ISSN: 1813-4890

Multidimensional Analysis of Cadmium Pollution in Agricultural Soils

Yuan Kuang

Shaanxi Dijian land comprehensive development Co., LTD, Xi'an 710075, China

Abstract

Cadmium (Cd) pollution in agricultural soils is a global concern due to its impact on food security and public health. This review article offers a comprehensive analysis of cadmium pollution sources, health risks, and sustainable remediation strategies. It explores the dual origins of cadmium accumulation from natural geological processes and anthropogenic activities, emphasizing the significant contributions of industrial emissions and agricultural inputs. The article also examines the chronic toxicity and carcinogenic risks associated with cadmium exposure, highlighting its biomagnification through food chains. Current challenges in remediation technologies are discussed, including the efficiency-cost trade-offs of phytoremediation and chemical immobilization. The paper proposes integrated approaches such as microbial-plant synergistic systems, precision source apportionment, and policy-driven governance frameworks to enhance cadmium pollution management. It underscores the necessity of region-specific strategies, long-term monitoring, and cross-media governance to address the complexity and spatial heterogeneity of cadmium pollution effectively.

Keywords

Cadmium pollution, Agricultural soils, Health risks, Source apportionment, Remediation strategies, Sustainable management.

1. Introduction

Cadmium (Cd), a non-biodegradable heavy metal with high biological toxicity, is accumulating in agricultural soils globally, posing a significant threat to food security and public health. Worldwide, 12%-20% of arable soils exceed ecological risk thresholds for cadmium (Kabata-Pendias & Mukherjee, 2007). In China, the combined effects of industrialization and intensive agriculture have increased this proportion to 28.6% (Huang et al., 2019). Soil cadmium concentrations near lead-zinc smelters have been measured at 26.0-2601.0 $mg \cdot kg^{-1}$, exceeding national regulatory standards by 43-870 times, with a clear spatial decay pattern (Zhuang et al., 2009; Liao et al., 2015). The temporal and spatial heterogeneity of multi-source pollution necessitates systematic analysis.

The synergistic effects of industrial emissions and agricultural inputs are the primary drivers of cadmium accumulation. Isotopic tracing ($\delta^{114}Cd/^{110}Cd$) reveals that 59% of cadmium pollution in Hunan's industrial regions originates from smelter dust, with cement factories contributing an additional 7%. Agricultural inputs, including fertilizers (20% contribution) and cadmium-containing phosphorus fertilizers (0.15-0.82 $mg \cdot kg^{-1}$ in compound fertilizers), are also significant. Studies near coal-fired power plants show a cadmium geo-accumulation index (Igeo) of 4.3 and an enrichment factor (EF) exceeding 12.0, highlighting the substantial impact of thermal facilities on regional heavy metal distribution (Li et al., 2017). Notably, in modern intensive agriculture, livestock manure and wastewater irrigation account for 30% of total agricultural cadmium inputs (Jia et al., 2016; Xiong et al., 2010), exacerbating rhizosphere pollution.

Cadmium pollution poses dose-dependent and exposure-specific health risks. In some Chinese rice-growing regions, cadmium levels in rice grain reach 0.38-2.74 mg·kg^{-1} (Xie et al., 2017; Wang et al., 2014). Infants' dietary cadmium exposure is 1.86 μg·kg^{-1}·d^{-1}, with a cancer risk index (CR) of 7.3×10^{-4}, 3.6 times higher than the USEPA safety threshold (USEPA, 1989; Zhang et al., 2015). Long-term exposure is associated with a 5.2-fold increased incidence of kidney damage (Huang et al., 2019).

Current remediation technologies face efficiency-cost challenges. Phytoremediation reduces soil cadmium load by 19%-42% but requires 10-15 years (Luo et al., 2015). Chemical immobilization with lime quickly suppresses cadmium activity (DTPA-Cd decreases by 53.8%) but risks soil acidification rebound (Luo et al., 2009). Developing dynamic prevention and control models based on source-sink relationships and promoting integrated microbial-plant remediation is essential for sustainable cadmium pollution management in agro-ecosystems (Huang et al., 2018; Zhang et al., 2018). This paper synthesizes global research, addressing key issues in pollutant migration quantification, cross-media fate simulation, and remediation optimization, to provide theoretical support for regional cadmium risk management frameworks.

2. Source Apportionment of Cadmium Pollution

Cadmium accumulation in agricultural soils stems from natural geological processes and anthropogenic activities (Chen et al., 2015). Industrial activities, agricultural practices, and atmospheric deposition are the main anthropogenic sources, with contributions varying significantly by region (Figure 1).

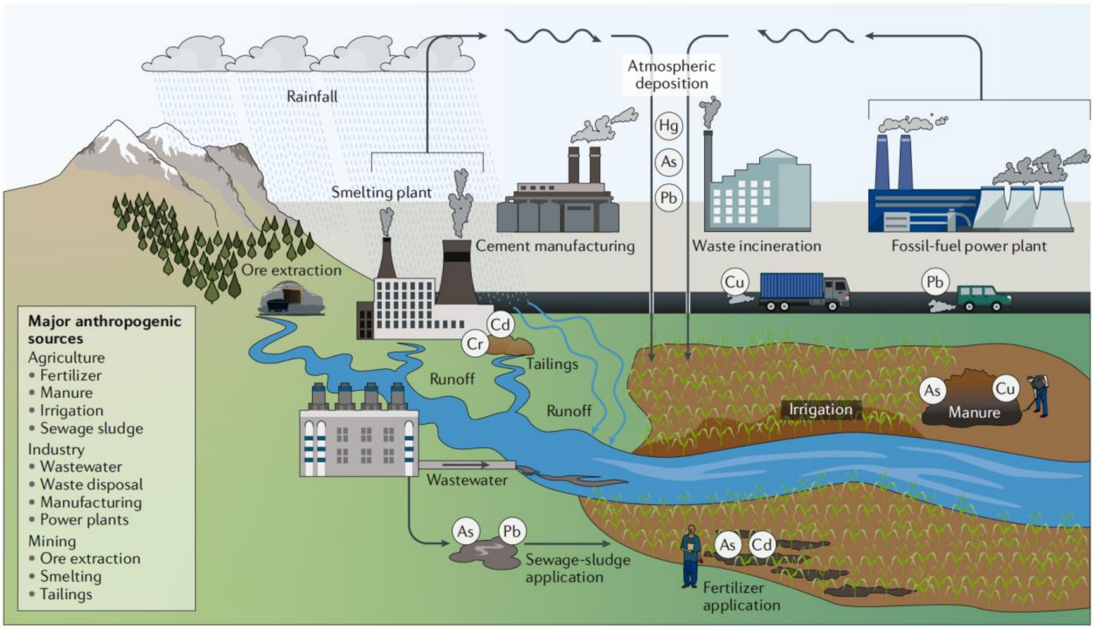

Figure 1. Sources of heavy metal(loid)s pollution in agricultural soil (Hou et al., 2020)

2.1. Industrial Activities

Industrial emissions, particularly from metal smelting, mining, and pigment production, are central sources of cadmium pollution. Smelter dust contributes 59% to cadmium pollution in Hunan's agricultural soils (Zhang et al., 2018), aligning with isotopic signatures of smelter emissions. Similarly, pigment production is the primary cause of cadmium pollution in southeastern towns (Li et al., 2018a). Long-term storage of mine tailings has increased surrounding soil cadmium concentrations to 6-10 times background levels (Wang et al., 2014), underscoring mining's persistent impact on regional cadmium cycling.

2.2. Agricultural Practices

Agricultural cadmium inputs mainly come from fertilizer application, livestock manure, and wastewater irrigation. Long-term phosphorus fertilizer use significantly increases soil cadmium due to the 0.1-3.0 mg/kg cadmium content in phosphate rock (Wang et al., 2014). Studies in Tianjin's suburbs show wastewater irrigation raises soil cadmium levels above background values (Wang & Guo, 2006), while livestock manure contains 1.5-3.6 mg/kg cadmium (Nicholson et al., 2003), making it a major pollution source in southern intensive agricultural areas. Cadmium from feed additives, such as zinc sulfate, enters manure through animal metabolism, further contributing to secondary soil cadmium pollution (Cai et al., 2007).

2.3. Atmospheric Deposition

Atmospheric wet and dry deposition is a key pathway for long-range cadmium transport, particularly in northern industrial regions. National-scale studies indicate atmospheric deposition contributes 50-93% of cadmium inputs (Wan et al., 2016), closely linked to point sources like coal-fired power plants and metal smelters. Northern regions, with higher industrialization, have a greater proportion of atmospheric cadmium sources compared to the south (Chen et al., 2018b).

2.4. Spatial Heterogeneity

The relative importance of pollution sources varies spatially. Hunan's industrial regions are dominated by smelter dust (59%) (Zhang et al., 2018), while pigment enterprises are prominent in southeastern coastal areas (Li et al., 2018a). Tianjin suburbs exhibit multi-source pollution, with wastewater irrigation and sludge application as primary sources (Wang & Guo, 2006). These differences suggest the need for region-specific management strategies, such as prioritizing industrial point source control in the north and regulating livestock manure and fertilizer use in the south.

3. Health Risks of Cadmium Pollution

Cadmium pollution poses significant health risks through chronic toxicity and carcinogenicity. Cadmium's biomagnification in food chains results in long-term health hazards (Shen et al., 2015).

3.1. Non-Cancer Health Risks

Target Hazard Quotient (THQ) analysis shows THQ values for rice consumption in five Chinese cadmium-polluted regions range from 1.5 to 7.8, exceeding the safety threshold of 1, indicating substantial non-cancer risks (Shen et al., 2015). In Guiyang's Hezhang County, the THQ reaches 7.8, signaling severe kidney damage risks for residents. Over 30% of individuals have urinary cadmium (UCd) levels above WHO thresholds (5 $\mu g \cdot g^{-1}$ cr), strongly correlated with chronic kidney disease (CKD) prevalence (Nordberg et al., 2002).

Chronic cadmium toxicity involves renal tubular dysfunction and calcium metabolism disruption. Long-term low-dose exposure can reduce glomerular filtration rates, elevate urinary β2-microglobulin, and induce osteoporosis (Jin et al., 2002). Studies in Beijing's suburbs reveal significant health risks from dietary exposure to heavy metals in vegetables, with cadmium contributing the highest risk (Song et al., 2009).

3.2. Carcinogenic Risk

The International Commission on Radiological Protection (ICRP)'s lifetime cancer risk threshold of 5×10^{-5} shows that rice consumption in study areas poses cancer risks of 1.1×10^{-4} to 4.0×10^{-4}, with high-exposure groups exceeding the threshold by 4-8 times (Shen et al., 2015). European epidemiological studies link environmental cadmium exposure to increased prostate

ISSN: 1813-4890

cancer incidence, potentially through endocrine disruption (Miller, 1996; Benbrahim-Tallaa et al., 2007). Animal experiments demonstrate that cadmium can induce abnormal DNA methylation via epigenetic regulation, activate the MAPK/ERK signaling pathway, and promote tumor cell proliferation (Waalkes, 2003).

3.3. Susceptibility of Special Populations

Children exhibit higher sensitivity to cadmium health risks, with THQ values 15%-22% higher than adults (Shen et al., 2015). This stems from children's higher food intake per unit body weight and immature detoxification systems. Although cadmium transfer through placenta and breast milk is limited in mammals (Lucis et al., 1972), long-term low-dose exposure can still produce cumulative effects in children during development.

3.4. Multiple Exposure Pathways

In addition to dietary intake, industrial area atmospheric deposition contributes 12%-18% to cadmium exposure (WHO, 1992a). Long-term application of cadmium-containing livestock manure in Beijing's suburbs increases soil cadmium by 0.03 mg/kg annually (Smith, 1986; Nicholson et al., 2003), creating secondary pollution sources. Multi-pathway exposure models indicate that residents in smelting areas face total cancer risks 1.8 times higher than those from dietary exposure alone (Shen et al., 2015).

4. Sustainable Remediation Strategies for Cadmium Pollution

4.1. Ecological Regulation Strategies Based on Phytoremediation

Phytoremediation offers an eco-friendly solution for cadmium pollution. Hyperaccumulator plants like Thlaspi caerulescens use root-specific transporters to concentrate bioavailable cadmium, with above-ground cadmium levels exceeding soil concentrations by 100 times (Lombi et al., 2001). Field trials show that three consecutive seasons of Ganges population planting reduce labile cadmium in the topsoil (0-20 cm) by 35% (McGrath et al., 2006). In southern China's seven-year, planting oilseed rape and peanuts in mildly polluted areas (Cd<1.5 mg/kg) ensures grain cadmium levels below national food safety standards (GB 2762-2017), while fiber crops like jute and mulberry have 40%-60% higher biomass accumulation efficiency than food crops (Wang, 1997).

4.2. Microbe-Plant Synergistic Remediation Systems

Microbe-mediated bioaugmentation enhances remediation efficiency. Plant growth-promoting rhizobacteria (PGPR) secrete siderophores and organic acids, lowering soil pH by 0.3-0.5 units and promoting cadmium mobilization (Huang et al., 2016). Field data show that inoculating heavy metal-resistant strains increases Brassica juncea's cadmium extraction by 28%-42% (Ahemad, 2019). Notably, combining microbial-plant systems with organic amendments—such as biochar (pyrolyzed at 600°C) and compost (C/N=25) in a 3:1 ratio—reduces DTPA-extractable cadmium in soil by 52% while maintaining microbial community diversity (Shannon index>3.5) (Huang et al., 2016).

4.3. Agricultural Ecological Safety Utilization Strategies

For moderately cadmium-polluted farmlands (Cd 0.3-1.0 mg/kg), integrating low-accumulator crop varieties with soil amendments is practical (Figure 2). Research shows that applying rice husk biochar (20 t/ha) reduces cadmium in rice grains from 0.35 mg/kg to 0.18 mg/kg, a 48.6% decrease, with residual effects lasting three growing seasons (Hamid et al., 2019b). Promoting energy crops like willow short-rotation coppices in cadmium-polluted areas achieves ecological and economic benefits, with annual biomass yields of 12-15 t/ha and annual cadmium extraction of 0.8-1.2 kg/ha (van Slycken et al., 2013).

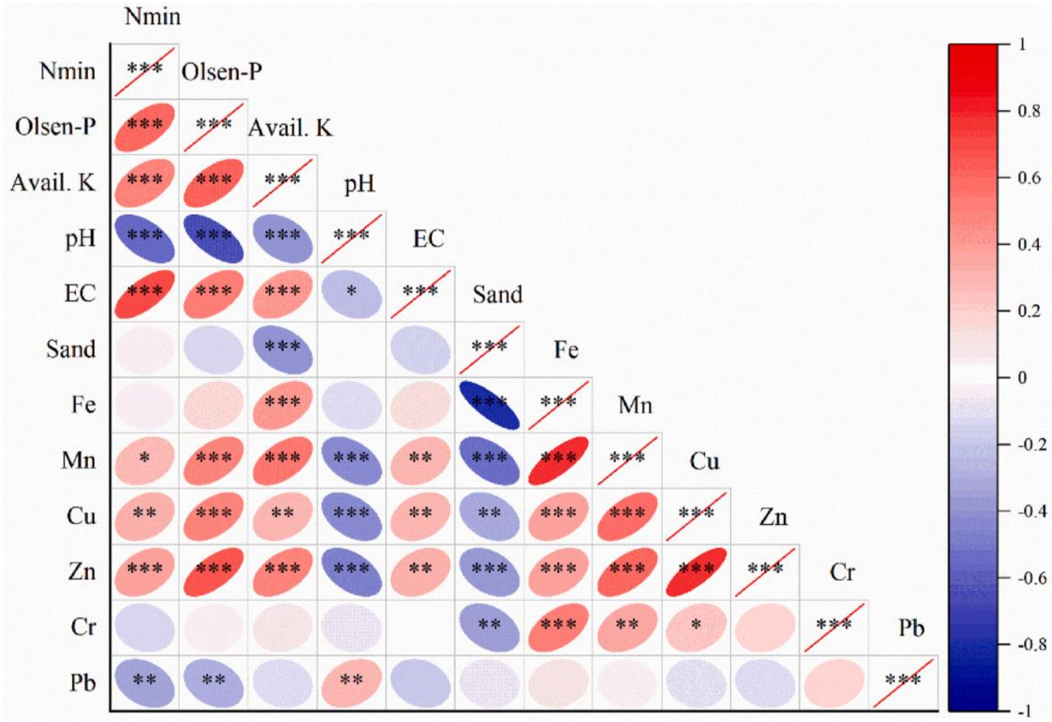

Figure 2. Correlation matrix showing the relationship between soil parameters and soil heavy metal and soil nutrient concentrations for the soil layer at 0–30 cm (Wan et al., 2022)

4.4. Precision Prevention and Control Systems Based on Source Apportionment

Combining isotope tracing ($\delta^{114}Cd$) with Positive Matrix Factorization (PMF) enables precise pollution source identification. In Hunan's industrial regions, smelter dust contributes 59±5%, while agricultural non-point sources account for 20±3% (Huang et al., 2018). Accordingly, a tiered management plan includes establishing dynamic lists of polluting enterprises within a 5 km buffer zone, real-time monitoring of wastewater cadmium concentrations (<0.01 mg/L), and constructing pollution dispersion models via GIS (100 m×100 m spatial resolution).

4.5. Policy-Driven Integrated Governance Frameworks

The EU REACH Regulation and China's Soil Pollution Prevention and Control Law provide institutional frameworks for cadmium pollution control. It is recommended to establish multi-channel funding mechanisms—"polluter pays, government subsidizes, market trades"—and implement differential land pricing policies for remediated lands (15%-20% premium for clean land). Additionally, blockchain-based agricultural product traceability systems should be developed to monitor cadmium levels from soil to table.

5. Challenges and Future Directions in Cadmium Pollution Control

5.1. Major Challenges in Cadmium Pollution Control

5.1.1. Complexity of Pollution Sources and Spatial Heterogeneity

Cadmium pollution sources are diverse, encompassing industrial emissions, agricultural inputs (e.g., cadmium-containing phosphate fertilizers), wastewater irrigation, and atmospheric deposition (Luo et al., 2009). In multi-metal mining areas, cadmium often coexists with copper and zinc, creating significant spatial heterogeneity (Liu et al., 2019). Research shows that cadmium pollution in farmlands near industrial cities is directly linked to smelting activities, but its migration is regulated by soil physicochemical properties (e.g., pH, organic matter content) and land use patterns (Huang et al., 2006), increasing the complexity of pollution tracing and precise control.

5.1.2. Limitations of Remediation Technologies

Current remediation technologies, including phytoremediation, microbial remediation, and chemical immobilization, are promising but suffer from low efficiency, long cycles, and high costs. For example, phytoremediation depends on the biomass and cadmium accumulation capacity of hyperaccumulator plants, which have long growth cycles and are easily affected by environmental factors (Wei et al., 2020). Furthermore, while organic amendments like compost can reduce cadmium bioavailability, long-term use may pose risks of heavy metal reactivation (Davis & Coker, 1980).

5.1.3. Lack of Regional Coordinated Governance Mechanisms

Cadmium pollution, with its cross-media mobility, requires a regional governance framework. Studies reveal significant differences in cadmium input inventories between northern and southern agricultural soils, with northern regions dominated by atmospheric deposition and southern regions more affected by wastewater irrigation (Luo et al., 2009). However, existing governance policies are often limited to administrative boundaries, lacking mechanisms for pollution prevention and control across watersheds and regions.

5.1.4. Insufficient Long-term Monitoring and Risk Assessment

Current monitoring systems primarily rely on static sampling, making it difficult to dynamically reflect the temporal and spatial evolution of cadmium pollution. Although Monte Carlo simulation can quantify uncertainties in health risks (Shi et al., 2008), its application in grassroots environmental management remains limited. Additionally, the predictive accuracy of soil-crop system cadmium migration models is constrained by field microenvironment parameters, restricting early warning capabilities (Li et al., 2014b).

5.2. Future Research Directions and Strategies

5.2.1. Precision Source Apportionment and Targeted Control Technologies

Develop pollution tracing technologies based on isotope tracing and multi-source receptor models (Liu et al., 2019), combined with artificial intelligence algorithms to analyze cadmium input-output fluxes (Li et al., 2014b). For key pollution sources (e.g., electroplating wastewater, cadmium-containing feed additives), develop efficient and low-cost targeted blocking materials, such as modified biochar and nano-iron oxides (Davis & Coker, 1980).

5.2.2. Integration of Green and Sustainable Remediation Technologies

Optimize plant-microbe joint remediation technologies, enhancing hyperaccumulator plants' cadmium accumulation efficiency through gene editing (Wei et al., 2020). Additionally, develop cadmium resource recovery technologies based on the circular economy, such as extracting cadmium from contaminated soils for photovoltaic material synthesis, achieving a closed loop of "pollution control-resource regeneration" (Davis & Coker, 1980).

5.2.3. Intelligent Monitoring and Digital Management Platforms

Construct integrated "space-air-ground" monitoring networks to track cadmium pollution dynamics in real-time using hyperspectral remote sensing and IoT sensors (Li et al., 2014b). Establish regional heavy metal pollution databases, integrating multi-scale models (e.g., HYDRUS-1D and health risk models) to enable intelligent decision-making for pollution early warning and remediation plans (Shi et al., 2008).

5.2.4. Regional Collaborative Governance and Policy Innovation

Establish differentiated cadmium pollution prevention and control standards, such as risk levels based on soil types and crop sensitivities (Luo et al., 2009). Improve ecological compensation mechanisms and promote the establishment of cross-regional pollution control funds (Luo et al., 2009). Additionally, strengthen regulations on clean agricultural production, restrict the use of cadmium-containing fertilizers and feed additives, and incentivize green production technology research and development through tax leverage (Davis & Coker, 1980).

6. Conclusion

This review provides an in-depth analysis of cadmium pollution in agricultural soils, emphasizing its sources, health implications, and management strategies. It highlights the urgent need for integrated and sustainable approaches to combat cadmium contamination. By synthesizing global research, the article identifies key challenges in current remediation practices and proposes innovative solutions, including green technologies and intelligent monitoring systems. The conclusion stresses that effective cadmium pollution control requires a multifaceted strategy combining precise source identification, advanced remediation techniques, and robust policy frameworks. Future research should focus on developing cost-effective and environmentally friendly technologies to ensure the safety of agricultural ecosystems and public health.

Acknowledgments

This work was funded by the project of Shaanxi Dijian Land Comprehensive Development Co., Ltd. (Grants No. DJNY2024-19, 24DJZK001).

References

[1] Ahemad, M. (2019). Remediation of metalliferous soils through the heavy metal resistant plant growth promoting bacteria: Paradigms and prospects. Arabian Journal of Chemistry, 12(7), 1365-1377.

[2] Benbrahim-Tallaa, L., Tokar, E. J., & Waalkes, M. P. (2007). Cadmium carcinogenesis: Mechanisms and implications for risk assessment. Mutation Research/Reviews in Mutation Research, 533(1-2), 107-120.

[3] Cai, Q., Long, M. L., Zhu, M., Zhou, Q. Z., Deng, Y. D., Li, Y., ... & Tian, Y. J. (2007). Correlativity study on pollution of cadmium element in cattle tissues with rear environment in Guizhou. Food Science, 28, 434-437.

[4] Chen, L., Zhou, S. L., Wu, S. H., Wang, C. H., Li, B. J., Li, L., & Wang, J. X. (2018a). Combining emission inventory and isotope ratio analyses for quantitative source apportionment of heavy metals in agricultural soil. Chemosphere, 204, 140-147.

[5] Davis, R. D., & Coker, E. G. (1980). Cadmium in agriculture, with special reference to the utilisation of sewage sludge on land. Water Research Centre Technical Report TR 139.

[6] Hou, D., O'Connor, D., Igalavithana, A. D., Alessi, D. S., Luo, J., Tsang, D. C. W., Sparks, D. L., Yamauchi, Y., Rinklebe, J., & Ok, Y. S. (2020). Metal contamination and bioremediation of agricultural soils for food safety and sustainability. Nature Reviews Earth & Environment, 1, 366-381.

[7] Huang, B., Shi, X., Yu, D., Oborn, I., Blomback, K., Pagella, T. F., ... & Sinclair, F. L. (2006). Environmental assessment of small-scale vegetable farming systems in periurban areas of the Yangtze River Delta Region, China. Agriculture, Ecosystems & Environment, 112, 391-402.

[8] Huang, Y., Deng, M., Wu, S., Japenga, J., Li, T., Yang, X., & He, Z. (2018). A modified receptor model for source apportionment of heavy metal pollution in soil. Journal of Hazardous Materials, 354, 161-169.

[9] Jia, W.X., Wen, J., Wang-Long, X.U., Duan, R., Zeng, X.B., & Bai, L.Y. (2016). Content and fractionation of heavy metals in livestock manures in some urban areas of China. Journal of Agro-Environment Science, 35(4), 764-773.

[10] Jin, T., Nordberg, M., Frech, W., Dumont, X., Bernard, A., Ye, T. T., ... & Nordberg, G. F. (2002). Cadmium biomonitoring and renal dysfunction among a population environmentally exposed to cadmium from smelting in China (ChinaCad). Biometals, 15(4), 397-410.

[11] Kabata-Pendias, A., & Mukherjee, A. B. (2007). Trace elements from soil to human. Springer.

[12] Li, R., Wu, H., Ding, J., Fu, W., Gan, L., & Li, Y. (2017). Mercury pollution in vegetables, grains and soils from areas surrounding coal-fired power plants. Science Reports, 7, 46545.

[13] Liao, Q.L., Liu, C., Wu, H.Y., Jin, Y., Hua, M., Zhu, B.W., ... & Huang, L. (2015). Association of soil cadmium contamination with ceramic industry: a case study in a Chinese town. Science of the Total Environment, 514, 26-32.

[14] Liu, J., Wang, D. Q., Song, B., Chen, Z., Zhang, X. F., & Tang, Y. T. (2019). Source apportionment of Pb in a rice-soil system using field monitoring and isotope composition analysis. Journal of Geochemical Exploration, 204, 83-89.

[15] Lombi, E., Zhao, F. J., Young, S. D., & Sacchi, G. A. (2001). Physiological evidence for a high-affinity cadmium transporter highly expressed in a Thlaspi caerulescens ecotype. New Phytologist, 149(1), 53-60.

[16] Luo, K., Ma, T., Liu, H., Wu, L., Ren, J., Nai, F., ... & Christie, P. (2015). Efficiency of repeated phytoextraction of cadmium and zinc from an agricultural soil contaminated with sewage sludge. International Journal of Phytoremediation, 17(6), 575-582.

[17] Luo, L., Ma, Y. B., Zhang, S. Z., Wei, D. P., & Zhu, Y. G. (2009). An inventory of trace element inputs to agricultural soils in China. Journal of Environmental Management, 90(8), 2524-2530.

[18] McGrath, S. P., Lombi, E., Gray, C. W., Caille, N., Dunham, S. J., & Zhao, F. J. (2006). Field evaluation of Cd and Zn phytoextraction potential by the hyperaccumulators Thlaspi caerulescens and Arabidopsis halleri. Environmental Pollution, 141(1), 115-125.

[19] Miller, C. A. (1996). Cadmium as an endocrine disruptor: Evidence from in vitro studies. Environmental Health Perspectives, 104(Suppl 3), 663-667.

[20] Nicholson, F. A., Smith, S. R., Alloway, B. J., Carlton-Smith, C., & Chambers, B. J. (2003). An inventory of heavy metals inputs to agricultural soils in England and Wales. Science of the Total Environment, 311(1-3), 205-219.

[21] Nordberg, G. F., Jin, T., Wu, X., Lu, J., Chen, L., Liang, Y., ... & Nordberg, M. (2002). Kidney dysfunction and cadmium exposure: Factors influencing dose-response relationships. Journal of Trace Elements in Experimental Medicine, 15(4), 397-410.

[22] Shen, K., Cheng, X. Y., Zhang, N., Hu, H. G., Yan, Q., Hou, L. L., ... & Chen, Z. N. (2015). Cadmium contamination of rice from various polluted areas of China and its potential risks to human health. Environmental Science and Pollution Research, 22(18), 13453-13465.

[23] Song, B., Lei, M., Chen, T. B., Zheng, Y. M., Xie, Y. F., Li, X. Y., & Gao, D. (2009). Assessing the health risk of heavy metals in vegetables to the general population in Beijing, China. Journal of Environmental Sciences, 21(12), 1702-1709.

[24] van Slycken, S., Witters, N., Meers, E., Peene, A., Michels, E., & Adriaensen, K. (2013). Field evaluation of willow under short rotation coppice for phytomanagement of metal-polluted agricultural soils. International Journal of Phytoremediation, 15(7), 677-689.

[25] Waalkes, M. P. (2003). Cadmium carcinogenesis. Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis, 533(1-2), 107-120.

[26] Wan, D., Song, L., Yang, J. S., Jin, Z. D., Zhan, C. J., Mao, X., ... & Liu, C. Q. (2016). Increasing heavy metals in the background atmosphere of central North China since the 1980s: Evidence from a 200-year lake sediment record. Atmospheric Environment, 138, 183-190.

[27] Wan, L., Lv, H., Qasim, W., Xia, L., Yao, Z., Hu, J., Zhao, Y., Ding, X., Zheng, X., Li, G., Lin, S., & Butterbach-Bahl, K. (2020). Heavy metal and nutrient concentrations in top- and sub-soils of greenhouses and arable fields in East China: Effects of cultivation years, management, and shelter. Environmental Pollution, 265, 114810.

[28] Wang, K. R. (1997). Status of Cd pollution and strategy of the treatments and utilization of Cd-polluted farmlands in China. Agro-Environmental Protection, 16(6), 274-278.

ISSN: 1813-4890

[29] Wang, Z.X., Hu, X.B., Xu, Z.C., Cai, L.M., Wang, J.N., Zeng, D., & Hong, H.J. (2014). Cadmium in agricultural soils, vegetables and rice and potential health risk in vicinity of Dabaoshan Mine in Shaoguan, China. Journal of Central South University, 21, 2004-2010.

[30] Wei, S., Zhou, Q., & Koval, P. V. (2020). Field trials of phytomining and phytoremediation: A critical review of influencing factors and effects of additives. Critical Reviews in Environmental Science and Technology.

[31] Xie, L.H., Tang, S.Q., Wei, X.J., Shao, G.N., Jiao, G.A., Sheng, Z.H., ... & Hu, P.S. (2017). The cadmium and lead content of the grain produced by leading Chinese rice cultivars. Food Chemistry, 217, 217-224.

[32] Xiong, X., Li, Y.X., Li, W., Lin, C.Y., Han, W., & Yang, M. (2010). Copper content in animal manures and potential risk of soil copper pollution with animal manure use in agriculture. Resources, Conservation and Recycling, 54(11), 985-990.

[33] Zhang, X. W., Wei, S., Sun, Q. Q., Wadood, S. A., & Guo, B. L. (2018). Source identification and spatial distribution of arsenic and heavy metals in agricultural soil around Hunan industrial estate by positive matrix factorization model, principal components analysis and geostatistical analysis. Ecotoxicology and Environmental Safety, 159, 354-362.

[34] Zhang, X., Zhong, T., Liu, L., & Ouyang, X. (2015). Impact of soil heavy metal pollution on food safety in China. PLoS One, 10(8), e0135182.

[35] Zhuang, P., Zou, B., Li, N.Y., & Li, Z.A. (2009). Heavy metal contamination in soils and food crops around Dabaoshan mine in Guangdong, China: implication for human health. Environmental Geochemistry and Health, 31(6), 705-715.