

Article

Decision Support Models for Site Remediation: An Evaluation of Industry Practice in China

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Abstract: China is currently facing great challenges in preventing land from further contamination by industrial activity. We evaluated the current state of business activity supporting the prevention and control of soil pollution through good waste management practice to restrict further soil contamination. The study focused on understanding drivers to improve the development of business activity in both waste management and remediation sectors in China. The status of organizations which manage solid waste and industrial operations providing remediation, professional materials, equipment, and approaches to site management are highlighted. Using questionnaires and a limited number of follow-up interviews, we consulted with remediation practitioners (>100 respondents including construction contracting workers, consultancy, equipment suppliers, and government department employees) working across China. The results identified that the site risk assessment and the wider construction phases for site remediation are typically based on guidelines from government and/or local government. The most frequently used materials for solidification or stabilization during remediation were clay minerals. Local government funds financed most remediation activities. Waste recycling would be a path to further reduce pollution from site development and its application in remediation techniques is possible. In addition to remediation methods, a strategic framework can be employed to provide decision support when assessing sites or decision-making for remediation projects. The priorities for remediation highlight that two types of soil use (arable land and land for construction) should be prioritized for remediation. This evaluation of industry practice provides useful models for wider decision-making in site remediation.

Keywords: regulation of land remediation; solid waste management; land remediation industry; decision-making model



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1. Introduction

In China, rapid economic growth, improvement of living standards, and overconsumption have deteriorated the quality of the environment since the implementation of the Reform and Opening policy in 1978 [1,2]. Through increased public awareness of environmental problems, much more effort has been made to decrease the impact of pollution. However, soil or land contamination is still poorly perceived by normal citizens as it is only highlighted when they have been directly affected by pollution or they are aware of soil quality tests. In addition, this creates difficulties for industrial development, even though the government has invested USD 164 billion in its treatment to date [3,4] and implemented better regulations, guidelines, and laws to guide remediation properly and prevent potential further contamination.

The impact of soil contamination started to draw public attention in 2004, when an incident took place at Songjiazhuang Subway Station in Beijing and three construction workers were poisoned [5]. Between 2013 and 2015, a total of 100 major soil remediation

projects were undertaken (28, 40, and 32 each respective year), with farmland restoration only accounting for 10% of the projects [6,7]. The first soil contamination map was made available to the public in 2016 after public outcry over the discovery of soil contamination in the Changzhou School in 2015, which led to symptoms of eczema and skin inflammation for almost 500 students [8]. To manage the soil contamination at the source, 4500 key industrial enterprises and solid waste treatment and disposal units were identified as priority targets (including 3998 state-controlled pollution sources and 502 non-state-controlled pollution sources with environmental violations), as well as 729 key sector industrial parks, and these were registered on a soil pollution risk source distribution map by the institute of Public and Environmental Affairs of the PRC [8]. Soil pollution is a costly issue that may limit land redevelopment and hamper future construction [7] with potential long-term health risks to humans and wildlife. The excavation and direct disposal methods ('dig and dump') are widely used to quickly resolve complex contamination problems as they are low-cost and consist of simple steps but increase the overall cost of the treatment of soil contamination. Public awareness of sustainable environmental management has increasingly discouraged non-sustainable landfill disposal of polluted soil or other solid waste [9]. The regulations for landfill operation show a trend in the implementation of more stringent legislation on the disposal process. These factors promote or force the development of remedial technologies or solid waste treatment methods for sustainable resource recycling/conservation in land remediation and waste disposal [10–14].

As soil pollution has received wider public attention, the first national soil contamination survey was carried out by the Ministries of Environmental Protection and Land and Resources [15]. The results showed that 16% of investigated land (6.3 million km², or two-thirds of China's total land area) was polluted beyond limits of acceptable standards, with 19% of investigated arable land polluted to limits of standards, and 83% of the contaminated sites contained excessive concentrations of potentially toxic elements [15]. National technical guidelines have been implemented since 2014 [16–19] and subsequently updated in 2019 (see Section 3.1 below). More detailed standards and regulations have also been implemented to guide soil pollution treatment. Treatment in China has also been based on regulations or limit guidelines from the US and other countries, increasing the diversity of treatment technologies available [20].

The causes of contamination come from many human activities, such as hazardous solid waste (HSW) being inappropriately sent to landfill and additional potential pollution for soil and even groundwater from landfill leachates [21]. New techniques include the application of specialist materials such as carbon nanotubes, composites, and magnetic materials, for example, for mercury removal [22]. Advances in soil stabilization as a treatment strategy have also produced impressive results with improved engineering properties for treated materials [23]. Many recycled materials from developed countries have been brought to China to supply raw resources for industrial development; however, improper dismantling of WEEE, and unqualified or illegal smuggling of wastes has resulted in toxic contaminants causing direct and indirect soil pollution [24]. The implementation of the Waste Ban by China in July 2017 was designed to stop the import of recycled waste and to reduce the impact and potential environmental and health risk from handling solid waste [25]. Recycled solid waste had been used as an industrial raw material for decades and the cancellation of imports created a shortage of recycled materials, so the Chinese government made an effort to encourage local industrial and private personal waste collection and classification to boost the development of solid waste management systems [26,27]. However, many potential sources, such as waste tailings from mining, have not previously been evaluated and applied because of the potential risk of secondary contamination, especially in the application of wastes associated with metal mining [28].

Solid waste governance aims to balance customer benefits and social costs, efficiency, and fairness to curb failures of government, society, and the business market, promoting industrialization and industrial planning in the treatment of solid waste [29]. Solid waste management mainly refers to the supervision and management of solid waste treatment,

such as governmental management of the solid waste treatment industry. It consists of methods or policies from the government to ensure the development of the solid waste treatment industry and their efficient working. To be specific, the process of solid waste management ensures solid waste treatment in a harmless, resource-reduced way [30]. Solid waste treatment includes the processes and techniques to reduce potential harm and provide efficient resource utilization, and reduces solid waste and identifies products and technology needed to cope with an increasing volume. More attention has been paid to specific sources of solid waste demanding direct management [31], material application, energy utilization, landfill disposal, and other processing work, as well as coordination of solid waste treatment processes [32,33].

While research on treating contaminants in air and water in China has been carried out for a few decades [34–37], research on polluted soil is poorly developed in comparison. The relationship between solid waste management and contaminated soil remediation is still more complicated as, for example, the improper treatment of metal mining tailings has led to contamination in soil, land, and sediment directly or indirectly through water flowing to rivers. Hazardous waste from dredged sediment from rivers is routinely landfilled, which also indirectly adds contaminants to the soil [38], as these sites are also used for solid waste management.

The specific activities in metal mining operations include waste generation and disposal and these are a major source of contamination in mining sites from primarily potentially toxic elements (PTEs). Management technologies used include capping to cut off the exposure pathways in soil remediation projects [39]. It is difficult to also consider the potential risk before the site investigation and post remediation if treatment does not include removal from the site. To manage all aspects of the soil remediation challenge, the “6w1h” ideology for consumer behaviour in innovation for problematic production processes can be applied. This includes the financial budget and considers the liability for the treatment of contaminated soil and groundwater [40].

Fast-paced development and large-scale applications related to soil remediation in contaminated sites pose several direct and indirect challenges for practitioners, regulators, and researchers [41]. Technological methods needed for soil remediation industries have been discussed for future application in China [39]. Practitioners in industries face all these unanticipated problems and need to be ready to solve them during the life cycle of remediation projects. However, little research has been carried out to understand the challenges or difficulties in target setting, capital guarantees, and marketing products for soil remediation industries that might impede the further development of environmental remediation industries in China.

We undertook an assessment of the status of industries in the soil remediation business and the potential for longer-term sustainable development for the industries that specialize in waste management in China. By using a questionnaire survey and interview of practitioners, we explored possible future business models for the design of regulations and related research methods to support the development of this industry sector. The objectives included: (a) To start the investigation of the relationship between remediation and waste management; (b) To analyze the solid waste management system in China with consideration of waste material classification: municipal solid waste (MSW) from cities and suburban areas, common industrial solid waste (CISW) from industries and processing, and HSW from contaminated sites and industries; (c) To confirm the current regulations for remediation aligned with waste management; (d) To develop a decision support model in soil/remediation with consideration related parameters in implementation of remediation projects.

This study investigated the behavior of practitioners in the Chinese soil remediation industry through a questionnaire and interviews. This was particularly important because of the specific localized characteristics against a background of a rapidly developing economy with a large growing human population, wide climatic and geographical variability, and complex regional characteristics. Limitations of the study arise from the decision-making

process to select methods and human analysis paths during the progress of implementation. Although decisions are made after much consideration to select the most suitable method, these are also influenced by language and culture-specific communicative styles.

2. Materials and Methods

A process flow chart for the survey and methodology summary is provided in Figure 1.

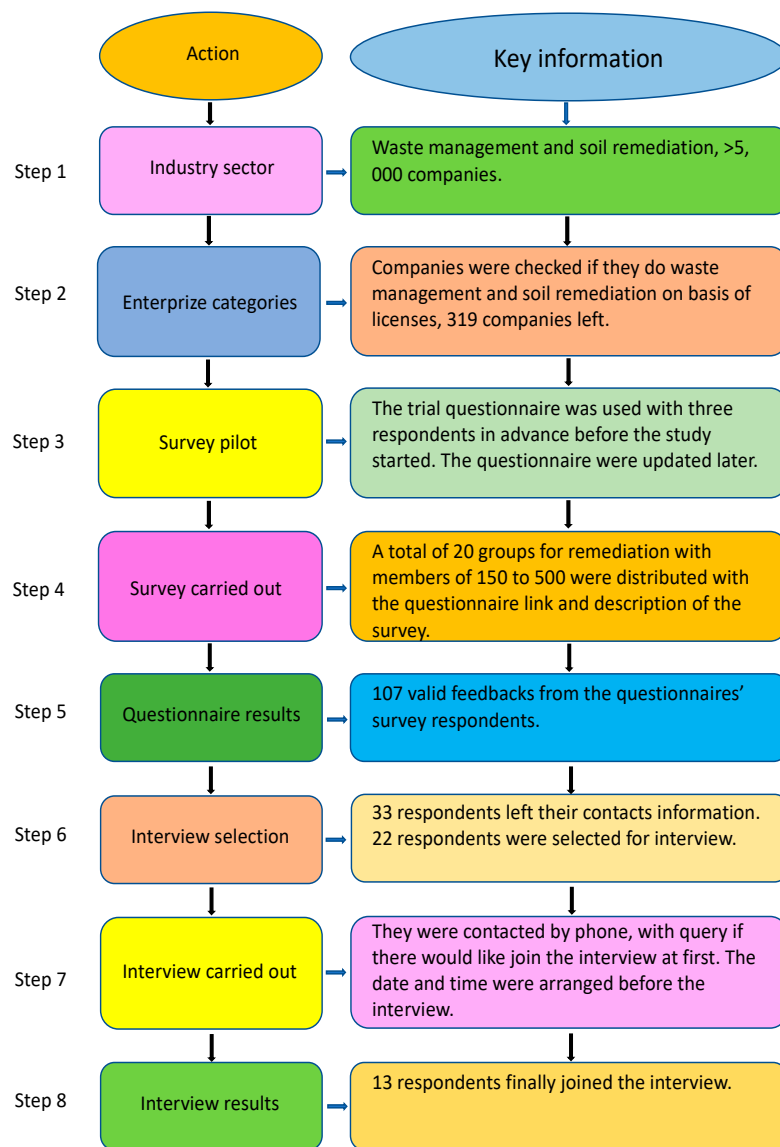


Figure 1. A summary of the methodology framework for data collection in this study.

The survey design and collection of data were approved by the Research Ethics Committee of the School of Engineering, Computing & Physical Sciences, University of the West of Scotland (approval #2019-9441-7769). The main stages included participant selection, recruitment, and carrying out a short pilot before releasing the main survey.

Candidate companies were identified from information collected from the website Qichacha.com and official website (available online at <http://www.mohurd.gov.cn/> (accessed on 1 July 2022) [42]) in 2019 before the start of the COVID-19 pandemic. More than five thousand Chinese companies were identified in the soil remediation and waste treatment sector in the first review of the database. These were screened for compliance with permit/certification by the Chinese government to provide a pool of >300 organizations (see Figure 1 and Table 1). A pilot survey with a draft questionnaire was carried out with

a group of three professionals and feedback was incorporated in the final questionnaire, designed following recognized guidelines [43,44].

Table 1. Companies that deal with solid waste treatment and/or soil remediation in China.

Areas of China	Provinces or Cities ¹	Either ²	SWT Only	S/LR Only	Both ³
North China	Beijing	18	14	8	4
	Tianjin	6	3	5	2
	Hebei Province	10	9	5	4
	Shanxi Province	10	7	5	2
	Inner Mongolia	1	1	0	0
Southwest China	Sichuan Province	24	20	11	7
	Yunnan Province	7	5	4	2
	Chongqing	7	4	5	2
	Tibet	1	1	1	1
	Guizhou Province	2	2	1	1
Central China	Hunan Province	58	52	51	45
	Hubei Province	17	12	13	8
	Henan Province	10	6	6	2
	Anhui Province	6	4	5	3
	Jiangxi Province	5	3	3	1
Northeast China	Heilongjiang Province	2	2	1	1
	Liaoning Province	12	7	10	5
	Jilin Province	1	0	1	0
East coast China	Shandong Province	8	6	5	3
	Shanghai	7	2	6	1
	Fujian Province	10	9	5	4
	Jiangsu Province	41	29	31	19
	Zhejiang Province	10	7	8	5
Northwest China	Shaanxi Province	7	6	2	1
	Xinjiang Province	2	2	2	2
	Gansu Province	1	0	1	0
Southeast China	Guangdong Province	32	22	22	12
	Guangxi Province	4	3	2	1
Total	28	319	238	219	138

¹ Only provinces or cities with data are listed in the table. Note: SWT refers to companies that deal with solid waste treatment; S/LR refers to companies that deal with soil/land remediation; ² either refers to companies that either deal with solid waste treatment or soil/land remediation; ³ both refers to companies that deal with both solid waste treatment and soil/land remediation.

The questionnaire survey was sent, via an online link with an invitation to various soil remediation specialist groups on the QQ/WeChat social media app, to a group that included practitioners who worked in different Chinese cities, to understand the relationship between soil remediation and waste management in China from their work experience. The survey targeted participants to include contractors, equipment providers, regulators, environmental consultants, contaminated site owners, and environmental groups, etc. Before the respondent started to complete the questionnaire, an introduction explained the objective of the survey, how data would be used and how the confidentiality of respondents would be guaranteed. All participants could withdraw from the study any time before submission. To encourage response, the participants were offered a future report and feedback from the survey.

Several studies have previously approached similar groups to explore the application of remediation technologies and decision-making in soil remediation-related practices [45–47]. However, we addressed the more immediate dynamic pressures on project delivery as directly identified by practitioners, rather than the outcomes of completed projects. The questionnaire was designed to address the following topics: (i) basic infor-

mation about the respondents, work experience, location of remediation sites, and their company type; (ii) various service types offered by companies and frequency of deployment (including third-party testing services, remediation construction, specialist materials and equipment support); (iii) one example of stabilization and corresponding waste application potential; (iv) regulations applied in various phases of development; (v) factors considered in decision-making for remediation. These latter factors were quite diverse and included issues of funding sources, intellectual property, the review of proposals and the decision-making process, the factors important in the assessment of the success of remediation, commercial activities and competitiveness of businesses and market advantage, target setting, remediation efficiency testing, and ranking of importance of the various factors. Respondents were asked to rank factors in order and were provided with an opportunity to identify any missing issues. Results were assessed based on the proportion of responses. The sample population of all groups together consisted of all stakeholders involved in practical projects and/or decision-making. A total of 107 valid feedback responses were received including from researchers at university and/or research institutes and staff in different positions in a range of companies in the sector.

Participants in the questionnaire were given the opportunity of a follow-up interview in which a total of 13 respondents/companies provided detailed interview feedback.

3. Results and Discussion

3.1. Regulations Applied

Some regulations are specifically focused on the application or development of treated polluted agricultural land and land for construction, such as Soil Environmental Quality: Risk Control Standard for Soil Contamination of Development land (GB36600-2018) and Soil Environmental Quality: Risk Control Standard for Soil Contamination of Agricultural Land (GB15618-2018).

A big change from treatment to management is that attention is being paid to management of contaminated industrial or mining sites on the basis of Measures for the Soil Environment Management of Industrial and Mining Land (for Trial Implementation). Many regulations have begun to be implemented since 2014 [48], so more domestic regulations can be adopted by practitioners, and the corresponding regulatory system is more comprehensive. There are still some special pollutants in project construction and US laws and regulations could be used as references for specific values if none can be found in Chinese regulations. As shown in Figure 2, the technical guidelines for risk assessment of soil contamination of land for construction (HJ 25.3-2019) had the highest percentage of 35% application in the risk assessment phase among all relevant regulations. This emphasizes the importance of legal compliance in the risk assessment phase. Most contaminated sites have legacy pollution and are occupied by state companies. Consequently, treatment is the responsibility of the government.

Risk assessment plays a significant role in driving the remediation process [49–51], and the guidelines are predominantly used to evaluate methods for risk assessment of treatment projects [40]. However, more detailed options for each guideline are provided [52–59] and locally focused standards were highlighted by the survey respondents as being applied in the risk assessment phase only, or were used repeatedly across the entire project delivery. For all regulations, the “risk assessment phase only” had the lowest category of application and generic guidelines and local standards were both significant components of the decision-making process across project lifetimes.

A significant proportion of respondents (69–83%) highlighted listed guidelines or standards, with 35% of respondents choosing the Technical Guidelines for Risk Assessment of Soil Contamination of Land for Construction (HJ 25.3-2019) for the risk assessment phase only, as other guidelines address risk control. However, 41–64% of respondents used all regulations, laws, and standards repeatedly in the entire project decision-making period, including both the Law of the People’s Republic of China on Prevention and Control of Soil Contamination (LPRCPCSC) and the Soil Environmental Quality Risk Control Standard

for Soil Contamination of Development Land (GB36600-2018) in the case of new problems or risk arising once the project had started. The second- and the third-biggest percentages of 62% and 61% related to use of Measures for the Soil Environment Management of Contaminated Land (MEP No. 42) and Notice of the State Council on Issuing the Action Plan for Soil Pollution Prevention and Control (SC issued (2016) 31), respectively.

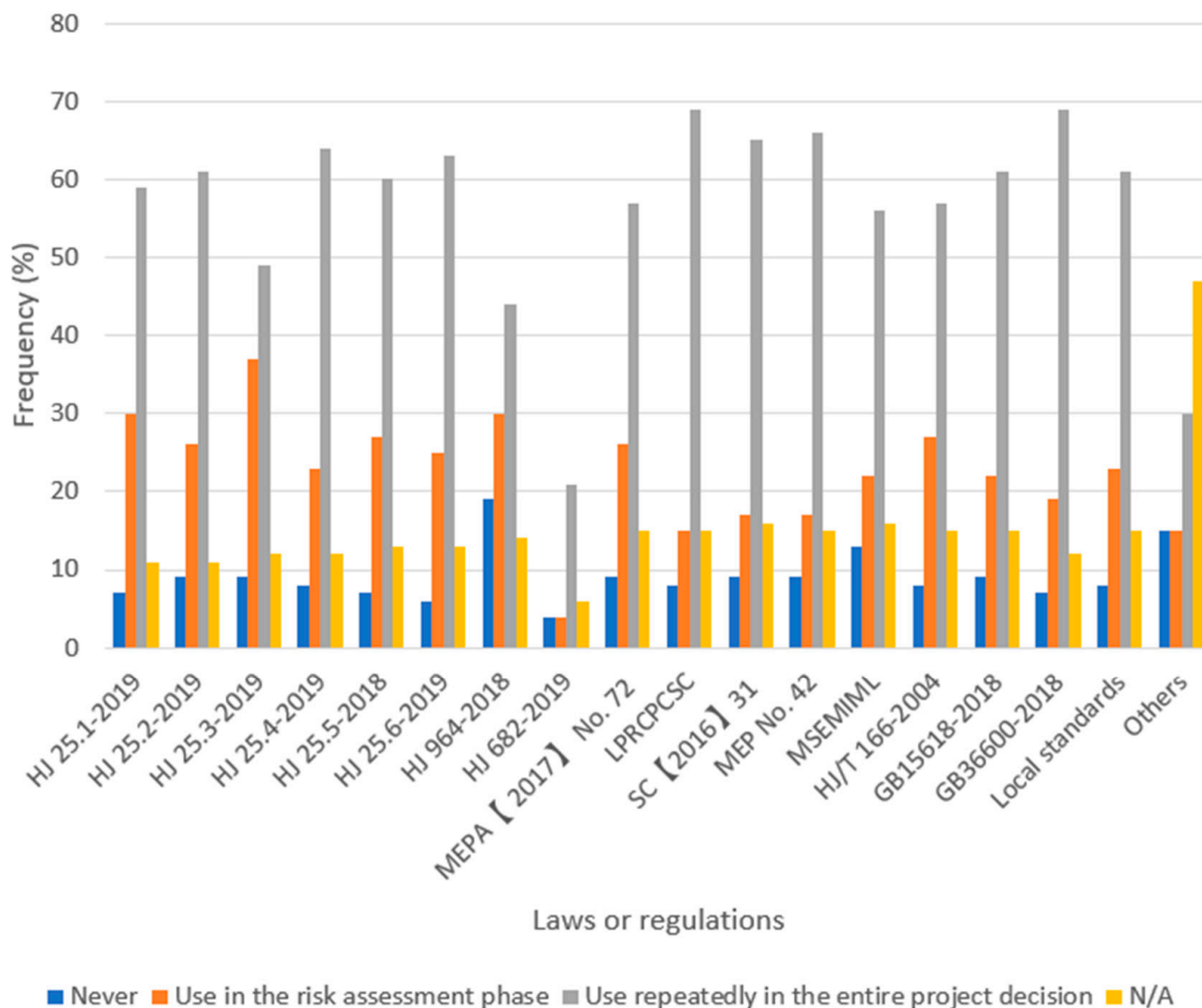


Figure 2. Frequency of use (%) for each relevant regulation/standard for different phases of remediation projects.

The feedback described a trend in decision-making where prevention, management, and control of soil contamination were of the same or even more significance compared to clean-up of contaminants. Around 60% of respondents used the Technical Guidelines for Soil Remediation of Land for Construction (HJ 25.4-2019). This is a comprehensive description of the soil remediation process that involves decision-making to select remediation models, screening of remediation technology, and developing a remediation plan. The Terms of Risk Control and Remediation of Soil Contamination of Land for Construction (HJ 682-2019) were also used by 60% of respondents because they can be used for the definition of terms, checking, and translating related guidelines from other countries such as the USA or UK.

‘Zero waste cities’ are emerging from the current Chinese urbanization process and this aspiration is also mentioned as an innovative method to gain funding support to help prevent further soil contamination. The methods for control of soil remediation in the

Measures for Funds Management of Soil Pollution Prevention and Control ((2021) Ministry of Finance of the People's Republic of China No. 42) (available online: http://bj.mof.gov.cn/ztdt/czysjg/zcfg/202108/t20210802_3742309.htm (accessed on 1 July 2022)) were promulgated and became effective on 2 June 2021. These regulations mention the point 'Carrying out the construction of 'zero waste cities' achieved practical results as a method to prevent and control contamination' for the first time since the launch of government funding for the remediation of soil pollution in 2011. The process revealed that the final goal of soil remediation is waste control and sustainable management, and the overall reduction of environmental pollution.

3.2. Solid Waste Management

During the process of remediation and treatment of land contamination, contaminated soil would be classified as solid waste if it was disposed of or utilized in any of the following methods: (a) landfill; (b) incineration; (c) co-processing in cement kilns; (d) production of bricks, tiles, road construction materials, and other building materials. The contaminated soil used as soil after remediation is not managed as solid waste (Identification Standards for Solid Wastes General rules of PRC (GB34330-2017)). The polluted soil needs to be identified and evidence provided to show it meets or does not meet hazardous waste criteria after being identified as solid waste. If ex situ remediation is used and contaminated soil is transported, the approval process for transportation of polluted soil should be based on the Law of the People's Republic of China on Prevention and Control of Soil Contamination 41, which demands: "If the remediation construction company transfers contaminated soil that is not hazardous waste, the company needs to formulate a transportation plan, and submit the report that consists of the transportation time, method, route and quantity of contaminated soil, destination of transportation, and final disposal measures to the ecological environment authorities of the site and corresponding receiving site in advance". If the remediation construction company transports polluted soil that meets hazardous waste criteria, the company should obey the in Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Waste.

If the leaching test applied to any hazardous material, prepared in accordance with the method HJ/T 299 (Solid Waste-Extraction Procedure for Leaching Toxicity—Sulfuric Acid and Nitric Acid Method. Environmental Protection Industry Standard of PRC) exceeds the concentration limit value listed in the national standard Identification Standards for Hazardous Wastes—Identification for Extraction Toxicity (GB 5085.3-2007) in PRC, the solid waste is determined to be hazardous waste with leachate toxicity characteristics. The contaminated soil could be treated as inert solid waste if the concentration of pollutants in the leachate does not exceed limit value in the national standard.

As shown in Figure 3, the total MSW generation has been growing over the past four decades. To be specific, the annual amount of MSW generation in China has increased eightfold from >30 Mt in 1980 to >240 Mt in 2019. When considering the volume of waste treated to meet harmless criteria (which means the solid waste was disposed of by methods such as landfilling, incineration, and composting) for MSW, this increase was one hundredfold, from >2 Mt in 1980 to >240 Mt in 2019 [42]. There was an abrupt decrease of the total MSW generation in 2006 and thereafter followed by an increase again, which might be attributed to the new certification standard adopted for landfill amounts in domestic MSW treatment since 2006 [42]. The quantity of treated MSW (including sanitary landfill, incineration, and composting) started to increase in 1991 and grew quickly from 2007 to 2018, with gaps between the quantity of MSW generated and quantity of MSW treated (harmless) becoming smaller, which shows the increased amount of treatment taking place in the sector.

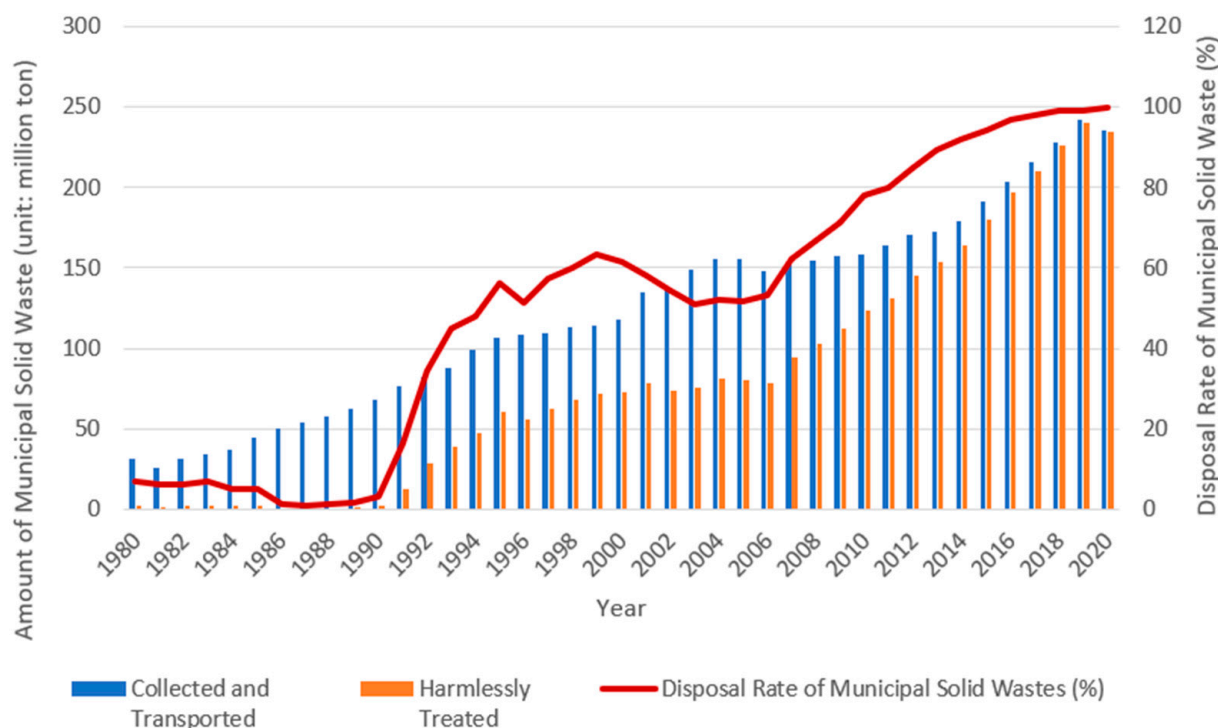


Figure 3. Amount of municipal solid waste collected, transported, and rendered harmless (treated) of PRC in 1980–2020 (all annual data are collected from the National Bureau of Statistics of PRC, available online: <http://www.stats.gov.cn/tjsj/ndsj/> (accessed on 1 July 2022)).

The waste ban in China started because of the illegal smuggling of hazardous waste [60], which increased the economic burden on the sector because of the increased need to remediate.

As shown in Figure 4, according to data from [61], the amount of CISW management generated in China was >3800 Mt in 2017. The generation of CISW in 2002 had increased by 66% compared with the amount in 1989 with continual growth [62]. As shown in Figure 4, the generation of CISW in 2009 had increased steadily by >100% compared with the amount in 2003. Then, there was a rapid increase of >18% in 2010 and a sharp growth of >30% in 2011 compared with data in the previous year. The generation of CISW was steady from 2011 to 2015, with a small drop of 5.46% in 2016 and a sudden increase of 25.08% in 2017 compared with the previous year. The reason for the huge growth of CISW in 2011 was the Promotion Plan for Promoting the Development of Recycled Non-Ferrous Metal Industry, which involves upgrading equipment related to the non-ferrous metal industry. Types of equipment that do not meet the regulatory requirements are being eliminated, improving the recycling system and reducing environmental pollution.

For the CISW management system, the ban on importation of secondary resources in 2017 was not introduced suddenly and it is one step of a policy to increase strict pollution prevention measures implemented since 1996 [60]. The production of HSW has increased slowly since 2000 to 2010, with huge growth in 2011 and a little drop in 2013 after a steady amount of 3400 Mt HSW generated in 2012, then a sharp increase from 2014 to 2017. The reason for the growth of HSW in 2011 was that the Twelfth Five-Year Plan for the Comprehensive Prevention and Control of Heavy Metal Pollution was formally approved by the State Council, which lists soil contaminated with potentially toxic elements as HSW, and this has led to increases in the amount of HSW recorded.

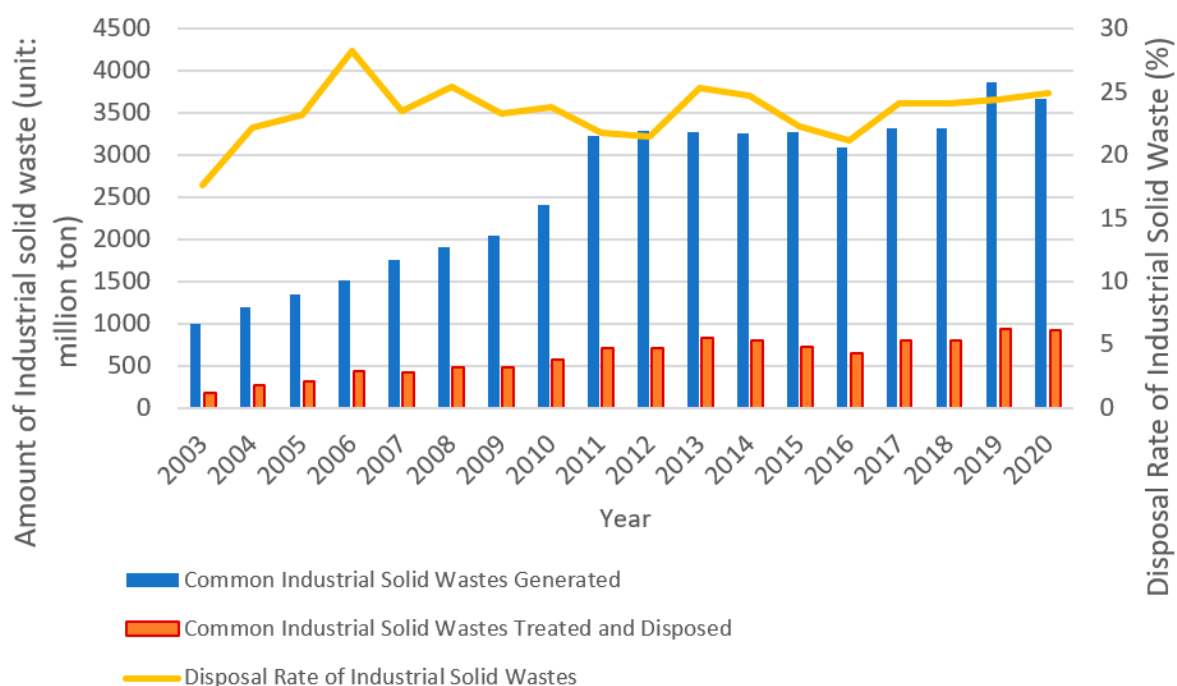


Figure 4. Amount of industrial solid waste generated and disposed of in PRC in 2003–2020 and disposal rates (all annual data were collected from the National Bureau of Statistics of PRC, available online: <http://www.stats.gov.cn/tjsj/ndsj/> (accessed on 1 July 2022)).

As shown in Figure 3, the disposal rate of MSW in mainland China has kept increasing from 53% in 2006 to more than 99% in 2019 (data for treated waste (harmless) is not comparable with data in past years because the new standard has been adopted in municipal waste landfill sites since 2006). The disposal methods include landfill, incineration, and composting. While, as shown in Figure 4, the disposal rate of CISW increased from 18% in 2003 to 28% in 2006, later the rate remaining was around 24% from 2007 to 2017. The disposal rate of HSW in mainland China was relatively stable at between 20% and 30% from 2011 to 2016. The results reveal that the disposal rate of CISW and HSW is still quite low compared to the disposal rate of MSW. The reason is that the treatment of CISW and HSW consists of their disposal, utilization, and discharge of solid waste in the year, with some left in storage (carried over) for next year [63]. The disposal of CISW and HSW is just a minor part of the treatment; utilization and discharge were not considered because of complicated calculation. ‘Disposal’ consists of the disposed part in the indicated year and disposal of CISW stored in previous years. The treatment of MSW was finished every year and there was no carry-over for the next year [63].

3.3. General Status of Remediation Industries in China

The 319 companies responding to this study were distributed in 28 Chinese cities and Provinces, with most of them located in areas with serious soil pollution levels, such as central China (Hunan Province, Hubei Province, and Sichuan Province), Northeast China (Liaoning Province), and economically developed areas (with higher consumption behavior and higher solid waste generation compared to other areas in China) including the east coast (Jiangsu Province, Zhejiang Province, and Fujian Province) and southern China (Guangdong Province). Among these companies, 138 companies (43%), focused on the business of both solid waste treatment and soil/land remediation. As shown in Table 1, for companies that either dealt with business of solid waste treatment or business of soil/land remediation, the highest number of companies was 58 in Hunan Province, followed by Jiangsu (41), Guangdong (32), Sichuan (24), Beijing (18), Hubei (17), and Liaoning (12), with a total of 202 companies accounting for more than 60% of the total number in this study.

Among them, 100 companies focused on solid waste treatment and 81 companies only focused on soil/land remediation. As shown in Table 1, for the solid waste treatment, the highest number of waste treatment companies was 52 in Hunan Province, followed by Jiangsu (29), Guangdong (22), Sichuan (20), Beijing (14), Hubei (12), Fujian (9), and Hebei (9). For the soil remediation, the highest number of soil remediation companies was 51 in Hunan Province, followed by Jiangsu (31), Guangdong (22), Hubei (13), Sichuan (11), Liaoning (10), Beijing (8), and Zhejiang (8). For all locations, East China had the highest frequency of companies (47), followed by Central China (24) and South China (22). East China is much more developed than Central and Southwest China. The citizens are relatively wealthy and business growth is higher and significant soil pollution from past development activity is present. The distribution of remediation projects mainly focused on economically developing zones and regions with the highest levels of contamination.

Soil remediation is regarded as a step that government cannot ignore [64] and it is beneficial for environmental quality and the daily lives of all stakeholders; however, it is a great financial burden, as seen in other regions of the world [65]. The impact on costs for the government and land developers may indirectly bring secondary pollution to the surrounding environment and citizens through incomplete treatment processes [66]. Although it brings potential opportunities for business growth [67], it does not create tangible products and associated services, such as site investigation, risk assessment, etc., need to be more cost effective, which might impede the sustainable development of soil remediation industries. This is found to generate excessive price competition and verification processes are much more sensitive to costs and even fraudulent reporting. This makes the verification of remediation more complicated and results in less reliable closure of contamination treatment. All these things mean that remediation status in the market might be confusing and more regulations focused on prevention of over remediation and consideration that it is unnecessary because of high costs.

Basic information on the age, gender, education, and work experience of respondents are shown in Table 2. More than 90% of respondents were younger than 45 years and the age distribution shows that most respondents were 26–35 years or early career professionals. This may be due to the sector being established when pollution became a ‘hot topic’ after the introduction of soil regulations of the Action Plan for Prevention and Control of Soil Pollution [37,68] and interest from professionals working in construction and environmental risk assessment. The gender distribution reveals that the proportion of males is four times that of females in the soil remediation industry, which is similar to that in the general civil engineering sector, traditionally involving multiple site work and physical work activity. More than 89% of people had less than 7 years’ work experience with more than 99% having at least a Bachelor’s or 3 year college degree. This emerging remediation industry has a young and well-educated workforce with huge potential. Education distribution reveals those with a higher education background are more focused on environmental science, environmental engineering, etc., rather than traditional engineering subjects, such as civil or process engineering.

Technical service companies, private enterprises, and state-owned businesses ranked the first, second, and third among various types of enterprises, with percentages of 45%, 24%, and 12%, respectively. The percentages of various types of enterprises shows most jobs focused on providing technical service in China, while in consultancies, planning consultancy was the most common service provided, with a percentage of 37%. Third-party testing, construction, and contracting services had similar percentages of 19%, 18%, and 16% among various services provided. The most common service was consultancy and planning consultancy carried out by technical service companies, private enterprises, and state-owned businesses. The percentages of various types of service provided by companies shows that work experience was a significant factor, as a lot of work needs to be carried out in the risk assessment phase before construction.

Table 2. Statistics for (unordered) categorical variables on basis of the data from responses from 107 participants in online survey of remediation sector.

Independent Variable		Distribution (%)
Age	16–25 years	10 (9.35)
	26–35 years	77 (71.96)
	36–45 years	10 (9.35)
	46–55 years	4 (3.74)
	56–65 years	6 (5.61)
	66 years and above	0 (0)
Gender	Male	86 (80.37)
	Female	19 (17.76)
	Other	2 (1.87)
Education	High school graduate or technical school	0 (0)
	Bachelor's or 3-year college degree	47 (43.93)
	Doctor's degree	48 (44.86)
	Master's degree	11 (10.28)
	Other	1 (0.93)
Working years	3 years	60 (56.07)
	4–6 years	36 (33.64)
	7–9 years	6 (5.61)
	10–12 years	4 (3.74)
	13 years	1 (0.93)

3.4. Professional Materials, Equipment, and Approaches

When attributing sources of funding for remediation, local government funds were highlighted by 67% of practitioners, with national special-purpose funds and businesses that were responsible for pollution (58% and 60%, respectively) being identified as being responsible for funding remediation activities. Only 40% and 13% highlighted land developers and third-party sponsors, respectively. Most contaminated sites are occupied by the state because of historical industrial development, with often unregulated activities. The old industries closed or moved out of the city center, leaving many contaminated sites that need to be remediated for use for residential construction or other public buildings. Land developers funded the remediation, which occurs much more frequently in developed cities rather than in small undeveloped cities as residential buildings are more popular in bigger cities because of the large population and better awareness and education in developed areas.

The application of remediation technologies in companies surveyed includes a range of bespoke and specialist tools. When assessing the role of intellectual property rights (IPR) in companies, patents on processes/tools were the most significant, with 40% of respondents identifying these. Other IPR protection included trade secrets (18%), copyrights and trademarks, both at 13%, which means that combining research and development with marketing for business development is a strong driver (the patent number could be shown on promotional materials, while trade secrets are an opaque long-term control on technology). Although trade secrets also imply competitive advantage, a company applying for a patent could see a fee reduction from the State Intellectual Property Office, as well as being more transparent in identifying the approach being used.

Typical steps for site investigation play a key role in remediation and the results show that solidification/stabilization, landfill, and chemical oxidation/reduction technology are more popular than phytoremediation, bioremediation, and plant-microbial remediation. The more rapid physical/chemical treatment as opposed to more long-term slow biotechnology is not as popular with industries in China. Absorbents are the most popular approach for professional materials provided by industries, and drilling and piling equipment is one of the more popular types of equipment applied in site development.

3.5. Decision-Making Model

Decision-making in soil remediation projects was determined by remediation target value (76%), the nature of land use (for purposes of growing crops or building or fishing, 69%), expert judgement (65%), specific rules and regulations (50%), government conditions (45%), and enterprise investment (29%).

Existing construction methods and appropriate technology were highlighted as the most commonly highlighted factors affecting the competitive advantage of the company in the soil remediation sector. New product/equipment development ranked as the second for 'strongly agreed' with both service/product price changes and market position third. Existing construction means and technology, and service/product price changes ranked first and second in the 'agreed' group. The most important considerations for setting remedial targets included future land use, the availability of national and industrial standards, and specific government conditions, respectively. Government planning and capital budgeting ranked along with technical means and payback period as the highest priorities in the survey's 'agreed' group for target setting in remediation.

For verification of the success of remediation, the most important factors considered were the data on the frequency of testing, checkup, and acceptance (validation data), project delivery and completion, and the wider socioeconomic benefits from remediation. All four factors were highlighted by more than 83% of respondents to verify success of remediation programs. As shown in Figure 5, factors important in commercial decision-making for soil remediation were remediation target value > capital guarantee > existing technology and means.



Figure 5. Importance of specific project factors in commercial decision-making for site remediation projects.

In addition to the main driving factors and historical development of the site, importance was also given to wider public opinion, corporate environmental awareness, and experience/company track record (past performance of similar projects). Additional drivers included the past and future land use scenarios in commercial decisions.

Remediation of agricultural soil is a long-term project that is normally based at national and local government level to ensure food safety over the long-term. It is typically a large-scale, regional activity and often includes a combination of agents and agricultural production. One example highlighted in the consultation was to consider crop use. In

planting corn in less contaminated shallow layers of soil, food safety was preserved, but changing to planting sorghum introduced a higher-risk land use due to deeper rooting and exposure to more contaminated soil. If the contaminated site was used for construction after remediation, the project was smaller scale with a much shorter project construction period compared to remediation of agricultural land. The approaches to agricultural land included treatment along with appropriate crop production, working at a larger scale and over a longer project remediation cycle. In terms of the capital guarantee, the risk of the budget was generally assessed in the feasibility research phase of the project. The choice of methods applied for the treatment could be decided with the consideration of the budget.

3.6. Case Study—Application of Sepiolite Tailings for Remediation

Modified and activated sepiolite materials are commonly applied as soil conditioners, pesticide carriers, or soil amendments [69]. Hunan Province has extensive contamination from potentially toxic elements caused by excessive base metal mining and industrial production activity [70], and produces a range of sepiolite mineral products which has resulted in a wide range of associated by-product materials [69]. The opportunity for their utilization was explored in part of the questionnaire, highlighting the potential of sepiolite for soil stabilization and later vegetable growth.

The questionnaire results show 48% of respondents had experience with soil stabilization or solidification, and of this >13% was specifically using sepiolite-derived materials. Here, 57% used sepiolite composite/modified products, with 26% and 17% of respondents using raw sepiolite mining and processing by-products, respectively. Among all materials applied in solidification, 35% of respondents and 20% of respondents used clay minerals and other minerals, respectively. The use of chemical treatment-based remediation (29% of respondents) compared to biological (11% of respondents) suggests the former application may be a better choice due to the speed of treatment and relative ease of validation.

3.7. Commercial Model

Interview results revealed that >45% of interviewees were in companies involved in both remediation and solid waste treatment. Discussion included the potential for soil treatment and solid waste disposal for most hazardous materials. Challenges of post-remediation testing were highlighted and the source of long-term funding for monitoring. The potential for cross-subsidy from MSW handling fees and costs of remediation was considered as unsustainable due to the high volume of soil needing to be remediated. Other opportunities include the potential of energy generation from waste. However, the commercial model for waste handling in China is still at a very early stage of development.

4. Conclusions and Recommendations

This study captured the general status of remediation industries in China with data collection and analysis by questionnaire and follow-up interview. It also highlighted the current professional materials, equipment, and approaches applied in remediation, and discussed the regulations referenced in only the risk assessment phase and the whole phase of the project construction phase. The impact of factors in decision-making concerning remediation was also included in consideration of successful implementation of projects. The details from remediation practitioners that described the lack of understanding of risks of contamination to ecology, and long-term monitoring of remediation, cannot be ignored. The integrated investigation of the remediation industries' status in China has relevance for the future development of solid waste treatment in China.

The level of awareness of total number various contaminated sites, their contaminants—such as metals, organic compounds, and combined pollution of both contaminants—is weak. The status of remediation industries shows an emerging young professional group with a high level of technological skill. Commercial performance is affected directly by the regulatory conditions. Although ambitious business development opportunities are being addressed, future trends in the transition from remediation to prevention and control

of polluted sites and waste management in a sustainable way are reflected by the new governmental funding measure introduced in 2021.

Current site remediation mainly focuses on construction projects, then site investigation and risk assessment. There is a lack of post-cleanup monitoring, especially long-term monitoring on efficiency after a remediation project is completed, such as long-term monitoring of potentially toxic elements' solidification and stabilization in remediation projects in mainland China. Another weakness is the shortage of fundamental research about the effect of contaminants on animal and human health, and the biosphere around the polluted sites. More consideration for site remediation was revealed as a principle of green and sustainable remediation [71]. Since commercial construction, residential construction, and increasing arable land are major reasons for redevelopment for treated sites, risk to human health may be affected if the remediation targets are not met. Further details on the collaboration between government departments are needed. In particular, more information is needed on the associated policy-making related to post-project monitoring and assessment of potential environmental effects of contaminants before carrying out remediation.

Risk-based land management is becoming more widespread with many problems of remediation and its relationship to waste treatment still needing to be addressed. In terms of overall remediation, capital guarantees and application of proven techniques are the keys to project decision-making. Policies or regulations have become much more comprehensive in terms of contaminant limits. Most guidelines demonstrate the process of risk assessment and provide step-by-step details for applications. The most important initial task is to investigate potential synergies of remediation and waste management, and to identify any related measures; for example, to produce nested industrial ecosystems. By locating similar industries close together or in an industrial park to deal common potential waste or pollution sources promotes the development of zero waste cities to reduce the possibility of increasing the amount of contamination or the number of polluted sites.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su141911811/s1>, Figure S1: Amount of hazardous solid waste generated in the PRC in 2000–2020. Figure S2: Amount of hazardous solid waste generated and disposed of PRC in 2011–2020 and their disposal rate (* date for total amounts only for 2019, 2020 due to COVID-19). Figure S3: Frequency (%) of location for remediation projects carried out by respondents. Figure S4: Relative frequency of the application of remediation technologies in site development. Figure S5: Frequency of material application (%) in stabilization or solidification treatment of soil contamination.

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References

1. Yu, J.-K.; Ma, J.-Q.; Liu, D. Historical evolution of marine functional zoning in China since its reform and opening up in 1978. *Ocean Coast. Manag.* **2020**, *189*, 105157. [CrossRef]
2. Yang, Q.; Zhang, L.; Zhang, J.; Zou, S. System simulation and policy optimization of China's coal production capacity deviation in terms of the economy, environment, and energy security. *Resour. Policy* **2021**, *74*, 102314. [CrossRef]
3. Hsu, A.; Wang, J.; Xu, K.; Zhang, W.; Yan, C. Data and Transparency Key for China's Pollution Clean-up. *Ecol. Econ.* **2021**, *183*, 106963. [CrossRef]
4. Lee, K.S.; Lee, D.-S.; Hong, B.-D.; Seo, I.-H.; Lim, C.-S.; Jung, H.-K.; Chung, D.Y. Status and future perspective for soil contamination of arable land in China. *Korean J. Agric. Sci.* **2019**, *46*, 869–883. [CrossRef]
5. Three Workers Were Poisoned during the Construction of Songjiazhuang Subway. Available online: <https://bbs.focus.cn/bj/22508/8ae30cd7adff4d90.html> (accessed on 1 May 2022). (In Chinese)
6. Market Situation and Development Trend of China's Environmental Protection Industry in 2016. Available online: <http://www.chyxx.com/industry/201604/406102.html> (accessed on 11 July 2022). (In Chinese)
7. Xu, C.; Yang, W.; Zhu, L.; Juhasz, A.L.; Ma, L.Q.; Wang, J.; Lin, A. Remediation of polluted soil in China: Policy and technology bottlenecks. *Environ. Sci. Technol.* **2017**, *51*, 14027–14029. [CrossRef]
8. The First Map of Soil Pollution Risk from the Institute of Public & Environmental Affairs. Available online: <http://huanbao.bjx.com.cn/news/20160429/729361.shtml> (accessed on 1 May 2022). (In Chinese)
9. Eikelboom, M.; Lopes, A.D.; Silva, C.M.; Rodrigues, F.D.; Zancunio, A.J.; Zancunio, J.C. A multi-criteria decision analysis of management alternatives for anaerobically digested kraft pulp mill sludge. *PLoS ONE* **2018**, *13*, e0188732. [CrossRef]
10. Nanda, S.; Berruti, F. Municipal solid waste management and landfilling technologies: A review. *Environ. Chem. Lett.* **2021**, *19*, 1433–1456. [CrossRef]
11. Xie, F.; Dong, K.; Wang, W.; Asselin, E. Leaching of mercury from contaminated solid waste: A mini-review. *Miner. Process. Extr. Metall. Rev.* **2020**, *41*, 187–197. [CrossRef]
12. Ayeleru, O.; Olubambi, P. Solid Waste Treatment Processes and Remedial Solution in the Developing Countries. In *Soft Computing Techniques in Solid Waste and Wastewater Management*; Karri, R.R., Ravindran, G., Dehghani, M.H., Eds.; Elsevier: Amsterdam, The Netherlands, 2021; pp. 233–246. [CrossRef]
13. Reddy, K.R.; Chirakkara, R.A. Green and sustainable remedial strategy for contaminated site: Case study. *Geotech. Geol. Eng.* **2013**, *31*, 1653–1661. Available online: <https://link.springer.com/article/10.1007/s10706-013-9688-5> (accessed on 8 January 2022). [CrossRef]
14. Madan, S.; Sachan, P.; Singh, U. A review on bioremediation of pulp and paper mill effluent—An alternative to conventional remedial technologies. *J. Appl. Nat. Sci.* **2018**, *10*, 367–374. [CrossRef]
15. The Report on the National General Survey of Soil Contamination. Available online: <http://www.gov.cn/foot/site1/20140417/782bcb88840814ba158d01.pdf> (accessed on 11 July 2022).
16. Technical Guidelines for Environmental Site Investigation (HJ 25.1-2014). Available online: <https://wenku.baidu.com/view/f22d7ffa50ea551810a6f524ccbff121dc36c576.html> (accessed on 11 July 2022). (In Chinese)
17. Technical Guidelines for Environmental Site Monitoring (HJ 25.2-2014). Available online: <https://www.doc88.com/p-3512173721395.html> (accessed on 11 July 2022). (In Chinese)
18. Technical Guidelines for Risk Assessment of Contaminated Sites (HJ 25.3-2014). Available online: <https://wenku.baidu.com/view/e14fbbef0f22590102020740be1e650e52eac626.html> (accessed on 11 July 2022). (In Chinese)
19. Technical Guidelines for Site Soil Remediation (HJ 25.4-2014). Available online: <https://www.doc88.com/p-00839069095616.html> (accessed on 11 July 2022). (In Chinese)
20. Rajendran, S.; Priya, T.; Khoo, K.S.; Hoang, T.K.; Ng, H.-S.; Munawaroh, H.S.H.; Karaman, C.; Orooji, Y.; Show, P.L. A critical review on various remediation approaches for heavy metal contaminants removal from contaminated soils. *Chemosphere* **2022**, *287*, 132369. [CrossRef] [PubMed]
21. Gautam, P.; Kumar, S.; Lokhandwala, S. Advanced oxidation processes for treatment of leachate from hazardous waste landfill: A critical review. *J. Clean. Prod.* **2019**, *237*, 117639. [CrossRef]
22. Wang, L.; Hou, D.; Cao, Y.; Ok, Y.S.; Tack, F.M.G.; Rinklebe, J.; O'Connor, D. Remediation of mercury contaminated soil, water, and air: A review of emerging materials and innovative technologies. *Environ. Int.* **2020**, *134*, 105281. [CrossRef]
23. Xi, W.-Y.; Du, Y.-J.; Li, F.-S.; Li, C.-P.; Yan, X.-L.; Arulrajah, A.; Wang, F.; Song, D.-J. In-situ solidification/stabilization of heavy metals contaminated site soil using a dry jet mixing method and new hydroxyapatite-based binder. *J. Hazard. Mater.* **2019**, *369*, 353–361. [CrossRef]

24. Why the World's Recycling System Stopped Working. Available online: <https://www.ft.com/content/360e2524-d71a-11e8-a854-33d6f82e62f8> (accessed on 11 July 2022).
25. Song, N.; McLellan, I.; Liu, W.; Wang, Z.; Hursthouse, A. The waste ban in China: What happened next? Assessing the impact of new policies on the waste management sector in China. *Environ. Geochem. Health* **2021**, 1–15. [[CrossRef](#)] [[PubMed](#)]
26. Wang, Y.; Shi, Y.; Zhou, J.; Zhao, J.; Maraseni, T.; Qian, G. Implementation effect of municipal solid waste mandatory sorting policy in Shanghai. *J. Environ. Manag.* **2021**, 298, 113512. [[CrossRef](#)]
27. Guo, W.; Xi, B.; Huang, C.; Li, J.; Tang, Z.; Li, W.; Ma, C.; Wu, W. Solid waste management in China: Policy and driving factors in 2004–2019. *Resour. Conserv. Recycl.* **2021**, 173, 105727. [[CrossRef](#)]
28. Edahbi, M.; Plante, B.; Benzaazoua, M. Environmental challenges and identification of the knowledge gaps associated with REE mine wastes management. *J. Clean. Prod.* **2019**, 212, 1232–1241. [[CrossRef](#)]
29. Wang, K.C.M.; Lee, K.E.; Mokhtar, M. Solid Waste Management in Small Tourism Islands: An Evolutionary Governance Approach. *Sustainability* **2021**, 13, 5896. [[CrossRef](#)]
30. Mesa Fernández, J.M.; Palacios, H.M.; Álvarez Cabal, J.V.; Martínez Huerta, G.M. Methodology for industrial solid waste management: Implementation to sludge management in Asturias (Spain). *Waste Manag. Res.* **2014**, 32, 1103–1112. [[CrossRef](#)]
31. Ghalekhondabi, I.; Maihami, R. Sustainable municipal solid waste disposal supply chain analysis under price-sensitive demand: A game theory approach. *Waste Manag. Res.* **2020**, 38, 300–311. [[CrossRef](#)] [[PubMed](#)]
32. Özbay, İ. Evaluation of municipal solid waste management practices for an industrialized city. *Pol. J. Environ. Stud.* **2015**, 24, 637–644. [[CrossRef](#)]
33. Sardarmehni, M.; Anchieta, P.H.C.; Levis, J.W. Solid waste optimization life-cycle framework in Python (SwolfPy). *J. Ind. Ecol.* **2022**, 26, 748–762. [[CrossRef](#)]
34. Bai, R.; Lam, J.C.; Li, V.O. A review on health cost accounting of air pollution in China. *Environ. Int.* **2018**, 120, 279–294. [[CrossRef](#)] [[PubMed](#)]
35. Li, X.; Hussain, S.A.; Sobri, S.; Said, M.S.M. Overviewing the air quality models on air pollution in Sichuan Basin, China. *Chemosphere* **2021**, 271, 129502. [[CrossRef](#)]
36. Huang, J.; Zhang, Y.; Bing, H.; Peng, J.; Dong, F.; Gao, J.; Arhonditsis, G.B. Characterizing the river water quality in China: Recent progress and on-going challenges. *Water Res.* **2021**, 201, 117309. [[CrossRef](#)]
37. Hu, Q.; Zhu, Y.; Lin, S.; Wang, H.; Gao, J. The Development of China's Contaminated Site Remediation Industry: A Decade in Review. In *Twenty Years of Research and Development on Soil Pollution and Remediation in China*; Luo, Y., Tu, C., Eds.; Springer: Singapore, 2018; pp. 125–132. [[CrossRef](#)]
38. Yang, X.; Zhao, L.; Haque, M.A.; Chen, B.; Ren, Z.; Cao, X.; Shen, Z. Sustainable conversion of contaminated dredged river sediment into eco-friendly foamed concrete. *J. Clean. Prod.* **2020**, 252, 119799. [[CrossRef](#)]
39. Chiang, S.Y.D.; Gu, Q. Brownfield sites remediation technology overview, trends, and opportunities in China. *Remediation* **2015**, 25, 85–99. [[CrossRef](#)]
40. Ma, Y.; Dong, B.; Bai, Y.; Zhang, M.; Xie, Y.; Shi, Y.; Du, X. Remediation status and practices for contaminated sites in China: Survey-based analysis. *Environ. Sci. Pollut. Res.* **2018**, 25, 33216–33224. [[CrossRef](#)]
41. Shen, Z.; Li, Z.; Alessi, D.S. Stabilization-based soil remediation should consider long-term challenges. *Front. Environ. Sci. Eng.* **2018**, 12, 16. [[CrossRef](#)]
42. Statistical Yearbooks of Urban and Rural Construction. Available online: <https://www.mohurd.gov.cn> (accessed on 11 July 2022). (In Chinese)
43. Brace, I. *Questionnaire Design: How to Plan, Structure and Write Survey Material for Effective Market Research*, 4th ed.; Kogan Page Limited: London, UK, 2018.
44. Saris, W.E.; Gallhofer, I.N. *Design, Evaluation, and Analysis of Questionnaires for Survey Research*, 2nd ed.; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2014.
45. Hou, D.; Al-Tabbaa, A.; Chen, H.; Mamic, I. Factor analysis and structural equation modelling of sustainable behaviour in contaminated land remediation. *J. Clean. Prod.* **2014**, 84, 439–449. [[CrossRef](#)]
46. Hou, D.; Al-Tabbaa, A.; Guthrie, P. The adoption of sustainable remediation behaviour in the US and UK: A cross country comparison and determinant analysis. *Sci. Total Environ.* **2014**, 490, 905–913. [[CrossRef](#)] [[PubMed](#)]
47. Hou, D. Divergence in stakeholder perception of sustainable remediation. *Sustain. Sci.* **2016**, 11, 215–230. [[CrossRef](#)]
48. Li, X.; Jiao, W.; Xiao, R.; Chen, W.; Chang, A. Soil pollution and site remediation policies in China: A review. *Environ. Rev.* **2015**, 23, 263–274. [[CrossRef](#)]
49. Chen, Y.; Hou, D.; Lu, C.; Spain, J.C.; Luo, J. Effects of rate-limited mass transfer on modeling vapor intrusion with aerobic biodegradation. *Environ. Sci. Technol.* **2016**, 50, 9400–9406. [[CrossRef](#)] [[PubMed](#)]
50. Hou, D.; Qi, S.; Zhao, B.; Rigby, M.; O'Connor, D. Incorporating life cycle assessment with health risk assessment to select the 'greenest' cleanup level for Pb contaminated soil. *J. Clean. Prod.* **2017**, 162, 1157–1168. [[CrossRef](#)]
51. Luo, J.; Kurt, Z.; Hou, D.; Spain, J.C. Modeling aerobic biodegradation in the capillary fringe. *Environ. Sci. Technol.* **2015**, 49, 1501–1510. [[CrossRef](#)]
52. Technical Guideline for Verification of Risk Control and Soil Remediation of Contaminated Site (HJ 25.5-2018). Available online: <https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/trhj/201901/W020200410503176383211.pdf> (accessed on 11 July 2022). (In Chinese)

53. Technical Guidelines for Environmental Impact Assessment—Soil Environment (HJ 964-2018). Available online: <https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/other/pjjsdz/201809/W020180921558586433773.pdf> (accessed on 11 July 2022). (In Chinese)
54. Technical Guideline for Groundwater Remediation and Risk Control of Contaminated Sites (HJ 25.6-2019). Available online: <https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/trhj/201906/W020190621398252083070.pdf> (accessed on 11 July 2022). (In Chinese)
55. Technical Guidelines for Investigation on Soil Contamination of Land for Construction (HJ 25.1-2019). Available online: <https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/trhj/201912/W020191224560365038697.pdf> (accessed on 11 July 2022). (In Chinese)
56. Technical Guidelines for Monitoring During Risk Control and Remediation of Soil Contamination of Land for Construction (HJ 25.2-2019). Available online: <https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/trhj/201912/W020191224561614977338.pdf> (accessed on 11 July 2022). (In Chinese)
57. Technical Guidelines for Risk Assessment of Soil Contamination of Land for Construction (HJ 25.3-2019). Available online: <https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/trhj/201912/W020191224560850148092.pdf> (accessed on 11 July 2022). (In Chinese)
58. Technical Guidelines for Soil Remediation of Land for Construction (HJ 25.4-2019). Available online: <https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/trhj/201912/W020191224560072891181.pdf> (accessed on 11 July 2022). (In Chinese)
59. Terms of Risk Control and Remediation of Soil Contamination of Land for Construction (HJ 682-2019). Available online: <https://www.mee.gov.cn/ywgz/fgbz/bz/bzwb/trhj/201912/W020191224561280943512.pdf> (accessed on 11 July 2022). (In Chinese)
60. Sun, M. The effect of border controls on waste imports: Evidence from China's Green Fence campaign. *China Econ. Rev.* **2019**, *54*, 457–472. [CrossRef]
61. China Statistical Yearbooks. Available online: <http://www.stats.gov.cn/tjsj/ndsj/2020/indexch.htm> (accessed on 11 July 2022). (In Chinese)
62. Huang, Q.; Wang, Q.; Dong, L.; Xi, B.; Zhou, B. The current situation of solid waste management in China. *J. Mater. Cycles Waste Manag.* **2006**, *8*, 63–69. [CrossRef]
63. Tang, J.; Wang, Q.; Choi, G. Efficiency assessment of industrial solid waste generation and treatment processes with carry-over in China. *Sci. Total Environ.* **2020**, *726*, 138274. [CrossRef]
64. Li, X.; Jiao, W.; Xiao, R.; Chen, W.; Liu, W. Contaminated sites in China: Countermeasures of provincial governments. *J. Clean. Prod.* **2017**, *147*, 485–496. [CrossRef]
65. Hills, J.J. A State's Perspective of the Problems Associated with Petroleum Contaminated Soils. In *Petroleum Contaminated Soils*, 1st ed.; Kostecki, P.T., Calabrese, E.J., Eds.; CRC Press: Boca Raton, FL, USA, 2021; Volume 1, pp. 21–26. Available online: <https://www.taylorfrancis.com/chapters/edit/10.1201/9781003210559-3/state-perspective-problems-associated-petroleum-contaminated-soils-john-hills> (accessed on 1 July 2022).
66. Hou, D.; Li, F. Complexities surrounding China's soil action plan. *Land Degrad. Dev.* **2017**, *28*, 2315–2320. [CrossRef]
67. Rajabi, H.; Mosleh, M.H.; Prakoso, T.; Ghaemi, N.; Mandal, P.; Lea-Langton, A.; Sedighi, M. Competitive adsorption of multicomponent volatile organic compounds on biochar. *Chemosphere* **2021**, *283*, 131288. [CrossRef] [PubMed]
68. Li, Z.; Wang, X.; Li, J.; Zhang, W.; Liu, R.; Song, Z.; Huang, G.; Meng, L. The economic-environmental impacts of China's action plan for soil pollution control. *Sustainability* **2019**, *11*, 2322. [CrossRef]
69. Song, N.; Hursthouse, A.; McLellan, I.; Wang, Z. Treatment of environmental contamination using sepiolite: Current approaches and future potential. *Environ. Geochem. Health* **2021**, *43*, 2679–2697. [CrossRef] [PubMed]
70. Delang, C.O. Causes and distribution of soil pollution in China. *Environ. Socio-Econ. Stud.* **2017**, *5*, 1–17. [CrossRef]
71. Song, Y.; Hou, D.; Zhang, J.; O'Connor, D.; Li, G.; Gu, Q.; Li, S.; Liu, P. Environmental and socio-economic sustainability appraisal of contaminated land remediation strategies: A case study at a mega-site in China. *Sci. Total Environ.* **2018**, *610*, 391–401. [CrossRef]