Advances in bioremediation of cadmium-contaminated soils

Xinshuai Wang¹, Guo Yu¹*, Hua Lin¹, Pingping Jiang¹, Yan Zhang², Yan Liu³, , Ziwei Wang¹
¹Guangxi Key Laboratory of Environmental Pollution Control Theory and Technology, Guilin University of Technology, Guilin, China;
²Guilin Drainage Engineering Management Office, Guilin, China;
³Guilin Environmental Protection Science Research Institute, Guilin, China
*Corresponding author’s e-mail: yuguo@glut.edu.cn

Abstract. Cadmium not only threatens the normal growth of plants, but also causes serious harm to human health through the food chain. In order to reduce the impact of cadmium pollution on the ecological environment, contaminated soil must be treated. This paper summarizes the current situation of soil Cd pollution in China, the main areas and sources of Cd pollution. We also analyze the characteristics of soil Cd pollution, introduces and reviews the physical and chemical technology, bioremediation technology, ecological remediation and combined remediation technology currently used to treat soil Cd pollution, in order to provide scientific reference for further research in this field.

1. Introduction
At present, soil pollution is becoming more and more serious in China. Heavy metal is easy to accumulate in the soil, which results in crop loss, accumulation in plants, and then harms the human health through the food chain[1]. Soil heavy metal pollution is dominated by lead (Pb) and cadmium (Cd). Cd is a non-essential element in biological growth and development, and is one of the heavy metals that are most harmful to animals, plants and human body[2]. Therefore, it is of great significance to analyze the current situation, region and source of soil Cd pollution in China, as well as various remediation technologies to remediate soil Cd pollution, in order to understand the current situation of Cd pollution in China and solve the food security problems caused by soil Cd pollution.

2. Soil Cd pollution in China
In recent years, the increasing Cd content in the environment in China has caused many Cd pollution incidents. Cd pollution of cultivated land and soil in China has been relatively serious since the 1990s. The cultivated land area polluted by Cd was 1.3×10⁴ ha, involving 11 provinces and cities. In 25 regions, Cd pollution has become increasingly serious in recent years[3].

2.1. Major soil Cd contamination areas in China
Cd mines are mainly distributed in central, southwest and east China. Cd pollution events in China mainly occurred in Yunnan, Guangdong, Hunan, Guizhou and other regions where co-associated Cd mines were relatively abundant and mining activities were relatively intensive[4]. Most of the mining and metallurgy areas and their surrounding soil showed heavy Cd contamination[5].
2.2. Sources and characteristics of soil heavy metal Cd contamination

Cadmium is a non-essential heavy metal. It is widely distributed in the earth's crust with an average concentration of about 0.1 mg/kg\[^6\]. In the environment, cadmium has strong chemical activity, great mobility, strong concealment and lasting toxicity. Because they cannot be decomposed by most microorganisms in the soil, they will accumulate in the soil and can even be converted into more toxic alkyl compounds that can be absorbed and enriched by plants and other organisms, thus accumulating in the human and animal bodies through the food chain and affecting human health\[^7\].

Sources of Cd in soils include both natural weathering of minerals and human activities. Cd concentration in the soil in China is 0.01~1.80 mg/kg, with an average of 0.163 mg/kg. The frequent interference of human activities often causes the heavy metal content in the soil to be higher than the background value and the Cd released into the atmosphere by human activities is 15 times higher than that released into the atmosphere by natural weathering\[^8\]. The most important source of heavy metal Cd pollution in soil is human industrial and agricultural activities. Heavy metal pollution is worst in soils and crops in areas where heavy industries, chemicals and textiles are booming, on both sides of highways and in soil-irrigated areas. The main ways for Cd to contaminate soil include atmospheric sedimentation, industrial waste accumulation, farmland sewage irrigation, agricultural utilization of urban garbage and sludge, and extensive use of chemical fertilizers, pesticides and agricultural membranes.

3. Remediation technologies of soil Cd pollution

Currently, soil remediation technologies can be divided into physical remediation, chemical remediation and bioremediation. The ultimate goal is to minimize the harm of cadmium-contaminated soil to groundwater, plants and soil microecology by transferring, degrading and passivating of heavy metals.

3.1. Physical remediation

Physical remediation refers to the removal or separation of cadmium contaminants from soil by various physical processes. Traditional physical remediation includes guest soil method, heat treatment, vitrification technology and so on\[^9\]. In addition, Electrodynamic remediation is a new physical remediation technology, which uses electrodes inserted at both ends of cadmium-contaminated soil to transfer Cd to the cathode or anode chamber for treatment through electric field electroosmosis and electromigration, so as to reduce or remove the toxicity of cadmium-contaminated soil\[^10-11\]. Because of its short repair cycle and high removal efficiency, it has become a research hotspot\[^12\].

3.2. Chemical remediation

Chemical remediation is an effective in situ remediation technique, including leaching and chemical fixation\[^13\]. Chemical leaching refers to the process of using external forces or gravity to push the leachate through the soil polluted by cadmium, so that the pollutants can be cleaned and migrated out from the soil. Then the leachate containing pollutants can be treated or separated. In situ fixation technology\[^14\] is to put chemical reagents or chemical materials into soil to make cadmium in the soil react with chemical reagents, forming insoluble or less mobile and less toxic substances, thus reducing the mobility and bioavailability of cadmium\[^15\].

3.3. Biological remediation

Bioremediation refers to the use of certain biological characteristics (such as enzymes, extracellular polymers and organic acids) to absorb, inhibit, transform and improve heavy metal pollution. The bioremediation of cadmium-contaminated soil is generally divided into microbial remediation, phytoremediation and animal remediation. Different types of bioremediation for heavy metal pollution are also different.
3.3.1. Microbial remediation
Microbial remediation is to reduce the toxicity of soil heavy metals by using some microorganisms in the soil that can absorb, precipitate and REDOX heavy metals\textsuperscript{[16]}. There are many kinds of soil microorganisms. Some microorganisms can fix, migrate or transform heavy metals in the soil, thus achieving the purpose of detoxification. The principle of microbial remediation of heavy metal contaminated soil mainly includes biological enrichment and biological transformation. Bioenrichment includes bioaccumulation and bioaspiration through extracellular complexation, precipitation and intracellular accumulation. Biotransformation includes oxidation and reduction of heavy metals by microorganisms, methylation and demethylation, dissolution of heavy metals and organic complexation coordination, so as to achieve the purpose of transforming heavy metals and reducing their toxicity. Microbial remediation has attracted much attention in the field of ecological remediation because it can reduce the technical cost and has little impact on the environment (soil fertility and rhizosphere microorganisms, etc.)\textsuperscript{[17]}.

3.3.2. Phytoremediation
Phytoremediation is a method of removing Cd contamination from soil by using hyperaccumulators. Hyperaccumulator is a plant with special ability to absorb and enrich Cd on Cd contaminated soil, then harvest the plant and recycle it properly, so as to control Cd pollution. This method is a reliable and environmentally friendly remediation technology with less investment, no damaging to the original soil structure and causing no secondary pollution. Hyperaccumulators need to have the following characteristics: high absorption rate to Cd, strong transport capacity; Cd enrichment ability is strong, and the aboveground can accumulate more than 10 times Cd than common plants\textsuperscript{[18]}.

3.3.3. Animal remediation
Animal remediation technology makes use of some animals that can absorb heavy metals in the soil, such as earthworms and rodents, to reduce the content of heavy metals in the contaminated soil to a certain extent\textsuperscript{[19]}. Cadmium remediation in animals is the least common method of bioremediation, and cadmium tolerance and enrichment in animals are rare. Earthworms can loosen the soil, increase the degradation of organic matter and waste residue in the soil, and then improve the chemical composition and physical structure of the soil\textsuperscript{[20]}.

4. Conclusion
The treatment and remediation of soil cadmium pollution is one of the most important issues in the field of environmental science. However, the remediation of cadmium pollution is a long-term and complex process. Although a variety of remediation measures have been developed all over the world, there are still some limitations in the application of these remediation measures, such as secondary pollution, narrow scope of application and long period. In addition, the remediation of soil cadmium pollution is still in the laboratory and field experiment demonstration stage, far from large-scale industrial remediation. Thus the problem of heavy metal pollution has not been fundamentally solved. Therefore, in the future we need to focus on the development of high efficiency cadmium pollution remediation technology and practical use of in-depth research. At present, the remediation of heavy metals by plants has become the focus of domestic and foreign scholars. Great progress has been made in the study of cadmium absorption, transport, tolerance and remediation mechanism.

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References
\[1\] Li J, Zhou Y W, Chen S, et al. (2015) Review on current situation, hazard and control methods of
soil cadmium pollution in China [J]. Anhui Agricultural Science Bulletin, 21(24):104-107.

[2] Ran L, Li H H. (2011) The status and harm of soil cadmium pollution [J]. Chongqing Higher Education Research, 30(4):69-73.

[3] Xu L J, zhang M L, Yang H. (2011) Progress in bioremediation of soil heavy metal cadmium pollution [J]. Journal of Nanjing normal university: Natural Science, 34 (1): 102-106.

[4] Guo Z H, Zhu Y G. (2004) Soil heavy metal pollution and available content in typical mining and metallurgy areas [J]. Ecology and Environmental Sciences, 13 (4) : 553-555.

[5] Yuan S S, Xiao X Y, Guo Z H. (2012) Regional distribution of cadmium deposits and risk analysis of soil cadmium pollution in China [J]. Environmental Pollution Control, 34 (6): 51-56.

[6] Matei N, Popescu A, Radu GL, et al. (2015) Cadmium and lead occurrence in soil and grape from Murtatlar Vineyard [J]. Ovidius University Annals of Chemistry, 26 (1): 37-40.

[7] Hu S H, Wang S L, Huang J H, et al. (2015) Effects of rice straw ash amendment on Cd solubility and distribution in a contaminated paddy soil under submergence [J]. Paddy and Water Environment,13 (1) : 135-143.

[8] Liu R L, Li S T, Wang X B, Wang M. (2005) Contents of heavy metal in commercial organic fertilizers and organic wastes[J]. Journal of Agro-Environment Science, 24(2): 392-397.

[9] Mo X R, Wang Y, Hu X X, et al. (2016) Research progress of soil heavy metal pollution remediation technology [J]. Guangdong Chemical Industry, 43 (4): 58-60.

[10] Hu Y P, Xu Z, Wang W, et al. (2015) Research progress on electrokinetic remediation of chromium pollution in the environment [J]. Chinese Journal of Rare Metals, 39 (10): 941-947.

[11] Arbai S, Mohamed Z, Mohamed K, et al. Electrokinetic Remediation to Remove Heavy Metal from Contaminated Soils Using Purging Solution[M]// InCIEC 2013. Springer Singapore, 2014 :531-538.

[12] Zhang T, Zou H, Wang Y, et al. (2013) Experimental study on enhancement technology for electrokinetic remediation of lead contaminated soil[J]. Chinese Journal of Environmental Engineering, 7 (9):3619-3623.

[13] Guo X F. (2012) Role of chemical leachants in remediation of heavy metal contaminated soil and environmental risks [D]. Guangzhou: South China Agricultural University.

[14] Ma C Y, Cai D J, Yan H. Research on soil cadmium pollution and its control technology [J]. Henan Chemical Industry, 2013, 30(16):17-22.

[15] Cao X D, Wei X X, Dai G L, et al. (2011) Advances in the study of combined heavy metal pollution in soil and its chemical passivation remediation technology [J]. Chinese Journal of Environmental Engineering, 5(7): 1441-1453.

[16] Cao H J, Wang L M, Yu Z M. (2012) Research status and remediation technology of soil heavy metal pollution [J]. Heilongjiang Science, (10):40-45.

[17] Zhang Y, Deng Y W, Luo X P, et al. (2012) Discussion on soil heavy metal pollution and microbial remediation technology [J]. Nonferrous Metals Science and Engineering, 3(1):63-66.

[18] January M C, Cutright T J, Keulen H V, Wei R. (2008) Hydroponic phytoremediation of Cd, Cr, Ni, As, and Fe: Can He—lantus annuus hyperaccumulate multiple heavy metals?[J]. Chemosphere,70(3):531-537.

[19] Ni Z Y, Xie G X, Zhang M K. (2017) Research on soil remediation technology for cadmium-contaminated farmland is progressing [J]. Anhui agricultural Sciences Bulletin, 23(6):115-120.

[20] Tang H, Cao N W. (2017) On the status quo of heavy metal pollution in soil and remediation technology in China [J]. Anhui agricultural Sciences Bulletin, 123 (7) : 103-105.