Disadvantages: 1) it is not suitable for the remediation of high-concentration contaminants; 2) the microorganism is too small to be separated from the soil; 3) the residual heavy metal after remediation is difficult to reuse; 4) some microbial remediation technologies are still under laboratory research, and the overall system and practical theory are not complete, thus the problems may not be solved when dealing with special situations and difficulties (Chen & Lu, 2019).

Methods	Properties	Description	Cost	In situ/ ex situ	Advantages and disadvantages
Chemical extraction	Chemical	Chemical extraction uses an aqueous solution of chemical extractant to separate and remove heavy metals contaminants from soil particles (Zhao & Zhu, 2011).	USD 36.1–166.7/m^3 (CHYXX, 2014).	In situ/ ex situ	In situ extraction technology refers to the removal of heavy metals in contaminated soil by means of in situ infusion of an extraction solution and recovering the filtrate. It has the advantages of convenient operation and low cost; however, the technology is low in efficiency, and it may cause pollution in the groundwater (Zhao & Zhu, 2011). Ex situ extraction technology consists of digging out the contaminated soil and then using the soil column cleaning process to remove heavy metals in the soil. The advantage is that it can effectively avoid the pollution of groundwater; the disadvantages are that it is inefficient and uneconomical (Zhao & Zhu, 2011).
Low-temperature thermal desorption	Physical	Low-temperature thermal desorption means that the contaminated soil is retorted at 300–600°C to separate the contaminants from the soil. It is mainly used to treat volatile organic pollutants and has also been used to deal with Hg-contaminated soil in recent years (Qiu et al., 2006).	<USD 83.3/m^3 (CHYXX, 2014).	ex situ	Hg can be quickly and efficiently separated from the soil, and it is regarded as one of the effective methods for the remediation of high-concentration Hg-contaminated soil (Yu et al., 2017); however, this technology destroys the organic matter and water in the soil and can require higher power consumption (CHYXX, 2014).

Methods	Properties	Description	Cost	In situ/ ex situ	Advantages and disadvantages
Chemical oxidation/ reduction	Chemical	Chemical oxidation/ reduction technology means oxidants (Fenton reagent, hydrogen peroxide, and so on) or reductant (sulphur dioxide, zero-valent iron, and so on) are added to the contaminated soil via oxidation or a reduction reaction; through this process, the toxicity of contaminants can be reduced, and some of them may be transformed into non-toxic substances (H. Wang, 2019).	The cost of in situ chemical oxidation/ reduction technology abroad is about USD 123/m^3; the cost of ex situ chemical oxidation/reduction technology is between CNY 500–1,500/m^3 in China and USD 200–660 /m^3 in some other countries (H. Wang, 2019).	In situ/ ex situ	The technology has a good treatment effect on chemicals in the benzene series, polycyclic aromatic hydrocarbons, organic pesticides, and other organic contaminants in contaminated soil. However, it is not suitable for the remediation of heavy metal-contaminated soil. It is generally applied in the remediation of combined soil and groundwater contaminated by organic contaminants at the same time (H. Wang, 2019).
Cement kiln co-processing technology	Physical/ chemical	Cement kiln co-processing refers to the process of putting the contaminated soil that meets the requirements of kiln entry into the cement rotary kiln and incinerating the contaminated soil while producing a cement clinker. The heavy metals are fixed in the produced cement clinker (H. Wang, 2019).	The cost is CNY 800–1,000/m^3 in China (MEE, 2019b).	ex situ	This technology can deal with organic pollutants and heavy metals (cadmium, chromium, manganese, nickel, lead, zinc) in the soil (L. Liu et al., 2021; MEE, 2019b). It is not suitable for soil with serious heavy-metal contamination such as Hg, arsenic, and lead. Due to the specific content requirements of chlorine, sulphur, and other elements in the process of cement production, the amount of contaminated soil should be determined carefully when using this technology (MEE, 2019b).

Methods	Properties	Description	Cost	In situ/ ex situ	Advantages and disadvantages
Soil replacement	Physical	Soil replacement involves replacing the contaminated soil with non-contaminated soil; mixing the two kinds of soil to reduce the concentration of heavy metals; or removing the upper surface of soil contaminated by heavy metals, and then replacing it with the same amount of soil that is not contaminated by heavy metals (Yan et al., 2019).	USD 11.1–27.8/m^3 (CHYXX, 2014).	In situ	This technology has a stable advantage in the treatment of heavy-metal pollution. However, the demand for manpower and material resources is significant, the investment cost is high, and it may damage the land structure, which may not be suitable for the treatment of large-scale polluted soil. Moreover, the content of heavy metals in the removed soil is often still high. If it is not treated properly, the heavy metals will still be in the soil. Therefore, this technology cannot be widely used (Yan et al., 2019).
Cement solidification stability technology	Physical/ chemical	Cement solidification stability technology has been widely used in contaminated site treatment due to its advantages of relatively low cost, convenient construction, and the high strength of treated foundation soil (Zhai et al., 2014).	CNY 2,976/m^3 (Chao, 2014).	In situ/ ex situ	Cement technology is relatively well established, and the cement solidification process is easy to operate. Cement materials are compatible with a variety of wastes; therefore, it can deal with a wide range of chemical components and can make most of the waste created in the liquid phase react with the cement; the formed cement solid has long-term chemical and physical stability, relatively good mechanical and structural characteristics, and relatively low permeability; it also has high resistance to ultraviolet radiation and biodegradation; it has a great self-shielding effect on nuclear waste; and the cost of cement material is relatively low (Zhai et al., 2014).

3.0 Governance Structure of Soil Remediation Projects in China

3.1 Soil Remediation Governance Structure and Stakeholder Analysis

As outlined above and in general terms, the oversight of soil protection and remediation lies with local governing authorities (T. Li et al., 2019; X. Wang, 2021). In circumstances where it is possible to identify the entity which has caused soil contamination, this entity bears the responsibility of restoring the identified soil pollution hazards. In situations where it is not possible to clearly identify this entity, the responsibility of remediating the soil rests on the land-use right holder. In addition, the state has decided to establish a special fund, drawing on both provincial-level and central-level funds, allocating resources to manage various aspects pertaining to both the prevention and remediation of soil pollution. Such funding will, in most cases, be allocated for utilization for the prevention of pollution on agricultural land and for the management and remediation in cases where the responsible party (for causing the pollution) cannot be identified (T. Li et al., 2019; X. Wang, 2021).

However, depending on the type of soil remediation task, different stakeholders will be involved to varying degrees. In Table 6 we outline the stakeholders who might be involved, their type of involvement, and which regulatory framework facilitates their involvement in soil remediation processes.

Table 6. Analysis of stakeholders and soil remediation projects in China

Stakeholder	Role	Relevant regulatory framework
Local government	Overarching responsibility and oversight of other government agencies involved in soil pollution prevention and mitigation processes.	**Law of the People's Republic of China on Prevention and Control of Soil Contamination** (LPCSC) (2018) 1. Local people's governments at all levels shall be responsible for the prevention and control of soil contamination and the safe utilization of soil within their respective administrative areas. The State implements a target-oriented responsibility and performance evaluation system for the prevention and control of soil contamination. The achievement of targets for preventing and controlling soil contamination will be included in the performance evaluation of the local people's governments at all levels and the persons in charge thereof, and the departments responsible for supervision and administration of soil contamination prevention and control and the persons in charge thereof in the people's governments at or above the county level (Article 5, 2018). 2. The people's governments at all levels shall strengthen their leadership over the work in preventing and controlling soil contamination, and organize, coordinate with and urge the relevant departments to perform, according to law, their duties of supervising and administering soil contamination prevention and control (Article 6, 2018).

Stakeholder	Role	Relevant regulatory framework
		3. The competent department of ecology and environment under the State Council shall, based on the soil contamination status, public health risks, ecological risks, and scientific and technological capacity, formulate national standards of risk control for soil contamination according to different land-use purposes, and enhance the efforts in establishing a system of soil contamination prevention and control standards. The people's governments at the provincial level may formulate local standards of risk control for soil contamination for items that are not specified in the national standards of risk control for soil contamination. As to the items that have national standards of risk control for soil contamination, stricter local standards of risk control for soil contamination may be formulated. The local standards of risk control for soil contamination shall be submitted to the competent department of ecology and environment under the State Council for the record. The standards of risk control for soil contamination shall be mandatory. The State supports research on the background concentrations in soil and environmental quality benchmarks (Article 12, 2018). 4. The State Council exercises unified leadership over the national survey on soil contamination. The competent department of ecology and environment under the State Council shall, together with the departments of agriculture and rural affairs, natural resources, housing and urban-rural development, and forestry and grassland and other departments under the State Council, organize a national survey on soil contamination at least every ten years. The relevant departments under the State Council and the local people's governments at or above the level of city divided into districts may organize and conduct detailed surveys on soil contamination according to the actual situation of their respective sectors and administrative areas (Article 14, 2018).

Stakeholder	Role	Relevant regulatory framework
Local ecological environment bureau	Detailed supervision and management of soil pollution and prevention. Whole-process supervision, including of any soil pollution status investigation and soil pollution risk assessment, risk control, remediation, effectiveness assessment of risk control, effectiveness assessment of remediation, and late management.	**LPCSC** 1. With respect to the agricultural land plots whose soil is at the risk of contamination as indicated by the general survey, detailed survey, monitoring or on-site inspection, the departments of agriculture and rural affairs, forestry and grassland under the local people's governments shall, together with the competent departments of ecology and environment and natural resources, investigate the soil contamination. With respect to the agricultural land plots in which the contaminants exceed the limits of the risk control standards for soil contamination as indicated by the soil contamination investigation, the departments of agriculture and rural affairs, forestry and grassland under the local people's governments shall, together with the competent departments of ecology and environment and natural resources, organize the risk assessment of soil contamination, and manage such plots according to the category-based administration system for agricultural land (Article 52, 2018). 2. With respect to the agricultural land plots under strict control, the departments of agriculture and rural affairs, forestry and grassland under the local people's governments shall take the following measures for risk control: (1) putting forward a proposal for the delineation of the areas where the production of specific agricultural products is prohibited, and submitting it for approval to the people's government at the same level before implementation; (2) conducting synergistic monitoring and evaluation on soil and agricultural products according to relevant regulations; (3) providing technical guidance and training for farmers, specialized farmers cooperatives and other agricultural producers and business operators; and (4) other risk control measures. The people's governments at all levels and their relevant departments shall encourage the adoption of risk control measures for agricultural land under strict control, such as adjusting the plantation structure, returning farmland to forests and grassland, returning farmland to wetland, crop rotation and fallow period, pasture rotation and fallow period, etc., and provide corresponding policy support (Article 54, 2018). 3. Where the soil contamination in the agricultural land plots under safe utilization or strict control impacts or may impact the safety of groundwater and drinking water sources, the competent departments of ecology and environment under the local people's governments shall, together with the departments of agriculture and rural affairs, forestry and grassland, formulate plans for prevention and control of soil contamination, and take corresponding measures (Article 55, 2018).

Stakeholder	Role	Relevant regulatory framework
Enterprise (polluter)	Initiation of soil remediation and management and prevention of future soil contamination (final-period management) and payment of soil remediation costs.	**LPCSC** 1. The person liable for soil contamination is obligated to carry out risk control and remediation of soil contamination. Where the person liable for soil contamination cannot be identified, the land use right holder shall carry out risk control and remediation of soil contamination. The local people's governments and their relevant departments may, in light of the actual circumstances, organize soil contamination risk control and remediation. The State encourages and supports the relevant parties to voluntarily carry out risk control and remediation of soil contamination (Article 45, 2018). 2. An assessment report on the effects of risk control and remediation shall be prepared after the assessments are carried out. The effect assessment report shall mainly include whether the targets for risk control and remediation defined in the risk assessment report have been met. Upon completion of the risk control and remediation activities, if ex-post management is deemed necessary, it shall be carried out by the person liable for soil contamination according to relevant requirements (Article 42, 2018). Measures for the Management of Soil Environment of Industrial and Mining Land (for Trial Implementation) (MEE, 2018a) (1) Industrial and mining enterprises are the main body responsible for the environmental protection of soil and groundwater in industrial and mining land and shall carry out relevant activities in accordance with the provisions of these Measures. Enterprises that cause soil and groundwater pollution in industrial and mining lands shall bear the main responsibility for treatment and restoration (Article 6, n.d.). (2) The land used by key units for new, renovated, and expanded projects shall meet the national or local standards for soil pollution risk management and control of construction land. If key units have investigated the current status of the soil and groundwater environment of new, renovated, and expanded projects and found that the pollutant content of the project land exceeds the national or local soil pollution risk control standards for construction land, the land-use right holder or the person responsible for pollution should refer to the contaminated land. Conduct detailed investigations, risk assessment, risk management and control, governance and restoration and other activities related to soil environmental management regulations (Article 8, n.d.). Measures for Environmental Management of Contaminated Lands (for Trial Implementation) (MEP, 2016) Under the principle of "whoever pollutes the environment shall eliminate and control the pollution," an entity or individual causing soil pollution shall assume the primary responsibility for the treatment and recovery.

Stakeholder	Role	Relevant regulatory framework
		Where the primary responsible party changes, the entity or individual inheriting its creditor's rights and debts after the change shall assume the relevant liability. Where a primary responsible party is extinguished or unspecific, the people's government of the county where it is located shall assume relevant liability according to the law. Where the right to use the land is transferred according to the law, the transferee of the right to use the land or the responsible person agreed by both parties shall assume relevant liability. Where the right to use the land is terminated, the original holder of the right to use the land shall assume relevant liability for the soil pollution caused during the period of using the land parcel. The lifelong responsibility system shall be implemented for the treatment and recovery of soil pollution (Article 10, 2016).
Soil remediation company	Initiation of the soil remediation process by signing a contract with either the local government or enterprise (causing the contamination) to implement the soil remediation project.	**LPCSC** The soil remediation company will engage in a soil pollution condition investigation and soil pollution risk assessment, risk control, repair, a repair-effectiveness evaluation, a risk-control effectiveness evaluation, and the late management activities of the unit, and it shall be equipped with the appropriate professional ability. The company will be entrusted to engage in the activities of the preceding paragraph of the unit for the survey report issued, risk assessment, risk-control effectiveness evaluation report; the company is responsible for the repair-effectiveness assessment report's truthfulness, accuracy, integrity, and remaining in accordance with the contract for the risk control, repair, and the late management activity, and is responsible for the results (Article 43, 2018). Professional institutions entrusted to engage in activities related to suspected contaminated land parcels or contaminated land parcels, or third-party institutions entrusted to assess the effectiveness of treatment and restoration, shall abide by relevant environmental standards and technical norms, and shall be responsible for the authenticity, accuracy, and completeness of the investigation reports and assessment reports of related activities. Professional institutions entrusted to engage in risk control, management, and repair shall abide by the relevant national environmental standards and technical norms and shall bear corresponding responsibilities for the effectiveness of risk control, management, and repair in accordance with the provisions of the commission contract. Professional institutions entrusted to engage in risk management and control, treatment, and rehabilitation shall, in addition to accepting punishment in accordance with relevant laws and regulations, bear joint liability with other persons responsible for environmental pollution and ecological damage who resort to fraud in risk management and control, treatment, and rehabilitation activities (Article 11, 2018).

Stakeholder	Role	Relevant regulatory framework
Real estate developer (developer)	Development of building projects (construction projects cannot be done if the land is not remediated/ does not reach the relevant standards).	**LPCSC** 1. With respect to the construction land plots that have achieved the targets for risk control and remediation as defined in the risk assessment reports on soil contamination, the person liable for soil contamination or the land use right holders may apply to the competent departments of ecology and environment under the people's governments at the provincial level to remove such plots from the catalogue of construction land under risk control and remediation of soil contamination. The competent departments of ecology and environment under the people's governments at the provincial level shall, together with the natural resources and other departments at the same level, organize reviews of the risk control effect assessment report and the remediation effect assessment report, timely remove the land plots that achieve the targets for risk control and remediation as defined in the risk assessment report and are available for safe utilization from the catalogue of land for construction under risk control and remediation of soil contamination, publicize the information according to relevant regulations, and regularly report such information to the competent department of ecology and environment under the State Council. Land plots that fail to achieve the risk control and remediation targets as defined in the soil contamination risk assessment report are prohibited from any construction project other than risk control and remediation (Article 66, 2018). 2. Prior to the change of land use or the taking back or transfer of the land use right of the production and operation land of an organization under priority supervision for soil contamination, the land use right holders shall carry out the investigation on the soil contamination status according to the regulations. Such investigation report shall be delivered to the real estate registration agencies under the local people's governments as part of the real estate registration materials and be submitted to the competent departments of ecology and environment under the local people's governments for the record (Article 67, 2018).

Stakeholder	Role	Relevant regulatory framework
Residents/ household owners	Potential victims of soil contamination can participate in soil pollution control and apply for compensation from polluting enterprises. They have a right to get information about remediation (public access).	**LPCSC** 1. The prevention and control of soil contamination should adhere to the principles of prevention first, prioritizing protection, administration based on classification, putting risks under control, ensuring accountability, and public participation (Article 3, 2018). 2. All organizations and individuals have the obligation to protect soil and prevent soil contamination. Land use right holders who engage in land development and utilization, and enterprises, public institutions and other producers and business operators which engage in the production and operation shall take effective measures to prevent and reduce soil contamination, and assume responsibility in accordance with law for any soil contamination resulted from their activity (Article 4, 2018). 3. Where national or public interests are damaged by soil contamination, the relevant authorities and organizations may file a lawsuit with a people's court according to the provisions of the *Environmental Protection Law of the People's Republic of China, the Civil Procedure Law of the People's Republic of China, the Administrative Procedure Law of the People's Republic of China* and other laws (Article 97, 2018). **Measures for Environmental Management of Contaminated Lands (for Trial Implementation)** (MEP, 2016) 1. **[Public Reporting]** Any unit or individual has the right to report to the competent environmental protection department the conduct of not carrying out activities related to suspected contaminated land plots and contaminated land plots in accordance with the provisions of these Measures (Article 7, 2016). 2. **[Risk Assessment]** The land-use right holder shall, in accordance with the relevant national environmental standards and technical specifications, carry out a risk assessment on the basis of a detailed investigation of the soil environment of the contaminated plot, compile a risk assessment report, and upload the contaminated plot information system in a timely manner. The main content of the evaluation report will be disclosed to the public through its website and other means that are easy for the public to know. The risk assessment report should include the basic information of the plot, the pollutants that should be paid attention to, the main exposure routes, risk levels, risk management and control, and governance and restoration suggestions (Article 17, 2016).

Stakeholder	Role	Relevant regulatory framework
NGOs	Supervision pertaining to information gathering and monitoring, potentially filing an environmental public-interest lawsuit.	**LPCSC** 1. The prevention and control of soil contamination should adhere to the principles of prevention first, prioritizing protection, administration based on classification, putting risks under control, ensuring accountability, and public participation (Article 3, 2018). 2. All organizations and individuals have the obligation to protect soil and prevent soil contamination. Land use right holders who engage in land development and utilization, and enterprises, public institutions and other producers and business operators which engage in the production and operation shall take effective measures to prevent and reduce soil contamination, and assume responsibility in accordance with law for any soil contamination resulted from their activity (Article 4, 2018). 3. Where national or public interests are damaged by soil contamination, the relevant authorities and organizations may file a lawsuit with a people's court according to the provisions of the *Environmental Protection Law of the People's Republic of China, the Civil Procedure Law of the People's Republic of China, the Administrative Procedure Law of the People's Republic of China* and other laws (Article 97, 2018). **Environmental Protection Law of the People's Republic of China** (2014) For an act polluting environment or causing ecological damage in violation of public interest, a social organization that satisfies the following conditions may institute an action in a people's court: (1) It has been legally registered with the civil affairs department of the people's government at or above the level of a districted city. (2) It has specially engaged in environmental protection for the public good for five consecutive years or more without any recorded violation of law. • A people's court shall, according to the law, accept an action instituted by a social organization that satisfies the provision of the preceding paragraph. • A social organization may not seek any economic benefit from an action instituted by it. (Article 58, 2014) Measures for Environmental Management of Contaminated Lands (for Trial Implementation) (MEP, 2016) (3) **[Environmental Public Interest Litigation]** The competent environmental protection department encourages and supports social organizations to file environmental public-interest lawsuits in accordance with the law for acts that cause soil pollution and damage social and public interests (Article 8, 2016).

Note: All text cited is quoted directly from the translated sources.

3.2 Soil Remediation Decision Making and Implementation

3.2.1 Soil Remediation Decision Making

In order to limit excessive remediation and as a means to re-establish the goals of soil management, the Chinese state has, through relevant legal frameworks, shifted the focus from remediation to management, with the ambition to prevent pollution from occurring in the first place, reducing the need for remediation in the long term. The pertinent risk management framework draws inspiration from a myriad of relevant regulatory framework and risk management approaches in the public health and environmental and ecological quality sectors (T. Li et al., 2019).

The soil remediation process will differ somewhat based on the category and sub-category of land as outlined in the previous sections; however, the general procedure tends to follow the same steps as outlined below and is based on a number of basic principles:

- **Polluter-pays principle:** Polluters should bear the cost of assessment and remediation (Article 47, MEE, 2019b).
- **Precautionary principle in the soil remediation implementation process:** Several relevant legal frameworks state that no new harm to the environment and the soil should be brought during the remediation process. When it comes to the disposal of effluent waste, gas, and solid waste, for instance, measures should be taken to ensure that such waste does not cause new harm (Article 40, MEE, 2019b).
- **Transfer of contaminated soil:** A special plan for the transfer of contaminated soil should be developed and implemented. In some cases, when the contaminated soil is considered to be hazardous, special procedures are put in place to prevent additional pollution in the transportation phase (Article 41, MEE, 2019b).
- **Soil remediation also includes underground water:** Pollution control for underground water should be included in the remediation plan (Article 57, MEE, 2019b).

1. **Step 1: Soil remediation project preparatory work**

   The first step in the soil remediation project preparatory work is to conduct a survey of the condition of the soil and to carry out a risk assessment. If the content of pollutant exceeds the standard as defined in relevant risk-control and management frameworks, information about the type and source of the pollutant(s) as well as information about whether or not the groundwater on the land is also contaminated (and if so, by which contaminants and the level of those) should be included in the study report (Article 36, LPCSC, 2018). The result of this survey will determine whether or not a remediation project should be initiated.

   Which entity should be given the task of conducting the aforementioned survey is not directly stipulated in the legal text. However, according to the *Guidelines for the Evaluation of Construction Land Soil Pollution Status Investigation, Risk Assessment, Risk Management and Remediation Effect Assessment Reports* (MEE & Ministry of Natural Resources of the People's Republic of China, 2019), the person with the land-use right should carry out the survey, while the environmental departments of the government are responsible for reviewing and approving the survey report (Article 2, 4). For contaminated lands, the requirements are more specific. For this category of land, a two-step procedure is outlined, namely a preliminary survey and a detailed survey (Article 13, 16, MEP, 2016). The preliminary survey starts when suspicion is raised about levels of pollution exceeding national standards. In such situations, the environmental agencies of local governments should inform the person with land-use right in writing about this suspicion. The informed person should complete a survey that results in a report containing basic information about the land and a conclusion about whether the land is contaminated or not. The survey must be completed within 6 months of receiving the notice from the environmental agencies (Article 13, MEP, 2016). The detailed survey should also contain information about the condition of pollutants, and impacts on the air, the soil surface, and underground water (Article 16, MEP, 2016).

Upon finalizing the survey, an assessment report should be developed. The assessment report should contain information about the relevant agricultural product, ecological, and public health risks; define the scope of the polluted soil and underground water; and outline the requirements and purpose of remediation and risk control measures to be undertaken (Article 37, MEP, 2016). Like the survey process, the responsibilities or qualifications pertaining to who should undertake and develop the risk assessment report are not specified in relevant legal frameworks. However, according to the *Guidelines for the Evaluation of Construction Land Soil Pollution Status Investigation, Risk Assessment, Risk Management and Remediation Effect Assessment Reports* (MEE & Ministry of Natural Resources of the People's Republic of China, 2019) and the *Measures for Environmental Management of Contaminated Lands (for Trial Implementation)* (Article 3, 16, 17, MEP, 2016), the person with the land-use right should commission the assessment, while environmental departments of governments are responsible for reviewing and approving the assessment report.

2. **Step 2: Soil remediation implementation**

   Although the LPCSC (2018) has clarified the soil remediation process significantly compared to prior, fragmented legal frameworks, gaps still exist pertaining to the detailed process of the actual soil remediation implementation procedure (X. N. Li et al., 2015). According to H. Wang (2020), although a series of technical guidelines and rules on environmental standards that should be included in a remediation plan exists (Article 2, Article 4, MEE & Ministry of Natural Resources of the People's Republic of China, 2019; Article 17, MEE, 2018a; MEP, 2019a; MEP, 2019c), currently no legal provisions explicitly clarify who (i.e., which type of institution) has the authority to carry out the remediation process and how the plan for the remediation should be evaluated prior to project start. Scholars have pointed out that the distribution of responsibility between local governments, polluters, and other actors (such as commercial remediation companies) is vague, creating obstacles for effective soil remediation processes in the long run (Hong & Pengcheng, 2020).

According to the *Guidelines for the Evaluation of Construction Land Soil Pollution Status Investigation, Risk Assessment, Risk Management and Remediation Effect Assessment Reports)* (MEE & Ministry of Nature Resources of the People's Republic of China, 2019), the soil remediation implementation plan should be undertaken by private entities and reviewed by the ecological and environmental departments in local government upon completion (Hong & Pengcheng, 2020). In practice, the entity to take on the remediation process is selected through a bidding process. Those who win the bidding should develop a remediation plan that should be approved by the ecological and environmental departments in local government prior to the project starting (Huang et al., 2020).

3. **Step 3: Soil remediation completion and approval**

Once a soil remediation project is considered complete by the entity undertaking the soil remediation project, an assessment should be made by a separate third party that reports on the outcome/quality of the soil remediation process to the ecological and environmental departments of the local government. Just like the procedures for the approval of the soil quality survey and assessment process, the ecological and environmental departments of the local government are responsible for reviewing and approving the assessment (X. N. Li et al., 2015).

The LPCSC (2018) also stipulates a so-called "later-stage management" to be carried out by the party responsible for the soil contamination (Article 42). However, this law does not provide details pertaining to which standards should be applied to determine whether or not a site should also include "later-stage management" or details on how such management should be conducted. In the *Technical Guidelines for Verification of Risk Control and Soil Remediation of Contaminated Sites* (MEE, 2018d), "later-stage management" is referred to as "advice on later environment," which should be applied under two conditions, whether the land is classified under risk control or in situations where the concentration of pollutant did not reach the standard of "first type land" as detailed in the guidelines.

"Later-stage management" includes two processes. The first is long-term "environmental monitoring," which applies when the land is under risk control (Article 8, MEE, 2018c). The second is a special form of "mechanism control," which includes different types of measures, such as limiting the utilization of the site, limiting the utilization of the groundwater on the site, and public notices on the risks of using the land. This form of "later-stage management" should be carried out until the concentration of pollutant reaches the standard of "first type land" in *Soil Environmental Quality Risk Control Standards* (2018b) and the concentration of pollutant in underground water reaches the standard in the *Technical Guidelines for Verification of Risk Control and Soil Remediation of Contaminated Sites* (Article 8, MEE, 2018d).

In addition to the LPCSC, several other legal provisions outline procedures that are relevant for the soil remediation process, and these are presented in Table 7.

Table 7. Special measures in major regulations on soil remediation

	Agricultural land	Contaminated land	Land for construction
Information system/special lists	Environmental information system classified into three categories.	Information system for contaminated land and a list of contaminated sites.	A catalogue for the management and control of soil pollution risk and remediation developed by relevant authorities.
Information disclosure	The results of the assessment after remediation should be uploaded to the system.	Risk assessment report and remediation plan should be shown to the public.	Remediation plan should be shown to the public.
Relevant legal framework	LPCSC (Article 49–Article 57) and *Measures for Soil Environmental Management of Agricultural Land (for Trial Implementation)* (MEE & Ministry of Agriculture and Rural Affairs, 2017).	*Measures for Environmental Management of Contaminated Lands (for Trial Implementation)* (MEP, 2016).	LPCSC (Article 58–Article 68) and *Measures for Soil Environmental Management of Industrial and Mining Land (for Trial Implementation)* (MEE, 2018a).

Source: Authors' compilation.

3.2.2 Overlaps Between Laws and Regulations Pertaining to Soil Remediation

Soil remediation processes are mainly governed by the LPCSC (2018), *Measures for the Management of Soil Environment of Industrial and Mining Land (for Trial Implementation)* (MEE, 2018a), and the *Measures for Soil Environmental Management of Agricultural Land (for Trial Implementation)* (MEE & Ministry of Agriculture and Rural Affairs, 2017). At times, these relevant regulatory frameworks overlap.

For example, Article 49 of the LPCSC (2018) states that the state is responsible for the classification of land, while Article 16 of the *Measures for Soil Environmental Management of Agricultural Land (for Trial Implementation)* (MEE & Ministry of Agriculture and Rural Affairs, 2017) states that the local government is tasked with the responsibility of determining the level of risk. As for the entity that is responsible for developing the soil remediation plan, different documents give different explanations. Article 57 of the LPCSC puts forward that polluters are responsible for developing a remediation plan, while Article 21 of the *Measures for Soil*

Environmental Management of Agricultural Land (for Trial Implementation) (MEE & Ministry of Agriculture and Rural Affairs, 2017) places this obligation on local agricultural departments. Article 24 of the *Measures for Environmental Management of Contaminated Lands (for Trial Implementation)* (MEP, 2016) places this obligation on the person(s) or entities holding the land-use right of the contaminated land. These overlaps show that the legal framework for soil remediation still has several gaps (X. N. Li et al., 2015).

Interactions between different regulations could be an approach to mitigate these overlaps and gaps, especially when there are overlaps between the different categories of land. For example, according to the classification of different types of lands, land for construction could also be polluted by industry and fall into the category of contaminated lands. The *Measures for the Management of Soil Environment of Industrial and Mining Lands (for Trial Implementation)* (MEE, 2018a) mention regulations for contaminated lands and posit that risk-control and remediation work should refer to the regulation of contaminated lands when the pollutant exceeds the standards for risk control for development land (Article 16, MEE, 2018a), which is a good example of interactions.

3.3 Regulations and Laws Related to Soil Remediation

3.3.1 China's Legal Framework for Soil Prevention and Control

Regulatory frameworks pertaining to water and air pollution prevention and control have been established since the 1980s, but until 2019, China lacked a comprehensive legal framework focusing specifically on soil pollution prevention and control (Prevedouros et al., 2006). Prior to that, regulatory frameworks pertaining to soil pollution prevention and control were scattered and fragmented in other legal frameworks such as the Environmental Protection Law (2014), the Law on Prevention and Control of Environment Pollution Caused by Solid Wastes (2020), the Atmospheric Pollution Prevention and Control Law (2018), Water Pollution Prevention and Control Law (2017), the Agriculture Law (2012), the Grassland Law (2021), the Agricultural Product Quality Safety Law (2018), and in several provincial regulations.

In parallel to the establishment of a legal framework, the Chinese state has taken other actions to address soil pollution. In 2016, issues pertaining to the risks related to poor soil quality gained attention on a political level in China, and in response, in May 2016, the State Council issued an Action Plan for Soil Pollution Control. Since then, the number of local Action Plans for Soil Pollution Control at the provincial and municipal levels has increased rapidly. According to Prevedouros et al. (2006), a number of cities and provinces, such as Beijing, Shanghai, Jiangsu, Hubei, and Chongqing, have all issued Soil Pollution Prevention and Control Action Plans. These documents, however, are only "working plans," which, of course, are of a lower legal level compared with laws and regulations.

3.3.2 Land Ownership Structure in China

In China, land is owned by the state. However, a number of different categories of land ownership exist, such as state ownership and collective ownership. According to the Chinese Constitution and the Land Management Law, lands in cities are generally owned by the state, while lands in rural areas and suburbs of the city are generally owned collectively by peasants unless explicitly regulated by law (Huang et al., 2017). Mineral deposits, streams, forests, mountains, grasslands, unclaimed land, beaches, and other natural resources are owned by the state (Ma & Sun et al., 2020). Homesteads, family plots of land, and hills are owned collectively. In addition, under the circumstances defined in the relevant legal framework, forests, mountains, grasslands, unclaimed land, and beaches can be governed by collective land ownership (Ma & Sun et al., 2020).

In addition, land in China is divided into and defined by a number of different categories, and different categories of land are governed by different regulatory frameworks. According to the Land Management Law of China, lands are divided into three categories: agricultural land, land for construction, and unused land (Huang et al., 2017).

According to Article 4 of the Land Administration Law of the People's Republic of China (2019 Amendment), "The State shall compile general plans to set usages of land including those of farm or construction use or unused. A strict control is to place on the turning of land for farm use to that for construction use to control the total amount of land for construction use and exercise a special protection on cultivated land (sic)" (2019). This law defines three different categories for land in China. "**Land for farm use**" refers to land directly used for agricultural production, including cultivated land, wooded land, grassland, land for farmland water conservancy and water surfaces for breeding; "**land for construction use**" refers to land on which buildings and structures are put up, including land for urban and rural housing and public facilities, land for industrial and mining use, land for building communications and water conservancy facilities, land for tourism and land for building military installations. The term "**land unused**" refers to land other than that for agricultural and construction uses (2019).

These categories are defined and used in the General Plans of Land Use, which are developed by local governments at all levels (Finlay et al., 2013). Plowland is protected, and changes to this type of land are, in theory at least, strictly controlled. Examination and approval procedures for the conversion of agricultural land are needed when converting agricultural land to land for construction (Jeppesen et al., 2005). Approval from the State Council should be acquired to change permanent basic farmland into land for construction (Jeppesen et al., 2005). Surveys on the condition of soil pollution should be conducted before unused lands are moved into the agricultural land category (Yan et al., 2016).

In addition, a number of different standards govern the three categories of land and their related sub-categories. The LPCSC (2018) divides agricultural land into three categories, namely, **land that will receive priority protection, land that will be managed for safe utilization, and land that must be strictly managed**. The level of contaminant concentrations in the soil and in relevant related agricultural products is used to determine the classification of agricultural land (T. Li et al., 2019).

The *Measures for Environmental Management of Contaminated Lands (for Trial Implementation)* (MEP, 2016) recognizes a distinct type of "contaminated land," namely, **"land that was previously used for industries such as non-ferrous metal smelting, petroleum processing, chemical [processing], coking, electroplating, and tanning, or for hazardous waste storage, utilization, and disposal activities"** (Daizhong et al., 2013). Land in which the level of pollution concentration exceeds the relevant national soil environmental standards will automatically be classified as contaminated land. The measures for contaminated land clearly state that the main objective for this category of land is to manage ecological and environmental risk as well as public health (Ding et al., 2018). Another category of classification of land is described in the *Measures for the Management of Soil Environment of Industrial and Mining Land (for Trial Implementation)* (MEE, 2018a). This document identifies a category of land under the heading of "industrial and mining land." According to the document, **"industrial and mining land refers to the land utilized in ongoing industrial and mining production and operation activities"** (L. L. Wu et al., 2017). When a certain type of industry and/or mining takes place on a piece of land, it falls under this category. Such industries include non-ferrous metal smelting, petroleum processing, chemical processing, coking, electroplating, and tanning, as well as large-scale enterprises engaged in mining non-ferrous metal ores and extracting crude petroleum (Article 3, 16). Relevant authorities are tasked with the responsibility of closely monitoring the status of the land falling under the category of "industrial and mining land" (T. Li et al., 2019).

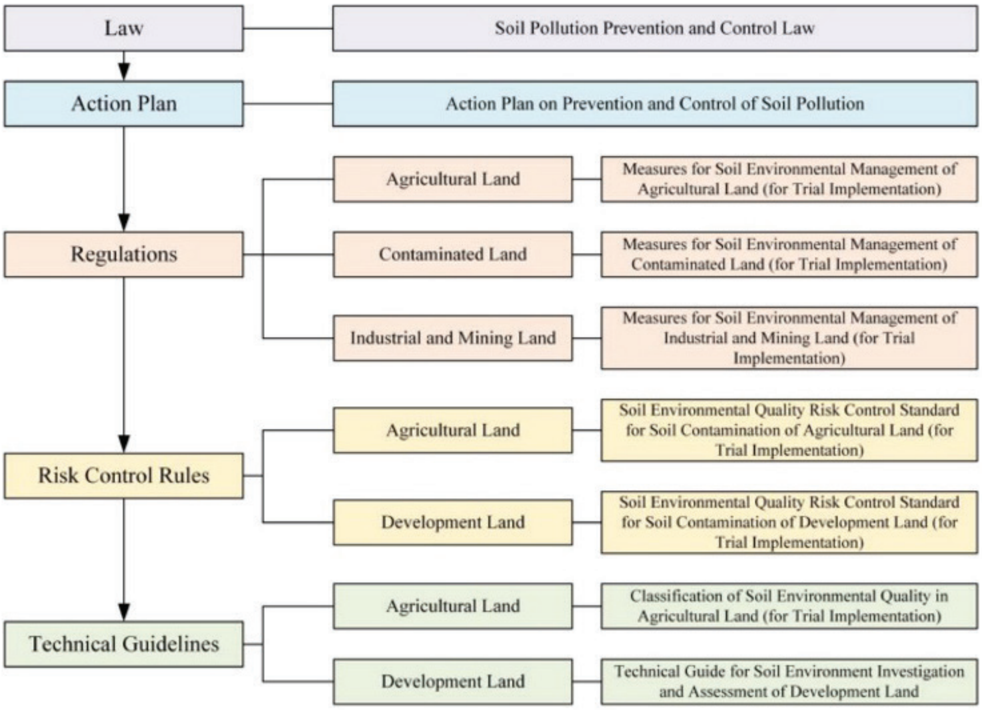
Furthermore, technical standards for the risk control and management of the soil also have a set of classifications; for these purposes, land is further categorized as follows:

Development land is divided into two categories with regard to the development of relevant risk-control rules:

1. *The first type of development land*: This type of land is mainly restricted to utilization for residential purposes and administrative and public services. It can also be used for commercial facilities, such as hotels and other business facilities, and so on. In land that falls under this category, it is both children and adults who are considered as being at risk of exposure to contamination (Deng et al. 2019; Xu et al., 2015).
2. *The second type of development land*: This category is for land that can be used for industrial land purposes. It also includes land used for the purpose of roads and transportation facilities and land for public facilities such as green spaces and public gardens. Certain types of business services facilities can also be placed on land in this classification. For studies of land that falls under this category, only adults are considered in terms of health risks posed by contamination (T. Li et al., 2019; Deng et al., 2019, Xu et al., 2015).

Regulatory frameworks set out different management systems depending on the category of land (Figure 6).

Figure 6. Policy framework of the Chinese soil management system



Source: T. Li et al., 2019.

REGULATIONS, MEASURES, AND OTHER REGULATORY FRAMEWORKS FOR DIFFERENT CATEGORIES OF LAND

Several regulations, guidelines, action plans, measures, and directives also constitute a part of the overarching soil governance structure in China. Among these, we find the *Measures for Soil Environmental Management of Agricultural Land (for Trial Implementation)* (MEE & Ministry of Agriculture and Rural Affairs, 2017), which govern agricultural land. Ensuring food safety, with a special focus on both the quality and quantity of products produced on agricultural land, is the overarching objective for these measures (Liland et al., 2020). In order to achieve this principle, a number of management measures are detailed. These include the investigation, monitoring, and classification systems for the soil on land classified as agricultural land, as well as a separate risk management and control mechanism for contaminated agricultural land. In addition, the aforementioned measures also contain details on procedures pertaining to the treatment and remediation of land that has been contaminated and falls under the category of agricultural land (T. Li et al., 2019). The *Measures for Soil Environmental Management of Agricultural Land (for Trial Implementation)* (MEE & Ministry of Agriculture and Rural Affairs, 2017) require the polluters to pay the principal amount for agricultural land soil remediation.

In addition, the *Measures for Environmental Management of Contaminated Lands* (MEE, 2016) present a central regulatory framework detailing the procedures used in the pre- and post-soil remediation process for land that has been classified as contaminated. The state has established a national register and information-sharing system for contaminated sites. The local government holds the responsibility of providing information about contaminated sites in their jurisdiction to the database, which is governed by relevant authorities at the national level (Zhao, 2019; X. Wang, 2021).

The *Measures for Environmental Management of Contaminated Lands* (2016) detail tasks and responsibilities shared between land-use rights holders and the local government. For instance, they stipulate that it is the local government's responsibility to investigate the contaminated site and provide an assessment of the risk level based on the findings from the investigation. The responsibility of managing and/or remediating the contamination lies with the entity that holds the land-use right, based on the findings from the investigation conducted by the local authorities (Zhao, 2019).

Depending on the proposed purpose of the land, different requirements for risk management and/or control will be required. For instance, for land that will be developed for the use of the public (examples include, but are not limited to, schools, hospitals, and real estate development, and so on), the risk management and control measures adopted must ensure the "safe utilization" of the land. On the other hand, for lands that are currently unused, the objective would be to prevent further contamination. The measures clearly state that, after undertaking satisfactory remediation processes, and in cases where the remediated land meets the relevant requirements for soil quality, the land can be utilized (T. Li et al., 2019).

A nationwide database and information system has also been established for land classified as industrial and/or mining land according to the *Measures for the Management of Soil Environment of Industrial and Mining Land (for Trial Implementation)* (MEE, 2018a). The measures outline the responsibilities for enterprises that are operating on land falling under these categories; regular monitoring of the quality of both the soil and the groundwater surrounding the enterprise is required (Zhao, 2019). Enterprises must also conduct specific investigations into the quality of both the groundwater and the soil prior to new projects and/or when making changes or alterations to existing projects on a given site. In addition, the measures also regulate mechanisms enterprises must comply with when a project is ending and the enterprise plans to end their operation at a given site. For instance, the enterprise must carry out an examination of the soil and groundwater prior to the termination of their operation, and the investigation results must be shared with the relevant authorities. Action must be taken by the enterprise to remediate the soil and or groundwater prior to the termination if irregularities are detected in the final assessment process (T. Li et al., 2019).

MANAGEMENT STRUCTURE FOR RISK-CONTROL RULES

Risk-control rules serve a central function in the overarching soil governance and management structure in China and are particularly important for land that is classified as land for agricultural or development. These specific rules contain information pertaining to standards for deciding whether or not the quality of the soil should be considered a risk to human health and details procedures pertaining to investigation, monitoring, and remediation (X. N. Li et al., 2015).

Risk-Control Rules for Agricultural Land

A special set of risk-screening values and intervention values, as shown in Table 8, have been developed for the purpose of determining whether or not the concentration of contaminants in agricultural land and/or an agricultural product is a risk to human health (Q. Wu et al., 2018).

Table 8. Risk-screening values and intervention values for agricultural land (measured in mg/kg^{-1})

Item		Soil pH							
		pH ≤ 5.5		5.5 < pH ≤ 6.5		6.5 < pH ≤ 7.5		pH > 7.5	
		S[1]	I	S	I	S	I	S	I
Cadmium	P[2]	0.3[3]	1.5	0.4	2.0	0.6	3.0	0.8	4.0
	O	0.3		0.3		0.3		0.6	
Mercury	P	0.5	2.0	0.5	2.5	0.6	4.0	1.0	6.0
	O	1.3		1.8		2.4		3.4	
Arsenic	P	30	200	30	150	25	120	20	100
	O	40		40		30		25	
Lead	P	80	400	100	500	140	700	240	1000
	O	70		90		120		170	
Chromium	P	250	800	250	850	300	1000	350	1300
	O	150		150		200		250	
Copper	OR	150	–	150	–	200	–	200	–
	O	50		50		100		100	
Nickel		60	–	70	–	100	–	190	–
Zinc		200	–	200	–	250	–	300	–
Hexachlorocyclohexane (Optional)[4]		0.10	–	0.10	–	0.10	–	0.10	–
DDT (Optional)[5]		0.10	–	0.10	–	0.10	–	0.10	–
Benzo[a]pyrene (Optional)		0.55	–	0.55	–	0.55	–	0.55	–

[1] S = screening value, I = intervention value. [2] P = Paddy field, OR = Orchard, O = Others. For land with water and drought rotation, the stricter limit is adopted. [3] Limits for heavy metals and metalloids are regulated for the total amount of the elements/compounds. [4] Including α-, β-, γ-, δ-Hexachlorocyclohexane. [5] Including p,p′-DDE, p,p′-DDD, o,p′-DDT, and p,p′-DDT.

Source: T. Li et al., 2019.

Some of these risk-screening procedures mainly focus on the safety of agricultural products, such as the presence of cadmium, mercury, arsenic, lead and chromium in the products. Others, which focus on the presence of such metals as copper, nickel, and zinc, predominately seek to assess the safety of crops (T. Li et al., 2019; Travel Trade Gazette, Asia, 2020).[1]

Risk-Control Rules for Development Land

In a similar fashion, screening and intervention values have been developed for land that is classified as land for development; these values largely focus on heavy metals and inorganics, volatile organic compounds, and semi-volatile organic compounds (Q. Wu et al., 2018). This set of screening values is used to assess whether land should be included

[1] Land contaminated by the same pollution source (or land with similar levels of pollution) should be grouped into the same assessment unit. Each contaminant is separately classified in an assessment unit. If the concentration of a contaminant is less than the screening level, the pollution level for the contaminant is priority protection. If its concentration lies between the screening level and the intervention level, it is defined as safe utilization. Moreover, if its concentration is higher than the intervention level, it is classified as strict management. After all contaminants are classified, the worst level is used to describe the soil contamination in the assessment unit. The classification of this unit is further determined by the soil contamination level and the pollution level in agricultural products grown in that soil (T. Li et al, 2019).

in the aforementioned national information system for contaminated sites.[2] In cases where land is found to have levels of contamination that exceed the intervention level, the land must undergo risk management procedures (i.e., remediation) (X. N. Li et al., 2015). Table 9 provides an overview of the risk-screening and intervention values as they apply for the "development land" category.

Table 9. Risk-screening values and intervention values for routine testing items for development land (measured in mg/kg^{-1})

Item	Screening Values		Intervention Values		Item	Screening Values		Intervention Values	
	S[1]	N[2]	S	N		S	N	S	N
Heavy Metals and Inorganics					**Volatile Organic Compounds (Continued)**				
Arsenic	20	60	120	140	Propane, 1,2,3-trichloro-	0.05	0.5	0.5	5
Cadmium	20	65	47	172	Ethene, chloro-	0.12	0.43	1.2	4.3
Chromium (VI+)	3.0	5.7	30	78	Benzene	1	4	10	40
Copper	2000	18000	8000	36000	Benzene, chloro-	68	270	200	1000
Lead	400	800	800	2500	Benzene, 1,2-dichloro-	560	560	560	560
Mercury	8	38	33	82	Benzene, 1,4-dichloro-	5.6	20	56	200
Nickel	150	900	600	2000	Ethylbenzene	7.2	28	72	280
Volatile organic compounds					Styrene	1290	1290	1290	1290
Carbon tetrachloride	0.9	2.8	9	36	Toluene	1200	1200	1200	1200
Trichloromethane	0.3	0.9	5	10	Benzene, 1,3-dimethyl- and p-Xylene	163	570	500	570
Chloromethane	12	37	21	120	o-Xylene	222	640	640	640
Ethane, 1,1-dichloro-	3	9	20	100	**Semi-volatile organic compounds**				
Ethane, 1,2-dichloro-	0.52	5	6	21	Benzene, nitro-	34	76	190	760
Ethene, 1,1-dichloro-	12	66	40	200	Aniline	92	260	211	663
Ethylene, 1,2-dichloro-, (Z)-	66	596	200	2000	Phenol, 2-chloro-	250	2256	500	4500
Ethylene, 1,2-dichloro-, (E)-	10	54	31	163	Benz[a]anthracene	5.5	15	55	151
Methylene chloride	94	616	300	2000	Benzo[a]pyrene	0.55	1.5	5.5	15
Propane, 1,2-dichloro-	1	5	5	47	Benzo[b]fluoranthene	5.5	15	55	151
Ethane, 1,1,1,2-tetrachloro-	2.6	10	26	100	Benzo[k]fluoranthene	55	151	550	1500
Ethane, 1,1,2,2-tetrachloro-	1.6	6.8	14	50	Chrysene	490	1293	4900	12900
Tetrachloroethylene	11	53	34	183	Dibenz[a,h]anthracene	0.55	1.5	5.5	15
Ethane, 1,1,1-trichloro-	701	840	840	840	Indeno[1,2,3-cd]pyrene	5.5	15	55	151
Ethane, 1,1,2-trichloro-	0.6	2.8	5	15	Naphthalene	25	70	255	700
Trichloroethylene	0.7	2.8	7	20					

[1] S = sensitive land. [2] N = non- sensitive land.

Source: T. Li et al., 2019.

3.4 Examples of Stakeholder Involvement in Soil Remediation Projects

In Table 10, we have developed a number of case studies to better illustrate how different types of soil remediation projects are undertaken at different locations and for different remediation purposes in China, as well as the involvement of different stakeholders in the soil remediation process.

[2] However, soil background values can have an impact on this process. In situations where concentrations are lower than that of the soil background values in the area, one does not have to undertake any further investigation and/or risk assessment (Q. Wu et al, 2018).

Table 10. Examples of soil remediation projects and involved stakeholders in China

Type of site	Category of land	Location	Short introduction to and explanation of the soil remediation process	Main stakeholder(s) involved
Brownfield	Construction land	Changzhou city, Jiangsu Province	This case took place in Changzhou city, in Jiangsu Province, and has by some observers been referred to as China's Love Canal Case, as it bears a strong resemblance to the events surrounding the well-known Love Canal in Niagara Falls, New York. Both cases involved students who were exposed to chemical residues buried in the soil on which their schools were located. Before the land was used for the school building in Changzhou, a chemical factory had been situated there; after the firm relocated, soil remediation was carried out by a remediation company. However, the remediation process was insufficient. In early 2016, students of the Changzhou Foreign Languages School noticed a strange smell, and many of the students started to complain about severe headaches, rashes, and/or skin problems. Journalists from the state-owned China Central Television took interest in the case, which subsequently led to the case receiving national attention, such that it became one of the most publicly discussed environmental issues of the year in China in 2016. In April 2016, two environmental NGOs— Beijing-based Friends of Nature and the China Biodiversity Conservation and Green Development Foundation—filed a public-interest litigation case against the three chemical manufacturers responsible for the pollution. The NGOs demanded the companies remove the pollution completely or pay for the	**Local government:** The New North District government of Changzhou organized the remediation of the contaminated land. **Local ecological environment bureau:** Changzhou Ecological Environment Bureau was responsible for the supervision and management of soil pollution in the relevant jurisdiction. **Enterprise (polluter):** Three chemical enterprises—Jiangsu Changlong Chemical Co., Ltd., Changzhou City Changyu Chemical Co., Ltd., and Jiangsu Huada Chemical Group Co., Ltd.—were responsible for the cost of the soil remediation. **Third party, an environmental remediation company:** Black Peony Company and Jiangsu Tianma Vientiane Construction Group Co., Ltd., signed a contract with the Changzhou Ecological Environment Bureau to implement the soil remediation project. Later in the process, the Changzhou Environmental Protection Institute was entrusted as the unit to evaluate the outcome of the soil remediation process.

Type of site	Category of land	Location	Short introduction to and explanation of the soil remediation process	Main stakeholder(s) involved
			clean-up costs. At first, the NGOs were unsuccessful. At a court hearing on December 22, 2016, a stalemate was reached after eight hours, and the court did not issue a ruling. A lawyer for the plaintiffs focused the discussion on who should be responsible for cleaning up historical pollution once the government had reclaimed land-use rights (Environmental Systems Research Institute, 2014). In January 2017, the intermediate court ruled that the plaintiffs had lost the case on the grounds that ownership of the land had transferred to the government and that relevant countermeasures were already being implemented. According to the ruling, not only were the chemical companies exempt from paying for the soil treatment, but the NGOs had to bear a “court acceptance” fee of CNY 1.89 million (USD 275,000). The two NGOs appealed the verdict, and when the case was reviewed again by the high court, the court decided that the original polluters should be held accountable for their wrongdoing despite the change in land ownership (Duan et al., 2017).	**Citizens:** Changzhou Foreign Language School students and local residents affected by the soil contamination took action to address the situation by, for instance, reaching out to media outlets. Legal frameworks provide citizens with the right to claim compensation and to obtain information on the land restoration process. **NGOs:** Friends of Nature and the China Biodiversity Conservation and Green Development Foundation undertook litigation against the chemical companies involved in the case. Legal frameworks provided a number of rights for NGOs (which have legal standing according to law) to file public-interest lawsuits against the three chemical companies that caused the pollution (Civil Judgment of Jiangsu Higher People’s Court, 2017).
Brownfield	Construction land	Songjia-zhuang subway station, Beijing	On April 28, 2004, a poisoning incident occurred during the construction of Beijing’s Songjiazhuang subway station. The station’s location was originally the site of a pesticide factory in Beijing. Although the factory had been moved many years before, some toxic and harmful gases still remained underground and on-site. When the excavation reached 5 m underground, three workers were acutely poisoned and were sent to the hospital for treatment.	**Local government:** Beijing Municipal People’s Government organized the remediation of the contaminated land. **Local ecological environment bureau:** The Beijing Municipal Environmental Protection Bureau (renamed Beijing Ecological Environment Bureau)

Type of site	Category of land	Location	Short introduction to and explanation of the soil remediation process	Main stakeholder(s) involved
			The Beijing Municipal Environmental Protection Bureau then carried out site monitoring and took relevant measures to remediate the site. The contaminated soil was dug up and taken away for incineration. The incident marked the beginning of China's emphasis on the rehabilitation and redevelopment of contaminated industrial sites. The soil index after remediation was tested by the Beijing Municipal Environmental Protection Bureau and met the standards.	**Enterprise (polluter):** A pesticide factory in Beijing **Third party:** An environmental remediation company **Citizens:** Three poisoned workers and local residents have the right to get information regarding remediation.
Mining site	Agricultural land	Guanzhai Village of Ciyan Township, Hunan Province	This case took place in Guanzhai Village of Ciyan Township, which has a history of mining that goes back thousands of years. Since 1958, the first state-owned lead–zinc mine was established in Ciyan township. For a long period of time, mining had a great impact on the local environment, but local residents did not have enough awareness of the impact of different environmental pollution problems caused by mining. The wastewater discharged from the former lead–zinc ore dressing plant and mine polluted most of the farmland near the mining area to varying degrees, resulting in cadmium, lead, zinc, and mercury in the rice and vegetables grown locally exceeding the relevant state regulations. Since 2014, the Fenghuang County People's Government has collaborated with scholars and researchers, experimenting with reducing the presence of contaminants in the soil by planting different kinds of rice. This is a special case where scholars and researchers got involved in experimenting with innovative soil remediation processes by seeking to absorb pollutants through uptake in plants.	**Local government:** The Fenghuang County People's Government organized the remediation of the polluted land. **Scholars and researchers:** Scholars and researchers worked with the local government and ecological environmental bureau on developing soil remediation experiments. **Local ecological environment bureau:** Fenghuang County Environmental Protection Bureau (renamed the Ecological Environment Bureau) collaborated with the local government and scholars to implement the soil remediation experiments. **Villagers:** Land users (many also former miners) and local residents whose physical health was affected by the presence of the contaminants in the soil. Many villagers were also involved in the soil remediation process.

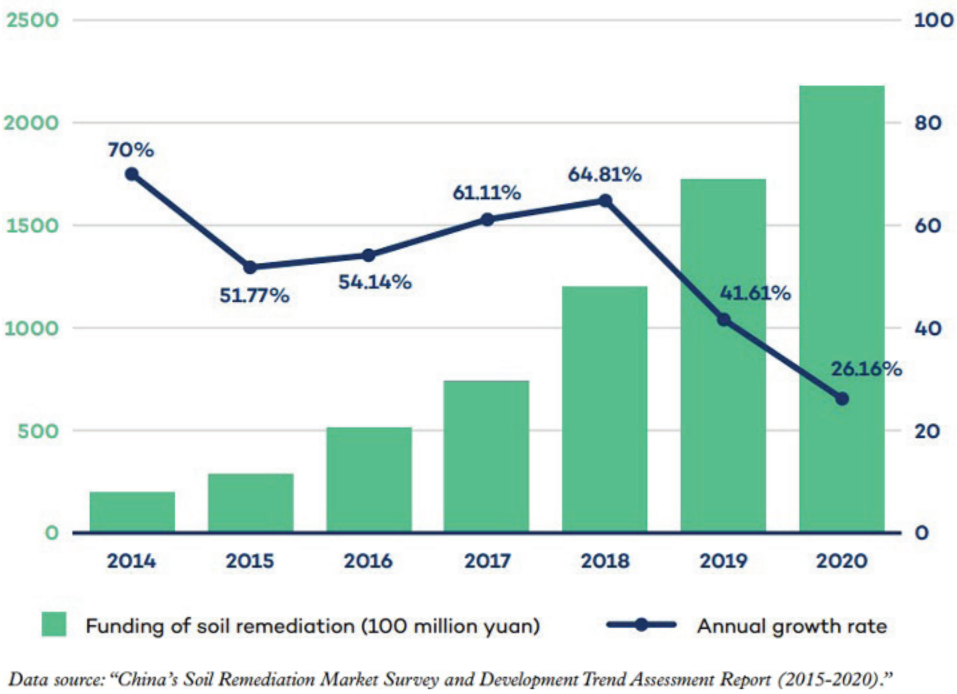
4.0 Financing Soil Remediation in China

Soil remediation, as outlined above, can be a costly endeavour that depends on a multitude of factors (outlined in Table 5). Aside from the size of the area to be remediated and the costs associated, soil remediation projects face numerous other questions that can introduce complexity into the financing of the projects. These questions include, among others: Who is the actor principally responsible for the contamination? When did the contamination occur? Who will benefit from remediation efforts? These questions are even more difficult to address when the actors responsible for the contamination no longer exist.

4.1 Challenging Issues Facing Soil Remediation Financing in China

While these questions must be faced by parties in any region, country, state, province, or municipality, the challenges facing soil remediation in China are unique. As documented by Dong et al. (2018), the most pressing issue facing interested parties is the sheer size of the funding required. While it is impossible to estimate the exact required costs of soil remediation efforts in China, estimates based on China's limited proposal in its 2016–2020 Five-Year Plan (FYP) were substantial. The 13th FYP set forth to remediate 660,000 ha of farmland and restore 5,000 m^2 of the polluted area to forest and grassland by 2020. It was estimated that this plan would cost CNY 7 trillion (USD 1.06 trillion); for context, the Chinese government invested CNY 9 billion in soil remediation in 2016 (Yang, 2016). Thus, even to meet the targets set out by the 13th FYP, which is only one small step, soil remediation efforts in China require other forms of capital.

Figure 7. China's soil remediation market forecast (2014–2020)



Source: Abaogao, n.d.

Capital from other investors has been flowing to these projects. As illustrated in Figure 7, funding for soil remediation continues to grow (Abaogao, n.d.). A possible hindrance to this continued growth is the tendency of soil remediation projects to require many small investments, which may inhibit investors from scaling their goals. On this topic, Dong et al. (2018) reported that almost 44% of China's remediation projects required an investment of CNY 50 million (USD 7.6 million) or less, whereas large-scale projects, requiring more than CNY 200 million (USD 30.3 million), only accounted for 19% of the market. Smaller investments tend to have higher relative transaction costs, a factor that may deter investors who are looking to address soil remediation but who are wary of the resources they may need to dedicate to take the investment to completion.

A second impediment to financing soil remediation in China is the uncertainty investors may face because of China's policy on land ownership. Under China's system of public land ownership, there is ambiguity with respect to which parties should be responsible for remediating land and preventing soil pollution. In countries that provide for private land ownership, individuals and firms are incentivized to make investments to improve the land they own as well as to make investments that will avoid costs in the future. To a certain extent, under private ownership, investments in land may be recovered by the individual or firm through operation and upon final sale of the land. However, under a regime of public ownership, these actors are not incentivized to undertake investment because these investments will never be recouped. Moreover, for firms that are primarily concerned with their economic interests, investments in public land could be detrimental to their potential profits, as these investments increase their capital expenditures.

Further, while land policies may deter investment in soil remediation, China's history and path to development have also created ambiguity around the financing of soil remediation. Much of the pollution of China's agricultural farmland is due to a transfer of industrial pollutants from urban areas to rural farmland. Moreover, as baselines of historical soil quality are unclear and with the gradual contamination happening over long periods of time, it is difficult to determine the main actor responsible for the soil pollution (Dong et al., 2018). Without these direct connections between the responsible actor and polluted soil, a model of "polluter pays" for past pollution is infeasible in many scenarios. The national government in China has attempted to address some of these issues through its 2019 legislation, the Law on the Prevention and Control of Soil Pollution. However, these regulations remain unclear in some cases and do not clearly distinguish between retroactive liability for past polluters and non-retroactive liability for current owners of usufructuary rights (H. Wang, 2020).

Finally, the last significant issue facing the financing of China's soil remediation efforts is that there is still a need to further develop China's soil remediation technology, construction capacity, and engineering experience for restoring contaminated sites. As seen in some other markets, employing proven, well-developed soil remediation techniques supported by suitable equipment and experienced professionals creates enabling conditions that allow investors a level of certainty that investments made in soil remediation will garner the intended outcomes. China's soil remediation market is going along this path but needs to continue to advance to overcome issues related to investor confidence.

To mitigate the risks involved in financing soil remediation in China, a variety of financing instruments can be employed by both the public and private sectors.

4.2 Financial Resources and Instruments for Soil Remediation

Given the challenges outlined above regarding the size and character of the financing challenge of soil remediation in China, it is important to note that there is a wide variety of financing modalities available to tackle this issue.

4.2.1 Domestic Government Resources

Perhaps the most obvious source of investment, government financing is crucial to many soil remediation efforts. In the case of China, government involvement will grow in importance because of the system of property ownership. No actor in China has more of a vested interest in the long-term health of the land than its owner: the state. While Dong et al. (2018) highlighted this point and noted that government funding for soil remediation has been less than needed, China is also becoming more aggressive in establishing environmental targets that may translate to the government viewing soil remediation as an increasingly important issue. An example of China's efforts toward environmental targeting is its recent commitment to achieving net-zero emissions by 2060 (Seaman, 2020).

However, the current state of affairs is an impediment to a financial push by the Chinese government to fund soil remediation in the near term. After expanding their borrowing in 2020 to respond to the COVID-19 crisis, the national and provincial governments have higher-than-usual debt levels relative to their economic activity. It was expected that borrowing would be scaled back throughout 2021 (Bloomberg News, 2021). Despite these constraints, China's Ministry of Finance, 11 provinces, cities along the Yangtze River, and numerous financial institutions established a CNY 88.5 billion (USD 12.7 billion) national green development fund in July 2020 (Hakim, 2020). The Ministry of Finance and 11 provinces have contributed one third of the funds. The new fund follows the establishment of the Yangtze Fund, which was created jointly in 2019 by the National Development and Reform Commission and two state-owned enterprises (China Three Gorges Corporation and Beijing Enterprises Water Group Limited). This previous fund initially raised capital of CNY 20 billion with the goal of scaling the fund to CNY 100 billion. The fund is mandated to address water pollution, water ecology restoration, water resources protection, green environmental protection, and innovative technologies for an energy revolution in the provinces and cities in the Yangtze River Economic Belt (General Office of Hubei Provincial People's Government, 2019). To this point, how these funds will be allocated across the myriad of environmental challenges facing China remains uncertain; however, previous funding priorities suggest that soil remediation projects may remain a lesser priority and not receive funding that is commensurate with the problem.

One way for government to increase funding, or at least to ensure that it is compensated for its remediation efforts, is by tax incremental financing (TIF). Essentially, the government entity levies special taxes on parties that will benefit from the remediated and redeveloped area (Schneider, 2019). At the outset of the remediation and development project, the municipality or other government agency issues a TIF bond to finance the upfront work (see Box 1 for an example). Once the project is completed, the increased tax revenues from the beneficiaries are used to service the debt of the TIF bond. Although the mechanism is not a "polluter-pays" mechanism in the traditional sense, the payer is also the direct beneficiary of the remediation project.

Box 1. The Atlantic Station (Atlantic Steel Site Redevelopment Project), Atlanta, United States

The Atlantic Station development project was a USD 2 billion cleanup and redevelopment of a 138-acre brownfield site (City of Atlanta, n.d.). The project involved the remediation of a former steel facility, the separation of sanitary and storm sewer systems, and the construction of a highway bridge to connect the site to both public transit and the closest highway. Financing for the project was a combination of instruments, including TIF proceeds, TIF bonds, water bonds, and federal general obligation bonds.

The project was deployed through a public–private partnership structure. The remediation process and the construction of roads and utilities were financed by the public sector using TIF bonds. The bonds were issued by the municipality and were structured to be repaid from the revenue received from a tax increment derived from new commercial activities on the redeveloped district. Over USD 200 million was raised through this instrument. In order to mitigate the risk of insufficient tax revenues to service bonds, a special district tax was designed to provide credit enhancement to the TIF bonds. The tax was aimed at new inhabitants of the remediated and rehabilitated district.

Source: Adapted from Perera et al., 2018

TIFs can present two main challenges when considering their applicability in certain geographies. First, TIFs require that remediation and redevelopment projects be completed quickly to avoid potential credit risks that may arise for the municipality issuing the bond; tax revenues need to be generated to service the bond. Second, the success of TIF systems relies heavily on the accurate forecasting of remediation and redevelopment costs and the related taxable income increases. In some geographies, this can be difficult to predict.

Box 2. BOFAS npo, the Reserve Fund for Soil Remediation in Petrol Stations (Belgium)

The Belgian BOFAS fund is an interregional cooperation agreement set up by the three regions of Belgium—Flanders, Wallonia, and Brussels—and the Federal Government of Belgium. The mandate of this fund is to advise on the remediation required and reimburse a portion of the remediation costs of petrol stations (Bodemsaneringsfonds voor tankstations, 2021). The fund is founded on the "polluter-pays principle" and is financed by clean-up duties on petrol stations and the petroleum industry in addition to an excise tax on every litre of gasoline sold. Penalties on polluters are imposed and duties collected by the Belgium Federal Department of Energy.

Source: Adapted from Perera et al., 2018.

A secondary method for governments to increase the resources they have available for soil remediation projects is through reserve funds. Governments can create and maintain reserve funds as liquid assets to meet specific future maintenance, refurbishment, and retrofitting costs. These types of funds are structured to establish a steady stream of deposits and payouts and are managed to ensure that the deposits, including the seed capital, earn interest over time, resulting in an increase in their value. The seed capital for reserve funds comes from the government, and the replenishment or working capital is contributed by the private polluters. Reserve funds essentially establish a "polluter-pays" system of financing soil remediation, but the polluters are paying incrementally instead of paying once the remediation is needed. Although Box 2 highlights the usage of reserve funds from soil remediation for petrol stations, this type of fund holds promise for paying for soil pollution caused by other sectors, such as agrochemicals, petrochemicals, mining, and shipping. It would be best practice to include plans for the remediation of sites related to these industries or other extractive industries in development contracts and other community development agreements.

Reserve funds can also offer governments flexibility, as they are often backed by other appropriate public guarantees that can be structured to provide concessional loans. In these cases, the fund can act as a first-loss protection mechanism and enable other socially conscious capital providers to co-invest. Both the TIF and reserve fund examples highlight that implementing "polluter-pays" methods to increase government resources for soil remediation is best done while the polluting entity is active and generating revenue; waiting until the soil needs remediating puts the government at risk of taking on an unfair share of the burden. The recent Law on the Prevention and Control of Soil Pollution attempts to address this issue by adopting risk-based controls to proactively determine whether contaminated land requires remediation—controls that are similar to those that exist in other countries that have more experience tackling soil pollution (T. Li et al., 2019). Key to the success of this new method will be the resources the government will dedicate to its implementation and enforcement.

4.2.2 Firm and Individual Resources

In many countries, the incentives for firms and individuals to invest in the land underneath their businesses or residences is clear due to ownership structures; this is not the case in China. There, the case for dedicating private resources to soil remediation and preventative measures is based on cost avoidance. Nevertheless, pre-emptively addressing issues of soil pollution may allow firms and residents to stay where they are and not have to relocate. As mentioned in previous sections of this report, recent laws are acknowledging the value of the prevention of soil pollution and are putting more onus on the users of land to be responsible for pollution. Given this changing landscape, it can be expected that private actors will have a larger role in financing soil remediation going forward. However, this role will be influenced by the enforcement of new laws by the government.

4.2.3 Bond Proceeds

Bonds that can be applied to soil remediation efforts come in many shapes and sizes. Within sustainable bond types, green bonds are the type most aligned to fund soil remediation projects. Green bonds, by definition, are bonds whose proceeds are used to fund projects that have quantifiable environmental benefits and help society mitigate and adapt to climate change. The types of projects that can be funded by green bonds include, but are not limited to, projects related to renewable energy, energy efficiency, green buildings, and pollution prevention and control (International Capital Market Association, 2018a). Soil remediation projects naturally fit as projects that address pollution prevention and control.

Green bond issuances have increased dramatically since 2007, when the European Investment Bank (EIB) issued the first green bond,[3] as investors have become more familiar with them and issuers understand their benefits (EIB, n.d.). Total proceeds from issuances have increased dramatically from about USD 1 billion in 2007 to over USD 300 billion in 2020 (BloombergNEF, 2021). As of 2019, China accounted for the second-highest amount for cumulative issuances among countries with over USD 100 billion issued, trailing only the United States (Climate Bonds Initiative, 2020). The USD 31.3 billion in green bonds issued in China in 2019 was issued by 79 entities, with the Industrial and Commercial Bank of China, the Industrial Bank, the China Construction Bank, and the China Development Bank as its most significant issuers.

While these figures bode well for a belief that soil remediation projects in China could receive increased funding, worldwide trends do not agree. The Climate Bonds Initiative reports that energy, buildings, and transport accounted for over 80% of global issuances; waste and land use, two categories in which soil remediation may fit, only accounted for 6%. Unsurprisingly, “land use” as a category is most present in bonds issued by sovereigns and has far less relative import for other types of issuers.

Sustainability bonds are instruments that have similar characteristics as green bonds. These bonds, however, expand the eligible project categories beyond green bond-eligible projects to include projects that provide a wide range of social benefits. For instance, they can promote affordable basic infrastructure, access to essential services, affordable housing, employment generation, food security and sustainable food systems, and/or socioeconomic advancement and empowerment (International Capital Market Association, 2018b, 2020). In the case of sustainability bonds, it is possible that soil remediation on agricultural land could be eligible under promoting food security and sustainable food systems or, as documented in Box 3, could apply to issues of safe drinking water and safe, affordable housing. A key point for issuers of sustainability bonds to consider is the requirement to specify the target populations of the investments made using the bond proceeds.

Like green bonds, the sustainability bond market has been growing in recent years. While data on the size of China’s sustainability bond market is difficult to source, there were details on a 2018 sustainability bond issued by the Bank of China that may be indicative. The bond, garnering net proceeds of CNY 2.44 billion (roughly USD 380 million), has had 43% of its proceeds invested in renewable energy and transportation, and 57% of its proceeds invested in employment generation and access to essential services (Bank of China, 2020). Interestingly, the investment in employment generation has been mostly in the form of loans to farmers. Although the conditions for these loans remain unclear at this point, these loans could act as a tool for bond issuers to work with those in China’s agricultural sector to ensure that soil pollution prevention and, when necessary, soil remediation are part of the loan agreement.

[3] EIB referred to it as a Climate Awareness Bond.

Loans to an agriculture sector that does not have a vested interest in the quality of the land they work or the safety of the goods they produce may impede repayment—a bad outcome for all involved.

Green bonds and sustainability bonds are particularly attractive for financing the much-needed transition to an environmentally responsible future because they allow the issuers, public and private, to attract investors to these projects. It is far easier for an asset manager to make investments toward a green future via a green bond than for that asset manager to build internal capacity and invest directly. However, what remains an impediment to these investor flows going toward soil remediation or soil pollution prevention projects is the lack of clear revenue available to the issuer for repayment. The investor will want to be repaid their initial investment plus interest over the time they hold the bond. For other investments using green bond proceeds, such as green buildings, solar and wind farms, or wastewater treatment facilities, the revenue streams are clearer. The same can be surmised for sustainability bonds and the way on-lending or equity investments in small and medium enterprises, hospitals, or education providers will offer revenue streams back to the issuer that will be, in part, passed on to the investor. Without these types of revenue streams, soil pollution prevention and soil remediation are less apt to attract bond proceeds.

Box 3. The Hong Kong and Shanghai Banking Corporation Limited and Sustainable Development Goals Bond

In 2017, the Hong Kong and Shanghai Banking Corporation Limited (HSBC) issued its Sustainable Development Goals (SDGs) bond as part of HSBC's commitment to provide USD 100 billion of sustainable financing and investment by 2025 (HSBC, 2017). The USD 1 billion bond's framework stated that the proceeds from the bond would be used to provide loans to businesses or projects that derive 90% or more of the revenues from activities linked to one of several SDGs that had been selected by HSBC. These selected goals include good health and well-being (SDG 3), quality education (SDG 4), and climate action (SDG 13). As of November 2018, 51% of the bond proceeds had been disbursed to projects related to SDG 9 (industry, innovation, and infrastructure); 30% to SDG 11 (sustainable cities and communities); 18% to SDG 7 (affordable and clean energy); and 1% to SDG 6 (clean water and sanitation).

Although the HSBC's SDG bond has not invested directly in soil remediation projects, it is noteworthy that the bond's eligibility criteria would definitely include soil remediation in relation to SDG 6, clean water and sanitation. The eligibility criteria outlined by HSBC includes activities that expand public access to safe and affordable drinking water and activities that improve water quality. Since soil remediation has a positive impact on groundwater quality (and, depending on location, also a positive impact on other freshwater sources), it could fall within the eligible criteria. Further, the eligibility criteria for SDG 11 on sustainable cities and communities include activities that expand or maintain the supply of affordable housing. Businesses and projects under this category would enable access for all to adequate, safe, and affordable housing, essential services, and sustainable transport systems. Remediated soils can be considered a component of ensuring safe housing, for example, for their use in the construction of social housing, therefore fulfilling the criteria.

Source: Adapted from Perera et al. (2018).

There are two coherent ways to alter the current state of bond financing for these types of projects: (i) change the design of the project, and (ii) change the investor. For this first idea of changing the project, while changing a soil remediation project may not be feasible, how that project is conceptualized can be altered. With a significant amount of green bond proceeds going to green buildings, soil remediation or mechanisms to prevent soil pollution can be funded so long as a green building is being constructed atop the land or an existing building is being renovated to meet certain green standards. Although the soil remediation and/or pollution prevention element of the project would add cost and may decrease revenue streams back to the bond issuer, attaching non-revenue-generating investments to revenue-generating investment is a method to address this issue. To enable this type of rethinking, policy support from all levels of the state will be required. This policy support would also force construction firms to include soil remediation or soil pollution prevention plans in all new buildings and renovations.

The second idea is to change the investor. Initiatives such as development impact bonds and social impact bonds have attracted investors who are willing to receive a lower coupon or lower repayment of principal if certain impacts from the bond are not attained (Center for Global Development, n.d.). These types of investors tend to have different motivations than purely financial returns and may pair well with soil remediation projects for which revenue may be tied to other outcomes. While the expansion of these types of specific initiatives may be limited due to the high transaction and monitoring costs associated with them, the funders that they attract align well with the type of investors needed to address the financing challenges of soil remediation projects. Developing innovative bond structures that focus on impact but do not endanger the principal repayment may be one way to attract these investors, alongside other traditional investors, to lower transaction costs and absorb the required costs of monitoring impact.

4.2.4 Climate Funds

For the purposes of this section, climate funds that may be used for soil remediation can be conceptualized in two ways: (i) as purely public vehicles in which only public funds are pooled, and (ii) blended funds in which public funds are combined with private finance. The first instance is exemplified by initiatives like the Global Environment Facility (GEF), Green Climate Fund (GCF), or the International Finance Corporation (IFC)–Canada Climate Change Program. Typically, countries, regions, and cities pledge at fund creation and during follow-on replenishments. These funds then have a capital base from which to fund projects through grants, loans, equity, results-based payments, and guarantees, among other instruments. In most cases, these funds only provide a share of the total capital required for a project, with other capital being provided by the investee company, other development banks, and/or local governments.

Climate funds are particularly advantageous sources of capital to tap for soil pollution prevention and remediation projects because of the clarity of their mandates. Their uniqueness lies in their flexibility with the types of instruments that they employ. In addition to this, as they are publicly funded or publicly backed, their funding is concessional, and they do not require at-market returns for their investments. Using the GCF as an example, it is clear that its funds are to be used for climate mitigation and adaptation projects that help developing countries reach their nationally determined contribution ambitions (GCF, n.d.-a). Therefore, if an entity has a soil project or any other climate-related project for which it needs funding, the GCF's mandate permits it to provide that funding. Moreover, as projects have varying capacities to return funds to investors based on the differences in how revenue may be generated from climate investments, the different types of instruments allow for flexibility to meet these issues. In many projects funded by the GCF, the fund will deploy grant funding that is coupled with equity or a loan. Frequently, the grant funding is earmarked for project development and technical assistance projects, which increase the likelihood of project success when funded by the second tranche of financing. For projects in countries that, either through project-specific or country-specific characteristics, are unlikely to have the capacity to repay, the grant share of the financing package is larger.

Box 4. InsuResilience Investment Fund

In 2017, the German Development Bank launched the InsuResilience Investment Fund (IIF) to align with the initiative on climate risk insurance that had been adopted at the 2015 G7 meetings in Germany. The purpose of the IIF was to improve access to insurance solutions in natural-catastrophe-prone official development assistance recipient countries. The IIF combined the provision of financial investments and technical assistance to participants across the insurance value chain, including insurance service providers, brokers, aggregators, and other businesses that can offer natural catastrophe coverage (IIF, n.d.). The IIF also aimed to reduce official development assistance countries' dependency on conventional public emergency assistance and international donors. Beyond that, premium systems of insurance companies incentivized insured parties to adapt to extreme weather events and other potential natural catastrophes by implementing effective measures to reduce their vulnerability and hence their premium payments. The fund is managed by BlueOrchard Finance, an impact investment firm; CelciusPro, a weather and climate insurance specialist; and reinsurers—all of which provide advice and guidance on risk capacity and risk tolerance.

Climate change has increased the risk of weather uncertainties and natural catastrophic events. Climate insurance products mitigate and hedge against risks associated with infrequent weather events. These products benefit by having access to donor funds that serve as seed money, first-loss provision, and a subsidy to reduce the insurance premiums of payers. This concessional capital allows private funders to provide complementary capital and technical assistance with less risk. Broadly, these types of insurance products can be classified among these two groups:

- Indemnity insurance: insurance payouts are issued when extreme events materialize in actual damage to the policyholders.
- Parametric insurance: insurance payouts are issued if defined threshold levels are exceeded (e.g., air temperature, precipitation volume, magnitude of an earthquake), irrespective of the actual damage.

Source: Adapted from Perera et al., 2018.

Much of the ability of these types of funds to have these focused goals and flexibility stems from the concessional capital to which they have access. For example, China and India, the two most populous developing countries and the two developing countries emitting the most carbon dioxide, have sovereign bond ratings of A+ and BBB- respectively (Balasubramanya, 2020; Bhat, 2020). The IFC, for its part, has had a AAA rating since 1989 (IFC, 2021). Therefore, a project financed by the IFC has a lower cost of capital than one that China or India can fund in its own country. Moreover, when donors create a fund, as is the case of the GCF, the cost of capital is effectively zero.[4] This allows these types of funds more flexibility to augment the risk-and-return parameters of a project and mobilize other funders—an important goal for these funds given the size of the climate-financing challenge.

This access to concessional capital is particularly important to the second stylized type of fund: blended funds in which public funds are combined with private finance. For the most part, these funds are based on the premise that concessional capital provided by governments or multilateral institutions can be catalytic in attracting private finance, as the concessional capital creates acceptable risk-return profiles for private investors and lowers the cost of capital to a reasonable level for beneficiaries in developing countries (Convergence, 2018). These blended funds and facilities are still able to provide financing to specific projects at below-market rates because the concessional capital is present (see Box 4 for an example).

An example of this type of mechanism is the AGRI3 Fund, which was launched in 2020 and is a partnership between UN Environment, the Dutch financial institution Rabobank, the development finance institution Nederlandse Financierings-Maatschappij voor Ontwikkelingslanden N.V. (FMO), and IDH–The Sustainable Trade Initiative. The AGRI3 Fund provides credit enhancement tools to commercial banks that are financing projects supporting (i) forest protection and reforestation and/or (ii) transition to more sustainable land-use practices, and that will (iii) improve rural livelihoods (FMO N.V., 2020). Among the financial instruments listed to support these endeavours are pari passu risk participation, tenor extension, maturity subordination, subordinated guarantee, first-loss risk participation, and a technical assistance facility (AGRI3 Fund, 2020b). Among the six primary key performance indicators that the AGRI3 Fund uses to target its investments is the number of hectares (ha) of degraded agriculture land restored (AGRI3 Fund, 2020a). As the degradation of agricultural land in China was flagged as an issue in the 13th FYP, it is evident that blended agricultural funds such as AGRI3 could provide funding to soil remediation projects.

Although climate funds appear to offer more flexibility than debt financing for those wanting to direct funds to soil remediation, these funds may not be as accessible as they appear at first glance. The GEF and GCF, for example, have stipulations whereby they will only work with specific parties in a specific country. For the GEF, a government needs to work with a GEF Partner Agency to secure GEF funding, and the project must be driven by the country rather than by an external partner (GEF, 2021a). Thus, if a private developer wants to undertake a large-scale soil remediation project, they have no access to GEF financing unless the government is involved. As of March 2021, the GEF had provided USD 1.4 billion in grants to projects in China; however, only 3.8% of these grants went to projects that specifically cited

[4] This crude example overlooks that donors to the GCF would also have sovereign credit ratings that imply a non-zero cost of capital; the funding of the GCF is not free.

land degradation as a focal area[5] (GEF, 2021b). The GCF operates slightly differently and requires that projects implemented using GCF funding are managed by an accredited entity (GCF, n.d.-b). However, the process to become accredited has been described as onerous and burdensome (Griffith-Jones et al., 2020). As of March 2021, only two China-based organizations have been GCF-accredited, and only one GCF project has been implemented.

A secondary issue that soil remediation projects in China are facing and will continue to face regarding the sourcing of climate fund finance is the mandate of these funds. Many of these funds, including the GEF and GCF, are specific in their desire to address issues in developing countries. Even in the face of economic difficulties associated with the COVID-19 pandemic, China expects to reach high-income status by 2025 (Fitch Wire, 2020). Therefore, investment managers and those responsible for meeting the mandate of these climate funds may view future investments in China as not meeting their goals of helping developing countries mitigate and adapt to climate change.

4.3 Applicability of Financing Instruments to China's Soil Remediation

As has been discussed above, the characteristics of soil remediation projects raise specific issues when they need to be financed. Among these characteristics, the long-term nature of the issue, the relatively small financial commitment required for individual projects, and the lack of clear capital repayment structures all weaken private investor appetite. The still-lagging specialized remediation industry and insufficient remediation technology and engineering experience needed for restoring contaminated sites create an additional barrier to financing. The soil remediation issue facing China requires patient capital from investors who have the ability to aggregate projects to make investments at scale and who are willing to take subordinated positions in the capital structure of soil remediation projects to attract private investment. The most likely providers of this capital are the various levels of government within China who, due to their abilities to take a long-term view of soil remediation, have the political and regulatory resources to "bundle" projects, and have the fiscal resources to incur lower or negative returns to capital in the pursuit of public goods provided by soil remediation projects. To take on this challenge, the various levels of government need to enhance financial resources and dedicate non-financial resources to solve the scalability issue.

Enhancing government resources for funding can be accomplished in several ways and alongside different actors. While financing instruments like TIFs and reserve funds outlined in the previous section enable the government to share the financial burden with actual polluters, it is imperative to acknowledge that China currently faces soil issues because these issues were not addressed in the past. In addition to this, in some cases, the polluters that are responsible no longer operate, and there is no recourse for the government. To resolve this problem, it is recommended that the government establish frameworks to ensure the accountability of current polluters. The new Law on the Prevention and Control of Soil Pollution is a first step in this regard but needs to be clearer to guarantee its efficacy. Further, the government must remain motivated to fund soil remediation projects, not only because it is a progressive political decision but also because the government is the "financier of last resort" in this case. If China's government resources are constrained because of its rising debt

[5] Based on the authors' calculations using GEF project database.

levels, the government will have to balance different needs and prioritize the most urgent soil remediation projects over other development goals, recognizing the role of remediated land for food security and livelihoods. The most recent FYPs have resulted in soil remediation receiving greater attention, but, given the size of the problem, it is unlikely that government resources on their own will be the complete solution to the problem.

Despite concerns over rising debt levels, innovative financing instruments like green and sustainability bonds can assist by being a part of the solution, whether they are issued by various levels of the state or private firms. The reason for this optimism is that in the case of both green and sustainability bonds, soil remediation projects can be part of a larger portfolio of projects funded by bond proceeds. These proceeds may allow other projects within the portfolio to compensate for the fact that revenue streams are unlikely to flow directly from soil remediation projects. These bonds could also address the scalability issue, as multiple soil remediation projects could be aggregated under one financing umbrella. Moreover, with the growth of the volume of bond issuances, in addition to the subsequent growth in investor appetite, there is a natural alignment for the usage of these instruments to increase in China's dynamic financial markets.

While it is feasible that both public and private actors can increase the amount of financing available for soil remediation, the recent evidence suggests that private actors are unlikely to invest in these types of projects without being incentivized to do so. It is here where government can play a vital role by taking riskier tranches of the project finance structure or by creating special-purpose vehicles with private investors that include the soil remediation of numerous sites. The current risk-and-return profile of soil remediation projects is not attractive enough for private investors; governments, with their access to cheaper capital, can alter these profiles to make these projects more investible or can alter the profiles by allowing private investors to minimize relative transaction costs through larger-ticket sizes if projects can be aggregated. As it seems that private actors have yet to attempt to aggregate these projects on their own in the context of China, it seems logical that government would have a role in this process. Moreover, under a special-purpose vehicle structure, the government may be able to off-load its interest if the project were to be financially viable without continued government funds or backing. As a first step, governments at all levels in China could conduct outreach and engage with private investors to better understand specific barriers to investment in soil remediation projects and the role of the public sector in lowering these barriers.

The discussion above acknowledges that even despite the economic power of the Chinese public sector, the required effort and heavy costs associated with soil remediation in China will require financing structures that access a combination of investors using diverse instruments for different types of projects. For example, the government may work with private investors and guarantee loans, a climate fund may provide a project developer with first-loss capital, or bond proceeds may be combined with reserve fund financing. The section above has presented these resources and instruments as independent, but, in reality, large, complex financing structures source their capital from multiple funders. As different investors have different risk-and-return profiles, the governments in China can employ their financial resources and regulatory capacities to fill gaps in financial structures that currently impede efficient soil remediation financing. Going forward, those looking to fund soil remediation and soil pollution prevention projects must remain mindful of these various options outlined above and maintain flexibility to respond accordingly.

5.0 Summary and Recommendations

Despite the seemingly widely adopted international standards on the management of soil remediation sites, contaminated sites remain a significant global challenge, causing irreparable harm to human health and the ecosystems of our planet (Food and Agriculture Organization & UN Environment Programme, 2021).

In China, according to a government survey report, nearly 20% of farmland was contaminated as of 2014 (MEE, 2014a), with only 2% expected to be remediated by 2020 (State Council, 2016). But China is not alone in facing this dire situation. In Europe, there could be as many as 2.5 million contaminated sites across the continent. Among the 650,000 sites officially registered by governments, only 10% are remediated (Paya Perez & Rodriguez Eugenio, 2018). Similarly, through its Comprehensive Environmental Response, Compensation, and Liability Act, the United States has established a National Priority List of hazardous waste sites that are eligible for long-term remedial actions under its Superfund program. Since 1980, 1,769 sites around the country have been added to that list, and over 75% still remain to be cleaned up as of October 1, 2021 (United States Environmental Protection Agency, 2021). Globally, soil contamination affects a third of our ecosystems. Although the exact scale of worldwide soil pollution is yet unknown, recent studies have estimated that at least 22 million ha of our planet is contaminated (Haller et al., 2020).

This guidance has explained some of the challenges preventing effective actions from being taken to tackle soil pollution:

- *Insufficient awareness and technical capacity in preventing soil pollution*

  As in many other situations, an ounce of prevention is worth a pound of cure. There is an urgent need for education regarding good soil management practices and awareness raising on the importance of preventing further soil pollution. There is also a strong need for technical capacity for on-site soil pollution monitoring and surveillance mechanisms, as well as the ability to take enforcement actions against polluters.

- *Significant risks in carrying out soil remediation projects*

  Soil remediation projects carry certain risks, which vary from one project to another depending on the level and type of degradation (biological, chemical, or physical). More specifically, these risks may include

  - Legal risks: for example, regarding the interpretation and compliance of contracts related to grants or loans for soil remediation projects
  - Regulatory risks: related to changing legal frameworks, requirements, and obligations
  - Social risks: related to citizens' dissatisfaction, for example, if the project implies resettlement
  - Political risks: for example, the acceptable level of pollution may be changed due to changes in political structure, and this impacts the project itself and the remediation methods used.

   - Technical risks: for example, equipment failures and breakdowns; problems with the use of new technologies; failure to follow the schedule of the remediation project
   - Market risks: the contamination of land usually impacts the property value negatively, which makes the investors reluctant to get involved.

  Those risks vary from project to project, but generally, they constitute an obstacle that often discourages stakeholders from getting involved in remediation projects. This problem links to the previous challenge, which clearly indicated that without proper education for stakeholders on minimizing the risks and using modern solutions, it will be very challenging to carry out effective projects and grasp stakeholders' attention.

- *Difficulty in identifying liabilities*

  Although the "polluter-pays principle" remains a fundamental principle in many jurisdictions, in practice, those responsible for soil contamination in the past often remain unidentified. This is due to the complex nature of soil pollution, which can be caused by multiple actors over a lengthy period. Even when the polluter is identified, in many cases, it would be difficult for them to fulfill the liability due to a lack of resources or know-how to carry out the necessary remediation.

- *Huge financial gaps in financing soil remediation projects*

  Soil remediation projects are known for their long project cycles. Many would require a large amount of capital commitment upfront and lack a clear business case for return on investment. As a result, most of the soil remediation projects to date rely entirely or primarily on public funding, which leaves a significant gap, considering the scale of the problem. For example, for the past 40 years, the Superfund program has cost the U.S. government an average of USD 1.2 billion per year, with a large number of the sites on the National Priority List yet to be remediated (as of 2018) (Furuseth et al., 2018). In China, although the government allocated CNY 150 billion (approximately USD 23.5 billion) for soil remediation projects from 2016 to 2020 (Dong et al., 2018), it remains unclear how China will meet the CNY 6,000 billion financing gap needed to remediate the polluted farmland across the country (Zhang & Zhou, 2016).

- *A significant science-policy gap*

  On the one hand, successfully carrying out soil remediation projects requires highly complex scientific knowledge. On the other hand, the process of soil remediation will result in direct and sometimes transformative impacts to the community where such projects are being carried out—not only an environmental impact but also social and economic impacts. However, to date, policy challenges are not yet often considered when making scientific calculations. At the same time, scientists have not always been successful in translating complex scientific knowledge to the decision-making process of the policy-makers.

Considering these challenges, this guidance document recommends the following for the relevant stakeholders in designing, implementing, and managing soil remediation projects in China:

- Soil remediation is a complex problem that requires a mix of different solutions for different situations. However, to prevent soil from being contaminated in the first place, emphasis should be focused on pollution prevention. More efforts should be invested in raising public awareness and improving technical capacity for pollution prevention.
- Effective soil remediation actions require a systemic approach, which should encompass scientific knowledge to policy-making to regulatory enforcement and implementation. In addition, soil remediation should also be considered in the context of other global challenges we are facing today, for example, climate change, biodiversity loss, health and food safety issues, and so on.
- Effective soil remediation action also requires active engagement from all stakeholders, such as property owners, scientists, policy-makers, local communities, and those in the business sector. It is important to engage these stakeholders at the early stage of remediation planning so a suitable remediation plan can be developed.
- Legal and policy frameworks should be established to encourage affordable, scalable, and effective technologies for soil remediation.
- The "polluter-pays principle" should remain the fundamental principle in identifying liabilities. Effective monitoring and enforcement mechanisms are crucial in ensuring accountability.
- Considering the risks associated with soil remediation projects and their social and environmental impacts, government should maintain a vital role by participating in the project financing structure or by creating special-purpose vehicles with private investors that include the soil remediation of numerous sites.
- Meanwhile, it is important to use public funding "intelligently" and to leverage the existing public funding to mobilize private resources; innovative financing instruments can play an important role in this regard. This may require enabling an environment for flexible financing structures that can access a combination of investors using diverse instruments for different types of projects.

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Appendix

Table A1. Formulations of human health risk assessment: The Hg exposure analysis

Types or model	Exposure pathway	Formulations	Absorption efficiency	Introduction
Risk-Based Corrective Action	Oral intake	$DI = \frac{C_s \times F_a \times AID \times EF \times ED}{BW \times AT}$	F_a	DI is oral intake of soil dose rate; F_a is the absorption factor; AT is exposure time; EF is exposure frequency; ED is exposure period; DAL is exposure dose rate of soil particles by skin contact; DAE is skin contact rate; AEXP is exposed area of skin; F_m is skin contact absorption factor; BW is body weight; AT is exposure time; and C_s and CW are Hg concentration in soil and water.
	Skin contact	$DAL = \frac{C_s \times DAE \times AEXP \times F_m \times EF \times ED}{BW \times AT}$	F_m	
	Drinking	$Intake = \frac{CW \times IR \times EF \times ED}{BW \times AT}$	None	
Risk Assessment Guidance of Superfund	Oral intake	$Intake = \frac{CS \times EF \times ED \times CF}{BW \times AT}$	None	In the Lake RBCA model, CF is unit conversion factors, and FI is the percentage of contamination in the total food.
	Skin contact	$Intake = \frac{CS \times SA \times ABS \times EF \times ED \times CF}{BW \times AT}$	ABS	
	Food intake	$Intake = \frac{CF \times IR \times FI \times EF \times ED \times ABS_{gi}}{BW \times AT}$	ABS_{gi}	
	Drinking	$Intake = \frac{CW \times IR \times EF \times ED}{BW \times AT}$	None	

Types or model	Exposure pathway	Formulations	Absorption efficiency	Introduction
Guidelines of risk assessment for contaminated sites	Oral intake	$OISER_{nc} = \frac{OISER_a \times ED_a \times EF_a \times ABS_{mouth}}{BW_a \times AT_{nc}} \times 10^{-6}$	ABS_{mouth}= 1	$OISER_{nc}$ is daily intake amount of soil; $DCSER_{ncs}$ is skin contact with soil exposure (non-carcinogenic effect); AI_{air} is exposure by respiratory inhalation; $FISER_{nc}$ is edible food exposure (non-carcinogenic effect); $CGWER_{nc}$ is groundwater exposure by drinking affected groundwater (non-carcinogenic effect); ED_a is exposure duration of adult; EF_a is adult exposure frequency; E_v is daily exposure event frequency; BW_a is body weight; AT_{nc} is exposure time; ABS are absorption factors for various exposure pathways; $OISER_a$, $DAIR_a$, $FIRL_a$, and $CGWCR_a$ are daily intake by oral intake, respiratory inhalation, food intake, and drinking; and SAE_a is the occupied area ratio of skin exposure for adults.
	Skin contact	$DCSER_{nc} = \frac{SAE_a \times SSAR_a \times EF_a \times ED_a \times E_v \times ABS_{skin}}{BW_a \times AT_{nc}} \times 10^{-6}$	ABS_{skin}= 0.001	
	Respiratory inhalation	$AI_{air} = \frac{DAIR_a \times EF_a \times ED_a}{BW_a \times AT_{nc}} \times 10^{-6}$	None	
	Food intake	$FISER_{nc} = \frac{FIRL \times EF_a \times ED_a \times ABS_{food}}{BW_a \times AT_{nc}} \times 10^{-6}$	ABS_{food}= 1 (MeHg), 0.07 (IHg)	
	Drinking	$CGWER_{nc} = \frac{GWCR_a \times EF_a \times ED_a}{BW_a \times AT_{nc}} \times 10^{-6}$	None	
Human Hg exposure	Respiratory inhalation	$ID = \frac{CM \times IR \times EF \times ED}{BW \times AT}$	0.7	ID is lifelong average exposure; CM is the Hg content in different media; IR is the intake rate; EF is frequency of contact; ED is exposure cycles; BW for body weight; and AT is life days.
	Drinking		1 (MeHg), 0.07 (IHg)	
	Crops intake			
	Meat intake			

Source: Sino-Norwegian Cooperation Project on Reducing Hg Pollution, Phase 3, 2016.

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