Water Air Soil Pollut (2023) 234:760
https://doi.org/10.1007/s11270-023-06758-y

Effects of Soil, Water and Air Pollution with Heavy Metal Ions Around Lead and Zinc Mining and Processing Factories

Seyed Alireza Sharifi · Mojgan Zaeimdar · Seyed Ali Jozi · Rokhshad Hejazi

Received: 6 September 2023 / Accepted: 13 November 2023 / Published online: 2 December 2023

Abstract Heavy metal contamination stemming from lead and zinc mining and processing operations is a prevalent and pressing environmental issue. This review article explores the multifaceted dimensions of this problem, examining the primary sources of contamination, which encompass mining activities, production and processing processes, waste management practices, and atmospheric deposition. The repercussions of lead and zinc contamination extend across various domains, including soil pollution and degradation, water pollution with consequential effects on aquatic ecosystems, plant uptake leading to crop contamination, health hazards, and risks associated with human exposure. Additionally, wildlife and biodiversity are profoundly impacted by these pollutants. The article delves into a comprehensive analysis of the diverse techniques employed for monitoring and assessing lead and zinc contamination in soil. This includes an exploration of sampling and analytical methods, geographic information systems, and remote sensing technologies. Mitigation and remediation strategies form a significant part of the review, with a focus on soil remediation techniques such as phytoremediation and other plant-based approaches. It also emphasizes the importance of human health protection and risk management measures in combating lead and zinc contamination. The article concludes by highlighting emerging technologies and approaches in the field, including innovations in mining waste management and remediation, the integration of green chemistry and sustainable practices within the mining industry, and the utilization of artificial intelligence for enhanced lead and zinc pollution control. This comprehensive review provides valuable insights into the multifaceted issue of heavy metal pollution associated with lead and zinc mining and processing factories, offering a roadmap for future research and effective environmental management.

Keywords Mining industry · Lead · Zinc · Soil pollution · Health effects · Monitoring · Pollution control · Sustainable practices

S. A. Sharifi · M. Zaeimdar (✉) · S. A. Jozi · R. Hejazi
Department of Environment, North Tehran Branch, Islamic Azad University, Tehran, Iran
e-mail: m_zaeimdar@iau-tnb.ac.ir

S. A. Sharifi
e-mail: sharifi.ali.r@gmail.com

S. A. Jozi
e-mail: saJozi@yahoo.com

R. Hejazi
e-mail: rokhshad47@yahoo.com

1 Introduction

The mining industry plays a vital role in global economic development, supplying essential materials for various sectors. However, mining activities have raised concerns due to their significant environmental impacts, including pollution, habitat destruction, and greenhouse gas emissions (Aghababai Beni & Jabbari, 2022). To address these concerns, new technologies and regulations have emerged to minimize the industry's ecological footprint, such as remote sensing and GIS monitoring (Koon et al., 2023) and sustainable mining practices. Remediation techniques like phytoremediation and bioremediation have also gained attention (Aliyu et al., 2023). Amidst increasing mineral demand worldwide, sustainable and responsible mining practices have become paramount (Dembele et al., 2022). Lead and zinc contamination in soil near mining plants pose significant environmental and health risks due to their widespread use in various industries, including mining and metallurgy. Studies have consistently reported elevated lead and zinc levels in soil near mining sites (Adedeji et al., 2020). This soil contamination has far-reaching consequences, impacting soil quality and health (Richardson et al., 2015; Zhou et al., 2022). The extent of contamination varies based on factors such as mining type, processing methods, and waste management (Y. Zhang et al., 2023a, 2023b, 2023c). Consequently, it is imperative to devise effective strategies for managing and remediating lead and zinc-contaminated soil to safeguard both human health and the environment (Durkalec et al., 2022; Zhang et al., 2018). In addition to this, the other reason for choosing the issue of two heavy metal pollutants, lead and zinc, is that lead and zinc pollution can have serious economic consequences for the affected areas. For example, reduced agricultural production, increased healthcare costs, and decreased property values are among the possible consequences. Lead and zinc contamination can affect local communities. For example, people may be exposed to higher amounts of these substances and experience health problems.

Therefore, the risks associated with lead and zinc, the need for control measures and strategies to reduce pollution are very important. This review article can help to gather information and effective control methods.

In light of this context, this review embarks on a comprehensive exploration of lead and zinc soil contamination in proximity to mining industry plants. It delves into the origins and drivers of this contamination, its far-reaching environmental and health consequences, the arsenal of techniques available for monitoring and assessment, and the evolving strategies for mitigation and remediation. The novelty of this review lies in its synthesis of the most recent research and developments in this critical field, thereby accentuating the urgency of addressing this issue. By offering a structured, in-depth, and up-to-date analysis, we aspire to guide future research and action, ultimately steering mining practices towards sustainability and responsible stewardship of the environment.

The important implications of this study for society and the environment in this study are:

Impact on human health: One of the main importance of this study is the effects of water, air and soil pollution on human health. The study can help to better understand the chronic and acoustic effects of these pollutions on people's health.

Environmental protection: assessment and control of water, soil, and air pollution can help to protect and improve the environment of the region. These measures can help preserve biodiversity, protect water resources, and prevent pollution.

Sustainable resource management: This study can contribute to a more sustainable management of mineral and water resources in the region. This includes optimizing mineral extraction processes, water consumption, and pollutant management.

Economic impacts: Assessment and control of pollution can also examine economic impacts. This includes health costs, pollution control and treatment costs, and impacts on local industries.

Environmental mapping: The information collected in this study can be used to prepare environmental maps and make data-based decisions in the field of environmental protection and sustainable development.

Innovation and technological advancement: The study can lead to the development of new and innovative technologies to control and reduce pollution in industries related to lead and zinc.

Promoting the culture of environmental protection: Publishing the results of this study can help increase awareness in society and promote the culture of environmental protection and social responsibility.

2 Sources and Causes of Lead and Zinc Contamination

2.1 Mining Activities and Exploitation of Mines

The level of pollution varies depending on the type of mine, mining methods, and the characteristics of the ore body (Y. Zhang et al., 2023a, 2023b, 2023c). In addition, the age of the mine also affects the level of pollution, with older mines generally causing more pollution due to the accumulation of waste and the lack of modern environmental management practices (Munanku et al., 2023).

Figure 1 shows that mining activities and the chemical characteristics of the ore body can directly affect the type and volume of waste generated (Mwaanga et al., 2019). The use and effectiveness of pollution control measures can also directly affect the amount of waste generated and how it is disposed of (Sanga et al., 2023). The environmental conditions and weather patterns can influence the movement of contaminated soil and water and the effectiveness of pollution control measures. The proximity to other sources of contamination can also contribute to the overall contamination levels (Dold et al., 2009). The time and duration of mining operations can also significantly impact the level of soil contamination, as the longer the operations continue, the greater the potential for contamination (Chen et al., 2007). The network graph demonstrates the complex interactions between these factors and highlights the importance of considering multiple factors when mitigating soil contamination in mining operations.

Fig. 1 Network graph illustrating the intricate interrelationships between various influential factors contributing to soil contamination in mining operations (Aghababai Beni & Jabbari, 2022; Beni & Esmaeili, 2020b)

The amount of pollution generated by mining activities can be seen in Table 1, which summarizes the data from various studies on the concentration of lead and zinc in the soil around different mining sites. The table provides information on the levels of lead and zinc pollution, health and environmental impacts, and economic consequences associated with mining and smelting activities in various cities and countries. By comparing the data in Table 1, the effective factors impacting the level of soil contamination around lead and zinc mines and mining industries can be summarized as follows:

- **Type of mining method used**: Open-pit mining causes more severe soil pollution than underground mining.
- **Type of mineral ore being extracted**: Lead mining caused more soil pollution than zinc mining.
- **The age of the mine** (Table 2): Older mines generally have accumulated more waste and have a higher likelihood of causing soil pollution than newer mines, which tend to have better environmental management practices.
- **The geographic location of the mining operation**: Mining operations in arid regions tended to have higher soil pollution levels than those in mountainous regions due to the lack of vegetation and moisture in the former.
- **The type and amount of mining waste generated**: Tailings and slag are the most common forms of waste.
- **Level of environmental management practices employed by mining companies**: Proactive measures taken by mining companies and compliance with regulations.

2.2 Production and Processing Activities

Production and processing activities have been identified as a significant source of soil pollution with lead ions. Table 3 presents the potential of polluting the environment around the factories of different industries. Lead and zinc are heavy metals that are frequently found in contaminated soils near mining and smelting activities, where the metals are extracted and processed from ores for metal production (Sapkota

Table 1 The amount of pollution produced by mining activities in different cities and the consequences of pollution

Country	City	Source of Pollution	Lead (mg kg^{-1})	Zinc (mg kg^{-1})	Health Impact	Effect on Plants	Effect on Animals	Impact on Economy	Reference
China	Baoji	Mining activities	2632	2508	Neurological damage, anemia, kidney damage, reproductive system damage	Reduced plant growth, decreased yield	Heavy metal accumulation in wildlife	Loss of agricultural productivity, decreased property values	(Hu et al., 2020; Zhao et al., 2019)
India	Zawar	Mining activities	40,000	14,000	Anemia, neurological damage, developmental delays	Reduced plant growth, decreased yield	Heavy metal accumulation in wildlife	Loss of agricultural productivity, decreased property values	(Setia et al., 2023)
Peru	La Oroya	Smelting activities	3188	4813	Respiratory illnesses, neurological damage, developmental delays	Reduced plant growth, decreased yield	Heavy metal accumulation in wildlife	Loss of agricultural productivity, decreased property values	(Chirinos-Peinado & Castro-Bedriñana, 2020)
USA	Leadville	Mining activities	2200	9600	Neurological damage, anemia, kidney damage, reproductive system damage	Reduced plant growth, decreased yield	Heavy metal accumulation in wildlife	Loss of agricultural productivity, decreased property values	(Walton-Day & Mills, 2015)
Nigeria	Zamfara	Mining	17,600—18,000	22,400—23,300	Lead poisoning outbreak resulting in over 400 deaths and affecting thousands of people	Crop failure and reduced agricultural productivity	Death and reproductive failure in livestock	Significant reduction in agricultural production and loss of livelihoods	(Mao et al., 2023)
China	Wujiang	Zinc smelting	938—3290	2008—8833	Respiratory problems, nervous system damage, and anemia in humans	Reduced biomass and growth rate in rice plants	Reduced growth rate and egg-laying capacity in earthworms	Loss of tourism revenue due to environmental degradation	(H. Li et al., 2023a, 2023b)
Peru	La Oroya	Mining and metallurgical complex	2900—5000	5800—19,000	High rates of lead poisoning and associated health problems in children	Reduction in plant growth and crop yields	Decline in bird populations and loss of biodiversity	Damage to agricultural and tourism industries	(Q. Li et al., 2023a, 2023b)

Table 1 (continued)

Country	City	Source of Pollution	Lead (mg kg^{-1})	Zinc (mg kg^{-1})	Health Impact	Effect on Plants	Effect on Animals	Impact on Economy	Reference
Australia	Mount Isa	Mining and smelting	300—2600	900—6100	Elevated levels of lead in blood of children and potential health risks	Reduced growth and reproduction in plants	Reduced abundance and diversity of soil invertebrates	Reduced property values and economic impact on tourism	(Zheng et al., 2021)
Morocco	Tarfaya	Phosphate mining	27—43	73—129	Respiratory problems and potential risks to human health	Reduced biomass and growth rate in plants	Reduced diversity and abundance of soil invertebrates	Economic impact on agriculture and fisheries	(Aubineau et al., 2022)
Iran	Zanjan	Zinc and lead mining	178.6–2780	419–4600	Increased risk of anemia, gastrointestinal disorders, kidney and liver damage	Reduced growth, photosynthesis, and yield	Reduced biodiversity and reproduction	Reduced agricultural productivity and loss of livestock	(Parizanganeh et al., 2010)
Iran	Isfahan	Zinc and lead smelting	500–800	1000–2000	Respiratory problems, neurological effects, gastrointestinal disorders	Reduced growth and yield	Accumulation and toxicity in aquatic and terrestrial species	Health costs and loss of agricultural and fishing industries	(Jafarian & Alehashem, 2013)
Iran	Darrehzar	Lead and zinc mining and smelting	211–13,290	169–10,730	Increased blood lead levels, neurological effects, gastrointestinal disorders	Reduced growth and yield	Reduced biodiversity and reproduction	Loss of agricultural and livestock productivity	(Soltani et al., 2017)
Iran	Arak	Lead and zinc mining and smelting	159–1038	86–355	Increased risk of neurological and gastrointestinal disorders	Reduced growth and yield	Accumulation and toxicity in aquatic and terrestrial species	Health costs and loss of agricultural productivity	(Mir et al., 2020)

Table 2 The impact of the mining age on the degree of soil pollution in surrounding areas across various cities

Mining Type	Country	Mine Location	Age of Mine	Lead (mg kg^{-1})	Zinc (mg kg^{-1})	Reference
Lead–zinc mining	China	Huize	> 50 years	1230	4280	(Cao et al., 2022; Luo et al., 2023)
Lead mining	Zambia	Kabwe	> 90 years	3150	3520	(Munanku et al., 2023; Yamazaki et al., 2021)
Chromite	India	Sukinda	> 50 years	820	1880	(Mohanty et al., 2023; Pradhan et al., 2020)
Lead–zinc mining	Peru	Cerro de Pasco	> 100 years	2760	2160	(Biamont-Rojas et al., 2023; Orellana Mendoza et al., 2021)
Nickel mining	Russia	Norilsk	> 80 years	89	325	(Karnaeva et al., 2021)
Copper mining	USA	Montana	30 years	382	1878	(X. Jiang et al., 2022a, 2022b)
Lead–zinc mining	Peru	La Oroya	98 years	3700	26,000	(Rosas et al., 2007; Sagan et al., 2018)
Lead–zinc mining	China	Zhongtiaoshan	40 years	1860	2620	(Liu et al., 2018)
Nickel-copper mining	Canada	Sudbury	120 years	30	220	(Mathieu et al., 2021)
Gold mining	Brazil	Paracatu	15 years	12.6	127.7	(Feitosa et al., 2021; Ng et al., 2019)
Lead mining	China	Shangba	10 years	873	1482	(Chen et al., 2007; Chi et al., 2022)
Zinc smelting	Peru	La Oroya	98 years	422.3	3353.3	(Castro-Bedriñana et al., 2021)
Gold mining	South Africa	Johannesburg	> 100 years	11.8	614.7	(Tibane & Mamba, 2022)
Silver mining	USA	Idaho	30 years	13.2	169.1	(Dembele et al., 2022; Schmitt et al., 2007)
Lead–zinc mining	China	Huixian	2–9 years	571–1226	1065–4115	(Ba et al., 2022; Xiao et al., 2019; Zhan et al., 2014)
Lead mining	Iran	Zanjan	35 years	2098–7424	426–3084	(Faraji et al., 2023; Tale et al., 2023)
Gold mining	Nigeria	Bagega	2–4 years	19,000–28000	600–1900	(Adewumi & Laniyan, 2020; Aliyu et al., 2023)
Lead–zinc mining	Peru	Cerro de Pasco	> 400 years	510–13500	1670–20600	(Y. J. Li et al., 2022a, 2022c, 2022d; Smuda et al., 2007)
Zinc mining	USA	Palmerton	97–102 years	330–50000	3500–84,800	(Vodyanitskii et al., 2020; Zhu et al., 2022)
Underground	Australia	Mount Isa	> 90 years	300—7600	1500—29,000	(Kolala et al., 2020; Li & Cai, 2021; Mackay et al., 2013)
Underground	Canada	Flin Flon	> 80 years	24—800	76—11,200	(Motomura et al., 2023; Shotyk et al., 2016)
Open-pit mining	China	Dabaoshan	> 30 years	226—1672	221—4085	(Liang et al., 2023)
Underground	India	Jharia	> 100 years	128—1567	348—2416	(Liang et al., 2023)
Open-pit mining	Peru	Cerro de Pasco	> 400 years	254—6237	276—22,300	(Dold et al., 2009)
Open pit mining	USA	California	> 100 years	5500–47500	3900–38800	(Wolkersdorfer & Mugova, 2022)
Underground mining	Canada	Sudbury, Ontario	> 100 years	310–1510	1200–2600	(Kumar Singh et al., 2022; Sapkota et al., 2023)

Table 2 (continued)

Mining Type	Country	Mine Location	Age of Mine	Lead (mg kg^{-1})	Zinc (mg kg^{-1})	Reference
Open pit mining	China	Hunan province	1–20 years	360–1255	450–2640	(Yang & Chen, 2023; H. Yu et al., 2023a, 2023b)
Underground mining	Ghana	Obuasi	100 years	760–3700	1200–6500	(Kazapoe et al., 2022; Obiri et al., 2010; Ros-Tonen et al., 2021)
Underground mining	India	Zawar	> 100 years	2,016–3790	3861–5753	(Rebello et al., 2020)

et al., 2023). The waste rock and tailings generated during these activities can contain high concentrations of lead and zinc ions, which can contaminate the surrounding soil and waterways through various mechanisms such as leaching, erosion, and runoff (Li & Cai, 2021). Improper handling and disposal of lead and zinc-containing materials also contribute to soil contamination (Y. J. Li et al., 2022a, 2022c, 2022d). For instance, lead-acid batteries used in vehicles can release lead ions into the environment if not disposed of properly (Nodeh et al., 2023). Similarly, galvanizing and plating processes also produce waste

Table 3 Soil Contamination Levels with Lead and Zinc Ions in Proximity to Major Industrial Factories

Factory/Industry	Location	Pollution concentration (mg kg^{-1})	Reference
ASARCO copper smelter	Hayden, Arizona, USA	Lead: 400 to 1300; Zinc: 3000 to 20,000	(Csavina et al., 2014; Gebhart et al., 2021)
ASARCO smelter	Tacoma, Washington, USA	Lead: 160,000	(Walls et al., 2022)
Hindustan Zinc Limited smelter	Rajasthan, India	Lead: 215 to 1100; Zinc: 8000 to 38,000	(Behera et al., 2021; Gared & Gaur, 2020; Prasad & Ramana, 2016)
Lead-acid battery recycling plant	Taizhou, Zhejiang Province, China	Lead: 320,000; Zinc: 1,090,000	(Shi et al., 2019; Xu et al., 2022)
Lead-acid battery recycling plant	Wuhan, China	Lead: 18,000	(M. Li et al., 2021a, 2021b, 2021c, 2021d; Tian et al., 2014)
USS Lead Superfund Site	East Chicago, USA	Lead: 40,000	(Haque et al., 2021; Ringwald et al., 2021)
Anaconda Copper	Montana, USA	Lead: 160,000; Zinc: 240,000	(Burt et al., 2003; Zhang et al., 2020)
Palmerton Zinc Superfund Site	Pennsylvania, USA	Lead: 1510; Zinc: 5800	(Ketterer et al., 2001; Richardson et al., 2015)
Textile dyeing and printing factories	Dhaka, Bangladesh	Lead: 35 to 188; Zinc: 192 to 6092	(Zerin et al., 2020)
Textile factories	Tirupur, India	Lead: 12 to 147; Zinc: 60 to 1479	(Swarnkumar Reddy & Osborne, 2020)
Textile factory	Istanbul, Turkey	Lead: 57 to 607; Zinc: 433 to 3574	(Barut et al., 2016)
Electronic waste recycling activities	Agbogbloshie, Accra, Ghana	Lead: 63 to 7631; Zinc: 141 to 12,847	(Ackah, 2019; Canavati et al., 2022; Fujimori et al., 2016)
Electronic waste recycling	Taizhou, China	Lead: 461; Zinc: 1556	(Lin et al., 2022a, 2022b)
Electronic waste recycling sites	Aba, Nigeria	Lead: 24 to 1606; Zinc: 71 to 4119	(Nieberl et al., 2023)
Paint manufacturing plant	Jiangsu, China	Lead: 20; Zinc: 73	(Wang et al., 2020)

materials that contain high levels of zinc and can contaminate soil and water if not managed appropriately (Aghababai Beni et al., 2021).

2.3 Waste Disposal and Management Practices

Table 4 illustrates several recent instances of soil contamination by lead and zinc ions resulting from heavy metal waste disposal. The results indicate a clear pattern of heavy metal contamination in soil due to improper waste disposal practices, with lead and zinc being the most commonly found contaminants. Electronic waste and mining waste are particularly problematic, with lead concentrations ranging from 2.01 $mgkg^{-1}$ to 12000 $mgkg^{-1}$ in different locations. The findings highlight the urgent need for stricter regulations and effective waste management practices to prevent soil contamination and its harmful effects on human health and the environment (Huynh et al., 2023).

2.4 Atmospheric Deposition

Lead and zinc are heavy metals that can be emitted into the atmosphere from various anthropogenic activities, such as mining, smelting, and combustion of fossil fuels. These metals can deposit onto soil surfaces through dry and wet deposition and accumulate over time, resulting in soil pollution (Liang et al., 2023; Shotyk et al., 2016). Several factors can affect atmospheric deposition and subsequent soil contamination with lead and zinc, including:

- **Industrial activities:** Industrial processes such as smelting, mining, and refining can release lead and zinc into the air, leading to increased atmospheric deposition and soil contamination (Khan et al., 2023).
- **Transportation:** Emissions from transportation, particularly from vehicles that burn leaded gasoline, can contribute to atmospheric deposition of lead and zinc (Chen et al., 2023; Peter et al., 2018).
- **Proximity to pollution sources:** The closer a soil sample is to a pollution source, such as an industrial facility or a busy road, the higher the levels of lead and zinc deposition are likely to be (Filonchyk & Peterson, 2023; Wong et al., 2022).
- **Soil properties:** Soil characteristics such as pH, organic matter content, and clay mineral content can affect the adsorption and mobility of lead and zinc in soil, which in turn can impact the extent of soil contamination (Li et al., 2024; M. Wang et al., 2023a, 2023b, 2023c, 2023d).
- **Climate and weather patterns:** Atmospheric deposition can be affected by weather patterns, such as precipitation and wind direction, which can transport pollutants over long distances (Wong et al., 2023).

It is difficult to determine the exact percentage of each factor, as the contribution of each factor can vary depending on the specific location and circumstances. However, here is a rough estimate of the

Table 4 Concentration of contaminants in different types of waste in various locations

Waste Type	Contaminants	Concentration (mg kg^{-1})	Location	Reference
Electronic waste	Lead	2500	Nigeria	(Jibiri et al., 2014)
Electronic waste	Lead	2.01–104.03	Ghana	(Acquah et al., 2021)
Electronic waste	Zinc	7.23–174.23	Ghana	(Adanu et al., 2020)
Electronic waste	Lead	1600	India	(Awasthi et al., 2022; Bansal et al., 2024)
Battery waste	Lead and Zinc	77–700	Italy	(Karpinski & Serenyi, 2023)
Battery waste	Lead	432	Nigeria	(Eze et al., 2023)
Mining waste	Lead and Zinc	250–12000	Mexico	(Ahumada-Mexía et al., 2021)
Mining waste	Lead	3000	Australia	(Valenta et al., 2023)
Industrial waste	Zinc	2444	China	(Gu et al., 2023)
Landfill waste	Lead	24.17–71.09	Mexico	(Rueda-Avellaneda et al., 2021)
Municipal solid waste	Lead and Zinc	78–103	India	(Borah et al., 2023)
Municipal solid waste	Zinc	470	Philippines	(Soni et al., 2022)
Agricultural waste	Zinc	23	Brazil	(Schwanke et al., 2022)

relative contribution of each factor in Fig. 2 (Green et al., 2022; Zhuk et al., 2022).

Table 5 provides data on pollutants emitted from industrial factory chimneys that result in the release of lead and zinc into the atmosphere in various cities and countries. Based on the data, it is evident that industrial activities such as lead and zinc smelting, zinc oxide production, lead smelting, zinc smelting, metal mining, waste incineration, and oil refineries have a significant impact on the environment. The pollution levels in the surrounding soil and smoke emissions from these activities are comparatively high and can have adverse effects on human health and the ecosystem. On the other hand, industries such as vehicle exhaust, nickel and copper mining, copper and gold mining, aluminum smelting, nickel smelting, and lead and zinc mining show relatively lower pollution levels. However, it is important to note that any form of pollution can have negative effects on the environment, and continuous efforts should be made to reduce pollution levels.

3 Environmental and Health Effects of Lead and Zinc Contamination

3.1 Soil Pollution and Degradation

Soil pollution can adversely affect the health and productivity of soil ecosystems, including the soil microbial community, and can impair plant growth and development (Goswami et al., 2023; Khan et al., 2023). As shown in Fig. 3, soil fertility evaluation under the effect of soil contamination with lead and zinc can be done using various methods. Some of the commonly used methods are: Soil nutrient analysis (Muller & Muller, 2014), Soil pH measurement (Nabuyanda et al., 2022), Plant growth analysis (Y. Liu et al., 2023a, 2023b; Schwanke et al., 2022), Microbial analysis (X. Jiang et al., 2022a, 2022b).

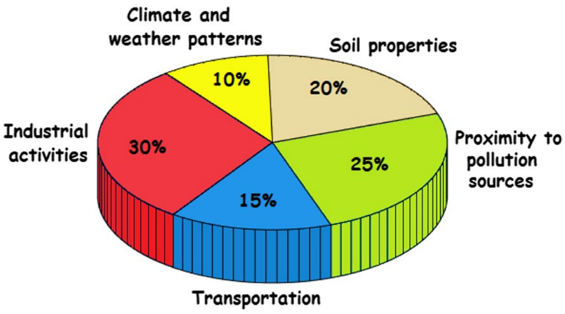

Fig. 2 Approximate estimation of the relative contribution of various factors that can affect atmospheric deposition and subsequent soil contamination with lead and zinc (Haghighizadeh et al., 2023; Haghmohammadi et al., 2023)

According to Table 6, the pH of the soil can be influenced by various factors, including the type of soil, the presence of organic matter, and the concentration of contaminants such as lead and zinc. Generally, soil pH tends to decrease (become more acidic) as the amount of lead and zinc contamination in soil increases. This is because lead and zinc can displace other cations, such as calcium and magnesium, that play a role in maintaining soil pH. When these cations are displaced, the pH of the soil can become more acidic. However, the extent of this pH change can also depend on the type of soil. For example, sandy soils tend to have a lower buffering capacity and are more susceptible to pH changes than clay soils. This means that the pH of sandy soils can change more quickly and drastically in response to changes in the concentration of contaminants such as lead and zinc.

3.2 Water Pollution and its Effects on Aquatic Ecosystems

Soils contaminated with lead and zinc can pollute water through a process known as leaching (Goswami et al., 2023). When it rains or when water is applied to the contaminated soil, the heavy metals can dissolve and move down through the soil, eventually reaching groundwater or surface water (Wolkersdorfer & Mugova, 2022). This can contaminate water bodies such as rivers, lakes, and streams. Once the heavy metals enter the aquatic ecosystem, they can accumulate in the tissues of fish and other aquatic organisms, which can be dangerous for the ecosystem (Sakaa et al., 2022).

Lead and zinc contamination poses a significant threat to aquatic organisms, impacting their health and growth. Lead exposure can lead to reduced fish reproduction, slower growth rates, and behavioral changes, while zinc can affect reproduction, growth, and weaken the immune systems of fish, making them more susceptible to diseases. The

Table 5 Industrial Activities and Associated Pollutants in Factory Chimneys Across Various Countries and Cities

Factory Activity	Country	City	Smoke Type	Chimney Height (m)	Pollution in Surrounding Soil (mg kg^{-1})	Pollution in Smoke (μg m^{-3})	Reference
Lead and Zinc Smelting	China	Shanghai	Acidic	30	506–6600	3015–6428	(Awasthi et al., 2017; Luo et al., 2022)
Zinc Oxide Production	China	Hangzhou	Alkaline	25	143.7–231.3	8.01–17.7	(Hien et al., 2022; Sun et al., 2017)
Lead Smelting	China	Zhuzhou	Acidic	35	67–225	344.6–589.9	(Long et al., 2021; Luo et al., 2023; Zhou et al., 2022)
Zinc Smelting	China	Suzhou	Acidic and Basic	45–80	27–511	257–4100	(Li et al., 2024; P. Yu et al., 2023a, 2023b; Zhang et al., 2018)
Metal Mining	India	Jharia	Acidic	15–50	14.3–584.3	218.9–1568.7	(Dutta Dey & Singh, 2021; Kim et al., 2021)
Waste Incineration	China	Jinhua	Acidic and Basic	45–70	4.4–40	67–181.5	(Li et al., 2016; Y. Wang et al., 2023a, 2023b, 2023c, 2023d)
Vehicle Exhaust	India	Bangalore	-	-	1.75–148.2	35.25–1404.4	(Alshetty & Nagendra, 2022; Peter et al., 2018)
Oil Refineries	Saudi Arabia	Jubail	Alkaline	40–80	7.4–200	470–1760	(Khan et al., 2023; Rojas-Rueda et al., 2021)
Coal-fired Power Plants	USA	Chicago	Acidic	100–120	5.5–168	5.5–168	(Filonchyk & Peterson, 2023; Tongyi Yang et al., 2022a, 2022b, 2022c)
Cement Production	Nigeria	Lagos	Alkaline	60–80	26–210	56–89	(Adedeji et al., 2020)
Nickel and Copper Mining	Canada	Sudbury	-	-	217–2600	-	(Simmatis et al., 2022; Z. Wang et al., 2023a, 2023b, 2023c, 2023d)
Copper and Gold Mining	Chile	Copiapo	-	-	56.5–2030	-	(Bundschuh et al., 2021)
Lead and Zinc Smelting	Kazakhstan	Karaganda	Acidic	57	183–290	21–63	(Coman et al., 2015; Ramazanova et al., 2021)

Table 5 (continued)

Factory Activity	Country	City	Smoke Type	Chimney Height (m)	Pollution in Surrounding Soil (mg kg^{-1})	Pollution in Smoke (μg m^{-3})	Reference
Aluminum Smelting	Russia	Volgograd	-	-	18.8–345	1.1–2.2	(Farjana et al., 2019; Zhuk et al., 2022)
Copper Smelting	Zambia	Kitwe	Acidic	85	200–3700	240–4500	(Mwaanga et al., 2019; Nabuyanda et al., 2022; Sanga et al., 2023)
Copper Smelting	Bulgaria	Pirdop	-	-	19–410	N/A	(Jordanova et al., 2021; Metcheva et al., 2003; Yotova et al., 2018)
Lead and Zinc Smelting	Germany	Duisburg	Acidic	75–175	91–596	8–11	(Cappucci et al., 2020; Suer et al., 2021; Zacharopoulos et al., 2023)
Nickel Smelting	Norway	Kristiansand	-	-	5.5–139	0.04–0.28	(Flem et al., 2018; Trannum et al., 2023)
Lead and Zinc Mining	Poland	Olkusz	-	-	108–5300	-	(Baran et al., 2023; Ghayoraneh & Qishlaqi, 2017)
Copper and Zinc Smelting	Spain	Huelva	Acidic	150	119–4900	27–294	(Bullock et al., 2023; Hao et al., 2020)

correlation between soil pollution with lead and zinc ions and water pollution around factories is evident in Table 7, showing a positive relationship where increased soil pollution corresponds to higher water pollution levels. This emphasizes the importance of addressing soil contamination to safeguard water quality and aquatic life.

3.3 Plant Uptake and Crop Contamination

Contamination of plants with lead and zinc typically occurs through the uptake of these metals by the plant roots from the contaminated soil (Usman et al., 2023). When the concentration of lead and zinc in the soil exceeds the safe limit, the roots of the plants absorb these metals along with water and essential nutrients (Lingrui Liu et al., 2022a, 2022b). Once inside the plant, these metals can accumulate in various plant tissues, including leaves, stems, and fruits, affecting plant growth, metabolism, and yield (Soltani et al., 2017). Additionally, metal-contaminated soil can also reduce the activity of soil microorganisms that help in nutrient cycling, leading to further plant stress and reduced growth (Liu et al., 2021). According to Table 8, the extent of plant contamination with lead and zinc depends on several factors, including the type of plant, duration and level of metal exposure, soil characteristics, and the presence of other contaminants in the soil.

The network model of the effect of soil contamination with lead and zinc ions on plants was presented in Fig. 4; These problems include:

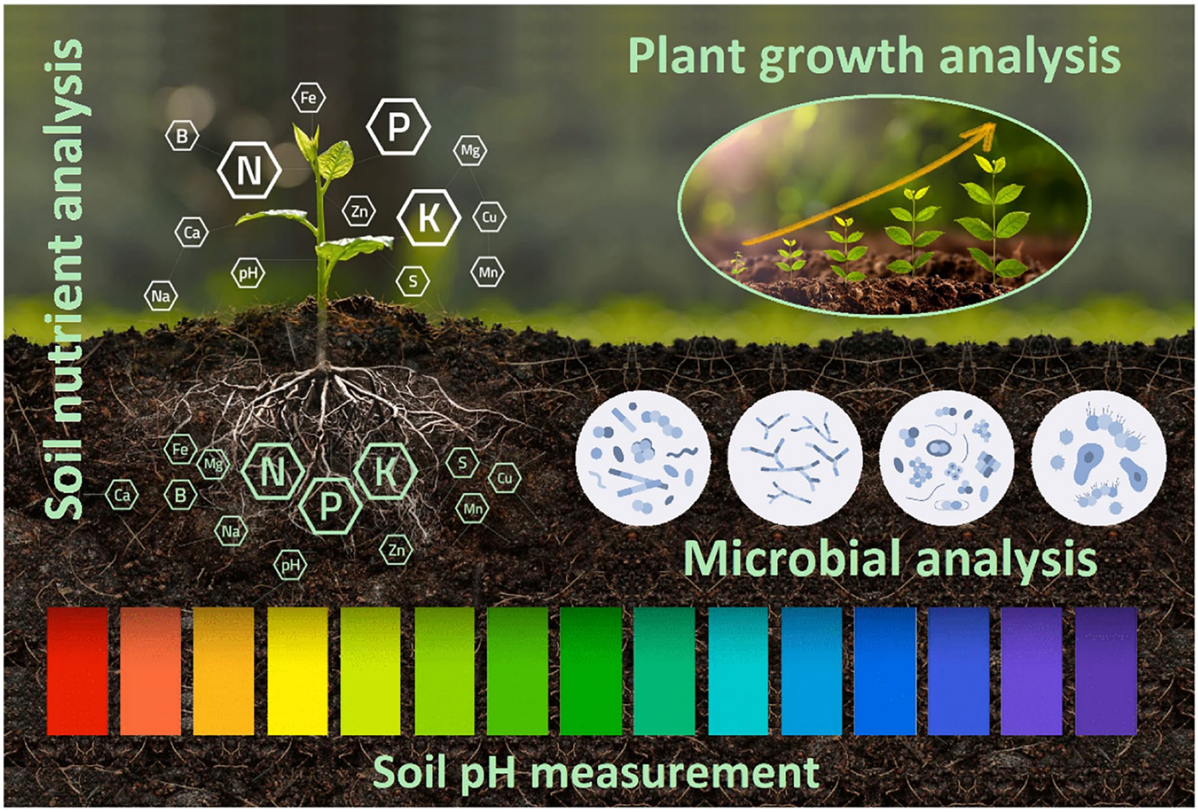

Fig. 3 Factors affecting soil fertility for plant growth under the influence of lead and zinc ions contamination in soil

Table 6 The effect of soil contamination with lead and zinc ions on soil pH changes in different types of soil from different regions

Location	Soil Type	Soil pH (Control)	pH of Contaminated Soil	Contaminants (mg kg^{-1})	Reference
Turkey	Sandy Loam	6.1	5.3	Pb: 2500; Zn: 3500	(Różański et al., 2021)
China	Clay Loam	6.8	5.8	Pb: 800; Zn: 1200	(Usman et al., 2023)
India	Sandy Loam	7.2	6.5	Pb: 200; Zn: 500	(Ahmed et al., 2021)
China	Loamy Sand	7.4	6.3	Pb: 500; Zn: 1500	(El-Ghamry et al., 2002)
China	Agricultural	7.47	6.66	Pb: 1476; Zn: 2245	(X. Li et al., 2022a, 2022c, 2022d)
India	Agricultural	7.42	6.36	Pb: 71.64; Zn: 85.39	(Tyagi et al., 2022)
Nigeria	Agricultural	5.85	4.45	Pb: 113.31; Zn: 173.02	(Mandal et al., 2022)
Iran	Forest	6.78	5.58	Pb: 8.14; Zn: 20.39	(Fathizad et al., 2020)
Poland	Forest	4.90	4.25	Pb: 5.18; Zn: 74.67	(Kicińska & Wikar, 2021)
China	Sandy Loam	6.8	4.6	Pb: 140; Zn: 280	(Wang et al., 2021)
India	Loamy Sand	7.2	6.5	Pb: 150; Zn: 170	(Setia et al., 2023)
China	Agricultural	7.5	5.8	Pb: 200; Zn: 400	(Y. Zhang et al., 2023a, 2023b, 2023c)
Bangladesh	Forest	6.9	5.8	Pb: 120; Zn: 240	(Khan & Shoumik, 2022)
China	Silty Clay	6.8	4.9	Pb: 80; Zn: 120	(Wei et al., 2023)
Nigeria	Silt Loam	7.0	6.2	Pb: 100; Zn: 200	(Aja et al., 2021)

Table 7 Information on the correlation between soil pollution with lead and zinc ions and water pollution around the factories

Location/ Source of Contamination	pH	Total Dissolved Solids (mg L^{-1})	Total Suspended Solids (mg L^{-1})	Chemical Oxygen Demand (mg L^{-1})	Biological Oxygen Demand (mg L^{-1})	Dissolved Oxygen (mg L^{-1})	Electrical Conductivity (mS cm^{-1})	Total Organic Carbon (mg L^{-1})	Total Nitrogen (mg L^{-1})	Total Phosphorus (mg L^{-1})	Lead (µg L^{-1})	Zinc (µg L^{-1})	Reference
China / Industrial	6.9	1800	350	40	10	7.8	2.3	3.8	10	0.8	1.7	3.2	(Lu et al., 2022)
Iran / Mining	7.2	400	150	50	20	8.1	1.5	2.6	5	0.6	0.5	2.8	(Biswas et al., 2023)
Australia / Agricultural	7.4	600	120	30	10	8.3	1.8	4.1	8	0.9	1.1	4.5	(Usman et al., 2021)
USA / Urban Runoff	7.1	750	200	60	15	7.5	2.2	2.9	12	1.2	2.0	2.5	(Rainey et al., 2022)
India / Industrial	6.8	1200	300	80	25	7.6	1.9	3.5	9	1.1	2.5	4.1	(Ambade et al., 2021)
India/ Agricultural	8.1	320	40	120	84	5.4	0.97	11.4	1.75	0.12	0.146	0.214	(Singh et al., 2023)
China/ Industrial	7.6	305	33.7	103.3	64.6	5.8	0.566	7.24	1.77	0.038	0.182	0.318	(Timalsina et al., 2022)
China/ Mining	7.4	500	47	300	200	4.5	1.4	10.3	1.21	0.053	0.728	0.964	(Singh et al., 2023)
USA/ Urban runoff	6.8	218	18.4	86.2	62.8	7.5	0.524	6.9	0.78	0.03	0.09	0.25	(Yang et al., 2020)
Mexico/ Mining	7.2	385	57	289	194	6.8	1.1	8.7	1.13	0.11	0.986	0.992	(Vargas-Solano et al., 2022)
Nigeria/ Industrial	5.4	480	70	120	15	5.7	0.72	7.2	0.9	0.06	113.31	173.02	(Osinowo, 2016)
USA/ Industrial	7.5	450	40	100	10	8.0	0.65	5.3	0.5	0.04	320	480	(Muller & Muller, 2014)
India/ Industrial	7.1	560	60	140	18	6.9	0.78	6.8	0.7	0.06	71.64	85.39	(Samson et al., 2023)

Table 7 (continued)

Location/ Source of Contamination	pH	Total Dissolved Solids (mg L^{-1})	Total Suspended Solids (mg L^{-1})	Chemical Oxygen Demand (mg L^{-1})	Biological Oxygen Demand (mg L^{-1})	Dissolved Oxygen (mg L^{-1})	Electrical Conductivity (mS cm^{-1})	Total Organic Carbon (mg L^{-1})	Total Nitrogen (mg L^{-1})	Total Phosphorus (mg L^{-1})	Lead (µg L^{-1})	Zinc (µg L^{-1})	Reference
Australia/ Mining	7.8	600	50	160	20	7.5	0.9	7.0	0.8	0.07	200	300	(Jara-Baeza et al., 2023)
Germany/ Industrial	6.5	420	30	90	12	7.8	0.6	4.5	0.4	0.03	180	270	(Perosa et al., 2022)
India/ Mining	6.8	1200	250	200	90	5.5	1.5	25	4.5	0.6	25	70	(Kumar et al., 2021)
USA/ Mining	6.5	800	120	120	60	6.8	1.1	20	3	0.5	10	60	(Kamrath & Yuan, 2022)
UK/ Industrial	7.2	500	100	80	50	7.2	0.9	15	2.5	0.4	20	80	(Begum et al., 2019)
Canada/ Industrial	6.8	200	45	55	20	7.8	0.35	6.5	0.9	0.4	15	22	(Meshesha et al., 2020)
India/ Industrial	8.1	350	80	80	30	7.5	0.45	7.8	1.2	0.6	20	28	(Shukla et al., 2020)
Brazil/ Industrial	7.5	175	35	65	18	7.9	0.3	5.8	1.0	0.5	18	24	(Silva et al., 2022)
Australia/ Industrial	6.4	100	20	35	12	8.3	0.22	4.5	0.6	0.2	10	15	(Rate & McGrath, 2022)

Table 8 The effect of soil contamination with lead and zinc ions on plants in different periods of time

Plant	Symptoms	Severity	Soil Concentration (mg kg^{-1})	Duration of Exposure (day)	Reference
Tomato	Chlorosis, necrosis, reduced growth, and yield	Moderate to severe	Pb: 56, Zn: 210	60	(Zia-ur-Rehman et al., 2023)
Wheat	Reduced growth, chlorosis, reduced photosynthesis	Moderate	Pb: 49, Zn: 156	90	(Li et al., 2022b)
Bean	Leaf necrosis, reduced nutrient uptake, reduced growth and yield	Severe	Pb: 70, Zn: 180	120	(Qin et al., 2020)
Corn	Stunted growth, chlorosis, reduced photosynthesis	Moderate to severe	Pb: 80, Zn: 250	45	(Mapodzeke et al., 2021)
Soybean	Leaf necrosis, reduced nutrient uptake, increased susceptibility to pests	Severe	Pb: 65, Zn: 200	75	(Lingrui Liu et al., 2022a, 2022b)

- **Reduced growth and yield:** Lead and zinc can negatively affect plant growth and development, leading to stunted growth and reduced crop yield (Li et al., 2022a, 2022c, 2022d; Zia-ur-Rehman et al., 2023).
- **Chlorosis:** High levels of lead and zinc can cause chlorosis, a condition where the leaves of the plant turn yellow due to a lack of chlorophyll (Borah et al., 2023; QIN et al., 2020; Yotova et al., 2018).
- **Leaf necrosis:** Leaf necrosis is another common symptom of lead and zinc toxicity (Guo et al., 2021; LI et al., 2022a, 2022c, 2022d). This condition is characterized by the death of leaf tissue, which can negatively affect plant growth and photosynthesis (Guo et al., 2021).
- **Reduced nutrient uptake:** Lead and zinc can interfere with the uptake of essential nutrients, such as iron, magnesium, and calcium, leading to nutrient deficiencies in plants (Lingrui Liu et al., 2022a, 2022b; Mapodzeke et al., 2021; Zia-ur-Rehman et al., 2023).
- **Lowered photosynthesis:** Lead and zinc can interfere with the photosynthetic process, leading to reduced energy production in plants (Li et al., 2022a, 2022c, 2022d; Liu et al., 2021; Y. Liu et al., 2023a, 2023b).
- **Increased susceptibility to pests and diseases:** Plants that are exposed to lead and zinc contamination may be more susceptible to pest and disease attacks due to weakened defenses (Bundschuh et al., 2021; Timalsina et al., 2022).

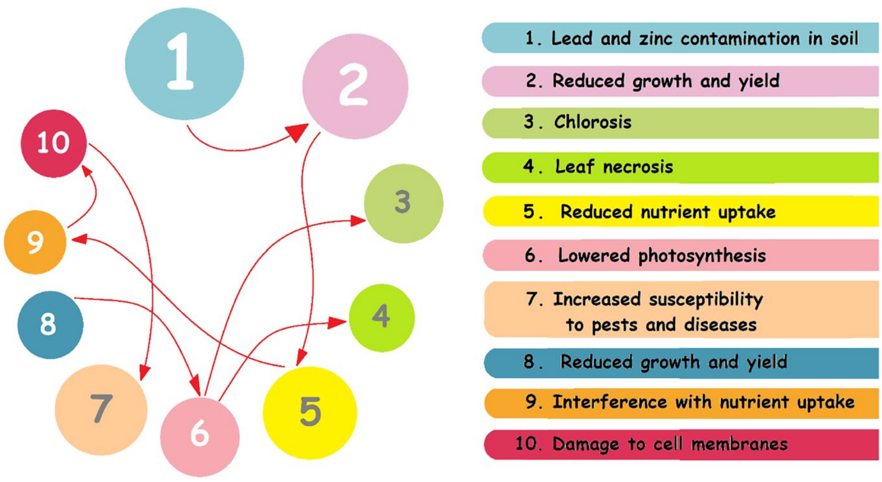

Fig. 4 Network model of soil contamination with lead and zinc ions and its effects on plants

- **Reduced growth and yield:** Lead and zinc can negatively affect the growth and development of plants, leading to stunted growth and reduced yield (Soltani et al., 2017; Timalsina et al., 2022).
- **Interference with nutrient uptake:** Lead and zinc can compete with other essential nutrients for uptake by plant roots, leading to nutrient deficiencies and other physiological disorders (Borah et al., 2023; Mapodzeke et al., 2021).
- **Damage to cell membranes:** Lead and zinc can cause damage to the cell membranes of plants, leading to leakage of cell contents and reduced plant vitality (Ahmed et al., 2021; Lingrui Liu et al., 2022a, 2022b; Z. Zhang et al., 2023a, 2023b, 2023c; Zia-ur-Rehman et al., 2023).

3.4 Health Risks and Hazards Associated with Lead and Zinc Exposure

One example of a disease caused by soil contamination with lead and zinc is poisoning (Green et al., 2022; Markowitz, 2016). Table 9 presents some of the diseases caused by soil contamination with lead and zinc ions for humans. Long-term exposure to lead-contaminated soil can cause lead to accumulate in the body (Beni & Esmaeili, 2019), leading to a variety of health problems including anemia (Piai and Olympio, 2023), kidney damage (Pérez-Vázquez et al., 2021), neurological disorders (Chauhan et al., 2022), developmental delays in children (Laidlaw et al., 2017; Zhang et al., 2020), and reproductive problems (Bundschuh et al., 2021). Zinc contamination can also have negative health effects, such as causing gastrointestinal issues (Luo et al., 2022) and impairing the immune system (Green et al., 2022).

3.5 Effects on Wildlife and Biodiversity

The impact of lead and zinc soil contamination on wildlife and biodiversity is a complex (Table 10) and multifaceted topic, and research in this area has highlighted several important topics that are worth considering, some of these topics are:

- **Direct toxicity effects:** Lead and zinc are toxic to wildlife and can cause a range of health effects, including damage to the nervous system, digestive system, and reproductive system. For example, lead exposure in birds was associated with reduced egg production and hatching success (Durkalec et al., 2022).
- **Indirect effects on food webs:** Lead and zinc contamination can also affect the food webs in which wildlife species are situated. For example, lead poisoning in predators can result from the ingestion of prey that have been exposed to lead (Green et al., 2022; Liang et al., 2023). Additionally, lead contamination can lead to a reduction in the abundance and diversity of invertebrates, which can have knock-on effects for higher trophic levels. For example, lead contamination in streams was associated with reduced invertebrate biomass and diversity, which in turn was associated with lower fish biomass (Thummala et al., 2022).
- **Habitat degradation:** Lead and zinc contamination can also result in habitat degradation, which can have negative impacts on biodiversity. For example, lead and zinc contamination in soils was associated with reduced plant biomass and diversity (Y. Liu et al., 2023a, 2023b; Rajkumar et al., 2012).
- **Synergistic effects:** Lead and zinc contamination can also interact with other stressors to produce synergistic effects. For example, lead exposure in birds was associated with increased susceptibility to avian malaria (Canavati et al., 2022; Mao et al., 2023; Ros-Tonen et al., 2021).

4 Monitoring and Assessment of Lead and Zinc Contamination in Soil

4.1 Sampling and Analytical Techniques

New techniques for monitoring and assessing lead and zinc contamination in soil have been developed, including extraction methods using magnetic nanoparticles (Lingrui Liu et al., 2022a, 2022b) and fractionation techniques (Soodan et al., 2014), and analytical techniques (Neo et al., 2022) such as spectroscopy (Milori et al., 2023) and laser-induced breakdown spectroscopy (LIBS) (Ying Zhang et al., 2021a, 2021b). Non-destructive techniques like micro-X-ray fluorescence (μXRF) (Marafatto et al., 2021)and synchrotron-based X-ray fluorescence microscopy (XFM) (Castillo-Michel et al., 2017) can provide detailed information about the distribution of lead

Table 9 Environmental pollution and health effects in various countries

Country	Symptoms	Sources of Exposure	Prevention and Control Measures	Pollution (mg kg^{-1})	Reference
Nigeria	Abdominal pain, anemia, developmental delays, seizures	Ingestion of contaminated soil, water, or food	Remediation of contaminated soil and water sources, public education campaigns	Lead up to 12,000	(Ogarekpe et al., 2023)
India	Anemia, fatigue, muscle weakness, joint pain	Ingestion of contaminated soil and dust	Remediation of contaminated soil, improved sanitation and hygiene practices	Lead up to 57,000	(Goswami et al., 2023)
United States	Neurological damage, developmental delays, anemia	Ingestion of contaminated soil, dust, or water	Remediation of contaminated soil, testing of soil and water sources, public education campaigns	Lead up to 5000	(Markowitz, 2016)
Australia	Gastrointestinal distress, anemia, developmental delays	Ingestion of contaminated soil or dust	Remediation of contaminated soil, public education campaigns	Lead up to 2000	(M. M. Li et al., 2020a, 2020b)
Romania	Anemia, vomiting, diarrhea, abdominal pain	Consumption of zinc-contaminated water and food, inhalation of contaminated dust and fumes	Limiting exposure to contaminated soil and dust, use of clean water sources	Zinc: 45–2348	(Chera-Anghel & Stefan-van Staden, 2023)
Mexico	Neurological symptoms, developmental delays, anemia	Ingestion of contaminated soil and dust	Removal of contaminated soil, use of clean soil	Lead: 61–1010	(Osten et al., 2023)
Australia	Developmental delays, behavioral problems, anemia	Ingestion of contaminated soil and dust, inhalation of fumes	Removal of contaminated soil, use of clean soil and dust control measures	Lead: 41–3000	(Laidlaw et al., 2017)
USA	Developmental delays, anemia, neurological symptoms	Ingestion of contaminated soil and dust, inhalation of fumes	Removal of contaminated soil, use of clean soil and dust control measures	Lead: 5–1746	(Stoneham et al., 2021)
Bangladesh	Anemia, abdominal pain, cognitive impairment	Contaminated soil, water, and food	Soil testing, avoiding contaminated areas, crop rotation, washing hands and food	Lead: 50–3780	(Z. Zhang et al., 2023a, 2023b, 2023c)
China	Developmental delays, learning difficulties, high blood pressure	Contaminated soil and dust	Removal of contaminated soil, improved hygiene, avoiding lead exposure	Lead: 6.8–65,500	(Piai and Olympio, 2023)
India	Vomiting, diarrhea, anemia	Contaminated water and food	Improved sanitation, water treatment, crop rotation	Zinc: 94.8	(Chauhan et al., 2022)
Mexico	Anemia, constipation, joint pain	Contaminated soil and dust	Removal of contaminated soil, improved hygiene, avoiding lead exposure	Lead: 50–5100	(Pérez-Vázquez et al., 2021)
United States	Abdominal pain, fatigue, learning difficulties	Contaminated soil and dust	Removal of contaminated soil, covering soil with clean soil or mulch, washing hands and toys	Lead: 400–3300	(Lobo et al., 2022)

Table 9 (continued)

Country	Symptoms	Sources of Exposure	Prevention and Control Measures	Pollution (mg kg^{-1})	Reference
China	Neurological damage, anemia, kidney damage, developmental delays in children	Ingestion of contaminated soil or water, inhalation of dust or fumes from smelting operations	Contaminated soil remediation, water treatment, reducing emissions from smelting operations	Lead: 1794	(Awasthi et al., 2017)
Australia	Abdominal pain, nausea, vomiting, diarrhea, anemia, kidney damage	Ingestion of contaminated soil or water, inhalation of dust or fumes from mining operations	Contaminated soil remediation, water treatment, reducing emissions from mining operations	Zinc: 2500	(Liu et al., 2021)
United States	Neurological damage, anemia, kidney damage, developmental delays in children	Ingestion of contaminated soil or water, inhalation of dust or fumes from industrial operations	Contaminated soil remediation, water treatment, reducing emissions from industrial operations	Lead: 424	(Green et al., 2022)
India	Abdominal pain, nausea, vomiting, diarrhea, anemia, kidney damage	Ingestion of contaminated soil or water, inhalation of dust or fumes from mining operations	Contaminated soil remediation, water treatment, reducing emissions from mining operations	Zinc: 620	(Thummala et al., 2022)
Mexico	Neurological damage, anemia, kidney damage, developmental delays in children	Ingestion of contaminated soil or water, inhalation of dust or fumes from mining operations	Contaminated soil remediation, water treatment, reducing emissions from mining operations	Lead: 312	(Pérez-Vázquez et al., 2021)

and zinc in soil samples at the microscale. Sampling techniques like random sampling, composite sampling, and grid sampling, along with analytical techniques such as atomic absorption spectroscopy (AAS) (Aliyu et al., 2023), inductively coupled plasma mass spectrometry (ICP-MS) (Hien et al., 2022), and X-ray fluorescence (XRF) (Marafatto et al., 2021), can accurately assess the extent and severity of contamination. Soil extraction using solvents can be analyzed using AAS or ICP-MS to determine contaminant concentration. Choosing appropriate techniques based on soil properties and contaminant types is crucial for effective monitoring and remediation; Table 11 summarizes various techniques for detecting and analyzing lead and zinc in soil samples.

4.2 Geographic Information Systems (GIS) and Remote Sensing Techniques for Mapping and Monitoring

Geographic Information Systems (GIS) and remote sensing techniques are important tools for mapping and monitoring various environmental parameters (Wong et al., 2020b). GIS is a computer-based system that allows users to store, analyze, and display spatial data (Khan et al., 2022). It is used to manage large datasets with geospatial information, such as maps, satellite imagery, and terrain models (Nwazelibe et al., 2023). GIS can be used to model and analyze complex relationships between environmental factors and human activities (X. Li et al., 2022a, 2022c, 2022d). Table 12 provides a comparison between GIS and remote sensing techniques for mapping and monitoring of soils contaminated with lead and zinc ions. From the table, it can be concluded that both GIS and remote sensing techniques have advantages and disadvantages, and the choice of technique depends on the specific requirements of the study. While GIS is better suited for spatial analysis and data management, remote sensing techniques provide valuable information about the spectral properties of the contaminated soil.

Remote sensing techniques are generally considered to be more accurate than GIS when it comes to data analysis. However, the use of remote sensing techniques requires specialized equipment and expertise, which may not be readily available to all researchers. On the other hand, GIS is more user-friendly and widely accessible, making it a more

Table 10 Impacts of soil pollution on animal and plant species

Location	Type of soil pollution	Pollution (mg kg^{-1})	Name of animal or plant species	Description	Reference
USA	Lead and zinc	High levels	Eastern fence lizard	Exposure to contaminated soil led to reduced growth rates and altered immune function in lizards	(Marsili et al., 2009)
Spain	Lead	Moderate levels	Olive trees	Lead accumulation in soil led to reduced growth, altered nutrient uptake, and changes in soil microbial communities in olive trees	(Moreno et al., 2013)
China	Lead and cadmium	High levels	Microbial communities	Soil contamination led to reduced microbial diversity and altered microbial community structure in an urban park	(Huang et al., 2023)
Sri Lanka	Lead and zinc	High levels	Groundwater microbial communities	Contamination led to reduced microbial diversity and altered microbial community structure in groundwater	(Cooray et al., 2021)
Poland	Lead and zinc	Pb: 465; Zn: 7325	Lichen communities	Soil contamination with lead and zinc was found to be negatively affecting lichen communities in urban and industrial areas of Poland	(Anderson et al., 2022)
Nigeria	Lead and cadmium	Pb: 275; Cd: 15	Tilapia fish	Contamination of river sediments with lead and cadmium was found to be negatively affecting the health and growth of tilapia fish in Nigeria	(Morshdy et al., 2021)
India	Lead	77–130	Wheat crop	High levels of lead contamination in soil were found to be affecting the growth and yield of wheat crops in India	(Bhatnagar et al., 2022)
China	Lead and cadmium	Pb: 43.2; Cd: 85.3	Microbial communities in urban park soil	Reduced microbial diversity and activity, altered community structure	(W. Liu et al., 2023a, 2023b)
India	Zinc	400–1000	Earthworms	Reduced survival and growth, altered soil properties and nutrient cycling	(Maity et al., 2011)

Table 10 (continued)

Location	Type of soil pollution	Pollution (mg kg^{-1})	Name of animal or plant species	Description	Reference
Poland	Zinc	200–3200	Red clover (plant)	Reduced growth and biomass, altered morphology and nutrient content	(Zielinska et al., 2012)
China	Lead and cadmium	Pb: 61.47; Cd:0.27	Plants and soil microbes	Reduced plant diversity and altered soil microbial communities in an urban park	(Guo et al., 2021)
Australia	Zinc	10–200	Grasses and invertebrates	Reduced growth and reproduction of grasses, and altered invertebrate communities in a mine site	(Wilder & Simpson, 2022)
Brazil	Lead	950	Ants	Reduced ant diversity and abundance in a lead-contaminated urban garden	(Mendonça-Santos et al., 2023)
Spain	Lead	300–900	Birds	Reduced reproductive success and survival in birds living near contaminated industrial sites	(Durkalec et al., 2022)
South Africa	Zinc	250–1000	Termites	Reduced termite abundance and diversity in a mine site with high zinc pollution	(Lesnik, 2014)
China	Lead and Cadmium	Pb: 6285; Cd: 312	Soil Microbial Communities	Contamination reduced microbial biomass and activity, altered community composition, and decreased soil nutrient availability	(Y. Liu et al., 2023a, 2023b)

practical choice for many studies. The decision to use remote sensing or GIS will ultimately depend on factors such as the nature of the research, available resources, and the level of expertise of the researchers involved (Hakim et al., 2023).

5 Mitigation and Remediation Strategies for Lead and Zinc Contamination

5.1 Soil Remediation Techniques: Physical, Chemical, and bBiological Approaches

There are several solutions to treat soil contaminated with lead and zinc ions, which can be classified into physical, chemical, and biological methods. Table 13 provides information on the effectiveness of various treatments for the removal of lead and zinc ions from contaminated soil. Physical methods involve the removal of contaminated soil through excavation or dredging (Lin et al., 2022b), which is then disposed of in a controlled manner (Osten et al., 2023). This process is often costly and disruptive, but it can effectively remove contaminated soil (Aghababai Beni et al., 2021). Chemical methods involve the use of chemicals to immobilize or remove contaminants from the soil (Chi et al., 2022). One common technique is soil washing, where contaminated soil is treated with a solution that dissolves the contaminants, which are then separated

Table 11 Summary of various techniques for detecting and analyzing lead and zinc in soil samples

Technique	Summary	Reference
Magnetic solid-phase extraction	A new method for extracting lead from soil samples using magnetic nanoparticles, resulting in higher extraction efficiency and lower detection limits	(Qu et al., 2022)
Portable X-ray fluorescence	A fast and non-destructive method for measuring the concentration of lead and zinc in soil samples in the field, with comparable accuracy to laboratory analysis	(Neo et al., 2022)
Sequential extraction	A technique for separating lead and zinc in soil samples into different fractions based on their binding forms, providing information on their bioavailability and mobility	(Barhoum et al., 2023)
Laser-induced breakdown spectroscopy	A method for analyzing the elemental composition of soil samples by generating a plasma with a laser, offering fast and cost-effective analysis with minimal sample preparation	(Ying Zhang et al., 2021a, 2021b)
In situ soil analysis	Developments in handheld devices and sensors for real-time analysis of lead and zinc in soil samples in the field, allowing for more efficient and accurate monitoring	(Alonso Castillo et al., 2011)
X-ray fluorescence (XRF)	Use of handheld XRF devices for rapid on-site screening of soils	(Liang et al., 2021)
Spectroscopic techniques	Combination of spectroscopic techniques (e.g. Fourier transform infrared spectroscopy, Raman spectroscopy) with chemometric methods for identification and quantification of lead and zinc in soil	(Lin Liu et al., 2022a, 2022b)
Electrochemical techniques	Development of electrochemical sensors for in situ measurement of lead and zinc concentrations in soil	(Castillo-Michel et al., 2017)
Laser-induced breakdown spectroscopy (LIBS)	Use of LIBS for on-site analysis of lead and zinc in soil with high sensitivity and accuracy	(Qin et al., 2023)
Magnetic susceptibility measurements	Use of magnetic susceptibility measurements for rapid screening of soils for lead and zinc contamination	(Kennedy & Kelloway, 2020)
Portable X-ray fluorescence (PXRF)	A non-destructive technique that can rapidly identify the elemental composition of a soil sample	(Xiao et al., 2023)
Laser-induced breakdown spectroscopy (LIBS)	A type of atomic emission spectroscopy that uses a laser to vaporize a small amount of soil and then analyzes the emitted light to determine the elemental composition of the sample	(Milori et al., 2023)
Sequential extraction	A technique that involves extracting different fractions of metals from soil samples using a series of chemical reagents	(Soodan et al., 2014)

from the soil (Shukla et al., 2022). Another technique is stabilization/solidification, where additives are mixed with the soil to bind the contaminants and prevent their migration (W. Li et al., 2019a, 2019b; Siyar et al., 2020). Electrokinetic remediation is also a chemical method that uses an electrical current to move the contaminants towards an electrode where they can be extracted (Xie et al., 2021).

Biological methods involve the use of living organisms or their byproducts to degrade or remove

Table 12 Comparison of GIS and remote sensing techniques for mapping and monitoring of soils contaminated with lead and zinc ion

Study Objective	Study Area	Contaminant(s)	Data Sources	Methodology	Results	Implications	Reference
Mapping and monitoring heavy metal pollution	China	Lead and Zinc	Remote sensing and GIS	Use of unmanned aerial vehicle (UAV) for high-resolution imagery	More precise and efficient mapping of contaminated sites	Offers new opportunities for more precise and efficient mapping and monitoring of contaminated soils	(Z. Yang et al., 2022a, 2022b, 2022c)
Identification of sources of lead contamination	Liberia	Lead	GIS analysis and statistical modeling	Integration of GIS data with soil and water quality data	Identification of key sources of lead contamination in soil and groundwater	Can inform targeted remediation efforts to address lead contamination	(Koon et al., 2023)
Mapping heavy metal contamination in urban areas and engaging the community	Hungary	Heavy Metals	GIS analysis	Effective communication and community engagement with residents	Improved awareness of lead contamination and potential health risks	Can help inform public health interventions and community-led cleanup efforts	(Horváth et al., 2018)
Mapping and monitoring of heavy metal contamination in agricultural soils	China	Lead and Zinc	Remote sensing and GIS data	Integration of machine learning algorithms and Sentinel-2 satellite data	More accurate mapping of contaminated areas and prediction of soil heavy metal concentrations	Efficient and cost-effective monitoring of soil contamination in agricultural areas	(Dai et al., 2022)
Mapping and monitoring of heavy metal contamination in industrial sites	Iran	Lead and Zinc	Remote sensing and GIS data	Integration of spectral indices and machine learning algorithms	Identification of areas with high heavy metal contamination and prediction of soil heavy metal concentrations	Improved efficiency and cost-effectiveness of monitoring soil contamination in industrial areas	(Goodarzi et al., 2023)
Spatial prediction of soil heavy metal pollution	China	Lead and Zinc	Machine learning algorithms and geostatistics	Integration of soil, geologic, and remote sensing data	More precise and efficient mapping and prediction of soil heavy metal pollution	Better understanding of the distribution and extent of heavy metal contamination in soil	(Chen et al., 2023)
Mapping of heavy metal pollution in agricultural soils	China	Lead and Zinc	Machine learning and remote sensing data	Integration of multiple spectral indices and random forest algorithm	Accurate identification of heavy metal pollution hotspots and mapping of contamination extent	Improved efficiency and accuracy of soil contamination mapping in agricultural areas	(M. Wang et al., 2023a, 2023b, 2023c, 2023d)

Table 12 (continued)

Study Objective	Study Area	Contaminant(s)	Data Sources	Methodology	Results	Implications	Reference
Developing an integrated approach for mapping heavy metal contamination	China	Lead, cadmium, and zinc	Remote sensing data and field surveys	Combination of machine learning algorithms and GIS analysis	High accuracy (up to 94%) in identifying contaminated areas	Improved efficiency and precision in mapping and monitoring contaminated sites	(J. Wang et al., 2023a, 2023b, 2023c, 2023d)
Assessing the spatial distribution of heavy metals in urban soil	China	Lead, zinc, and copper	Remote sensing data and field surveys	Spatial interpolation and mapping	Identified hotspots of heavy metal contamination in urban areas	Implications for urban planning and management of contaminated sites	(Deng et al., 2023)
Mapping the spatial extent of lead contamination in soils	USA	Lead	Aerial photographs and field samples	Object-based image analysis	Accurately mapped the extent of lead contamination in soil	Improved understanding of the distribution and extent of lead contamination in soil	(Miao et al., 2015)
Developing a decision support system for mapping heavy metal contamination	Iran	Lead, cadmium, and nickel	Remote sensing data and field surveys	GIS analysis and decision tree algorithms	High accuracy (up to 97%) in identifying contaminated areas	Improved efficiency and precision in mapping and monitoring contaminated sites	(Azizi et al., 2022)
Mapping lead and zinc contaminated soils	Tunisia	Lead and Zinc	Remote sensing imagery, Field measurements	Random forest model and GIS analysis	High accuracy mapping of contaminated areas and identification of potential pollution sources	Efficient and accurate identification of contaminated areas and potential sources of pollution	(Mezned et al., 2022)
Identification of areas of heavy metal contamination	India	Lead and Zinc	Sentinel-2 satellite data, field measurements	Machine learning algorithms and GIS analysis	High accuracy mapping of contaminated areas and identification of potential pollution sources	Efficient and accurate identification of contaminated areas and potential sources of pollution	(Khan et al., 2022)
Assessing the spatial distribution of heavy metal pollution	Nigeria	Lead	Remote sensing imagery, field measurements	Geostatistical analysis and GIS	Identification of hotspots and spatial patterns of heavy metal contamination	Improved understanding of the spatial distribution and severity of heavy metal contamination	(Nwazelibe et al., 2023)

Table 12 (continued)

Study Objective	Study Area	Contaminant(s)	Data Sources	Methodology	Results	Implications	Reference
Identifying the sources of heavy metal pollution	Iran	Lead and Zinc	Remote sensing imagery, field measurements	Spectral indices and machine learning algorithms	Identification of potential sources of heavy metal pollution	Efficient identification and management of pollution sources	(Asadzadeh et al., 2020)
Identifying and mapping contaminated soils using spectral indices and machine learning	Turkey	Lead and Zinc	Sentinel-2, soil samples	Spectral indices, Support Vector Machine (SVM)	Overall accuracy of 86.7% for mapping contaminated soils	The proposed method can be used for identifying and mapping contaminated soils, which can aid in site-specific management strategies	(Albayrak et al., 2021)
To map the distribution of lead and zinc in soil using remote sensing and GIS techniques	China	Lead and zinc	Landsat 8 OLI, Sentinel-2A MSI	A novel approach that combines decision tree, random forest, and back propagation neural network algorithms with spectral indices	The results showed an overall accuracy of 87.33% for lead and 91.08% for zinc mapping, with high correlation coefficients between the predicted and observed values	The study demonstrates the potential of integrating various techniques to accurately map lead and zinc in soil, which can inform management strategies in mining areas	(Wu et al., 2022)
To assess the suitability of different remote sensing techniques for mapping lead contamination in soil	UK	Lead	Hyperspectral imaging, Sentinel-2A MSI	Comparison of two different remote sensing techniques for lead mapping using supervised classification and accuracy assessment	Hyperspectral imaging was found to be more suitable for mapping lead contamination in soil than Sentinel-2A MSI, with overall accuracy of 96.3% compared to 87.5%	Hyperspectral imaging can provide more detailed information on the distribution of lead in soil, which is important for targeted remediation strategies	(Yingjie Li et al., 2021a, 2021b, 2021c, 2021d)
To investigate the use of drone-based hyperspectral imaging for mapping lead and zinc in soil	Australia	Lead and zinc	Drone-based hyperspectral imaging	Development of a novel classification method using support vector machine algorithm and feature selection techniques	The results showed that the drone-based hyperspectral imaging technique was effective for mapping lead and zinc in soil, with an overall accuracy of 87% for lead and 88% for zinc	The study demonstrates the potential of using drone-based hyperspectral imaging for efficient and accurate mapping of lead and zinc in soil in mining areas	(Pfitzner et al., 2022)

Table 12 (continued)

Study Objective	Study Area	Contaminant(s)	Data Sources	Methodology	Results	Implications	Reference
To develop a model for mapping and monitoring lead contamination in soil using machine learning algorithms	Morocco	Lead	Field data and Landsat-8 satellite imagery	Random Forest algorithm and spectral indices	Achieved an accuracy of 94% in mapping lead-contaminated soils	Machine learning algorithms combined with spectral indices can be an effective tool for mapping and monitoring lead-contaminated soils	(Acharki, 2022)

contaminants from the soil (Darroudi et al., 2018; Schulte et al., 2022). Bioremediation is a common technique that uses bacteria or fungi to break down contaminants into less harmful substances. Phytoremediation is another biological method that uses plants to absorb contaminants through their roots and store them in their tissues or transform them into less harmful substances (Steliga & Kluk, 2020; Xiao et al., 2021).

5.2 Phytoremediation and other Plant-based Approaches

Plant remediation, also known as phytoremediation, is a process that uses plants to remove contaminants from soil, water, or air (Sakaa et al., 2022). Plants used for remediation are selected based on their ability to accumulate heavy metals in their tissues without being affected by their toxicity (Enyoh & Isiuku, 2021; Huang et al., 2023). These plants are referred to as hyperaccumulators, and they can accumulate a large amount of heavy metals in their tissues without suffering from any adverse effects. Table 14 compares the phytoremediation process with different plants for the removal of heavy metals, lead and zinc ions from contaminated soil. Once the plant has accumulated a sufficient amount of heavy metals, it can be harvested and disposed of, effectively removing the contaminants from the soil (Borah et al., 2023). Phytoremediation is a promising method for the remediation of soils contaminated with lead and zinc ions, as it is a cost-effective, environmentally friendly, and sustainable solution (Timalsina et al., 2022). However, it is important to note that the success of phytoremediation depends on several factors, including the type of contaminants, the soil properties, and the specific plant species used (Lingrui Liu et al., 2022a, 2022b). Therefore, careful selection of the plant species and proper site management are crucial for the successful implementation of phytoremediation (M. Li et al., 2021a, 2021b, 2021c, 2021d).

5.3 Human Health Protection and Risk Management Strategies

There are several strategies for protecting human health and managing the risks associated with soil contamination by lead and zinc. These strategies include:

Table 13 Comparison of different approaches and techniques for soil remediation

Approach	Technique	Material	Removal Efficiency	Advantages	Limitations	Reference
Electrokinetic remediation	Electrodes	Citric acid	Pb: 80–98%; Zn: 60–96%	Effective for low permeability soils; minimal soil disturbance	High energy usage; potential for metal redeposition; slow process	(Xie et al., 2021)
Phytoremediation	Plant uptake	Sunflower; vetiver grass	Pb: up to 90%; Zn: up to 70%	Sustainable and low cost; can be used on-site; aesthetic value	Slow process; dependent on plant species and growth conditions; not effective for deep contamination	(Chen et al., 2004)
Soil flushing	Surfactant flushing	Tween 80	Pb: up to 98%; Zn: up to 80%	Effective for removing surface contaminants; can be used on-site	High cost of surfactant; potential for groundwater contamination	(Y. Li et al., 2020a, 2020b)
Soil washing	Pump-and-treat system	Surfactants, chelating agents	Pb: 70–95%; Zn: 60–95%	Effective in removing surface contaminants; can be used in situ or ex situ	High cost; generates large amounts of contaminated waste	(Shukla et al., 2022)
Electrokinetic	Electrical current	Electrodes, electrolyte	Pb: 74–94%; Zn: 60–94%	Can treat deep-seated contaminants; minimal soil disturbance; reusable electrodes	High energy consumption; only applicable to low-permeability soils; may generate acidic/alkaline waste	(Thatikayala et al., 2023)
Soil vapor extraction	Air sparging	Blowers, vapor extraction wells	Pb: 80–99%; Zn: 40–80%	Can treat volatile and semi-volatile contaminants; low cost; minimizes excavation and soil disturbance	Limited to shallow soils; may not be effective for non-volatile contaminants; may require post-treatment of extracted air	(Song et al., 2017)
Phytoremediation	Plant uptake	Various plant species	Pb: 20–80%; Zn: 30–90%	Low cost; aesthetically pleasing; can be used in situ; sustainable	Long treatment time; limited to shallow soils; dependent on plant species and growth conditions	(Pal et al., 2023)
Magnetic separation	Magnetic field	Magnetite	Pb: 99.99%; Zn: 98.65%	High efficiency; low cost; reusable material	Limited to surface contamination; requires pre-treatment of soil	(Steingräber et al., 2022)
Chemical fixation	Stabilization	Kaolinite, lime	Pb: 84–99%; Zn: 33–95%	Effective for long-term immobilization of contaminants	High cost; may require multiple applications	(Faiza Amin et al., 2023)

Table 13 (continued)

Approach	Technique	Material	Removal Efficiency	Advantages	Limitations	Reference
Solidification	Stabilization/solidification	Cement, fly ash	Pb: 90–99%; Zn: 60–99%	Effective for reducing leachability of contaminants	High cost; may require significant soil disturbance	(W. Li et al., 2019a, 2019b)
Thermal treatment	Incineration	Soil	Pb: 97–99%; Zn: 97–99%	High efficiency; reduces volume of contaminated soil	High cost; energy intensive; may release pollutants to air	(Zhan et al., 2023)
Magnetic separation	Magnetic field	Magnetite	Pb: 99.99%; Zn: 98.65%	High efficiency; low cost; reusable material	Limited to surface contamination; requires pre-treatment of soil	(Y. Li et al., 2019a, 2019b)
Chemical fixation	Stabilization	Kaolinite, lime	Pb: 84–99%; Zn: 33–95%	Effective for long-term immobilization of contaminants	High cost; may require multiple applications	(El-Dib et al., 2020)
Solidification	Stabilization/solidification	Cement, fly ash	Pb: 90–99%; Zn: 60–99%	Effective for reducing leachability of contaminants	High cost; may require significant soil disturbance	(Q. Jiang et al., 2022a, 2022b)
Thermal treatment	Incineration	Soil	Pb: 97–99%; Zn: 97–99%	High efficiency; reduces volume of contaminated soil	High cost; energy intensive; may release pollutants to air	(Zhan et al., 2023)
Magnetic separation	Magnetic field	Iron oxide	Pb: 93–99%; Zn: 72–93%	High efficiency; low cost; reusable material	Limited to surface contamination; may require pre-treatment of soil	(Ma et al., 2019)
Chemical fixation	Stabilization	Biochar, cement, fly ash	Pb: 80–99%; Zn: 50–97%	Effective for long-term immobilization of contaminants; can improve soil fertility	High cost; may require multiple applications; limited applicability to certain soil types	(Lei et al., 2023)
Solidification	Stabilization/solidification	Cement, fly ash	Pb: 78–99%; Zn: 52–98%	Effective for reducing leachability of contaminants; can improve soil strength	High cost; may require significant soil disturbance; potential for secondary waste generation	(Lei et al., 2023)
Thermal treatment	Pyrolysis	Soil	Pb: 70–98%; Zn: 35–95%	High efficiency; reduces volume of contaminated soil; can recover energy and nutrients	High cost; energy intensive; potential for air pollution	(Lei et al., 2023)

Table 13 (continued)

Approach	Technique	Material	Removal Efficiency	Advantages	Limitations	Reference
Chemical immobilization	Co-treatment with phosphate and calcined oyster shell	Phosphate and calcined oyster shell	Pb: 98%; Zn: 99%	Low cost, eco-friendly, and easy to apply	Only effective in slightly acidic or neutral soil conditions	(Lei et al., 2023)
Chemical immobilization	In-situ stabilization	Biochar and lime	Pb: 90%; Zn: 83%	Low cost and eco-friendly	Lime may increase soil pH, potentially affecting soil properties and plant growth	(J. Li et al., 2022a, 2022c, 2022d)
Chemical oxidation	Fenton-like oxidation	Ferrous sulfate and hydrogen peroxide	Pb: 95%; Zn: 92%	Effective in a wide range of soil conditions and removes both Pb and Zn	Generates large amounts of sludge and potential environmental risks associated with disposal	(SOUFI et al., 2021)
Chemical reduction	Sulfide treatment	Sodium sulfide	Pb: 78%; Zn: 88%	Low cost and eco-friendly	Generates H2S gas which is toxic and has an unpleasant odor	(H. Zhang et al., 2023a, 2023b, 2023c)
Chelation	EDTA	Soil amendments containing EDTA	Pb: 90%; Zn: 97%	Effective for both lead and zinc removal	Can potentially mobilize other metals and cause leaching	(Rathika et al., 2021)
Ionic exchange	Anion exchange resin	Macroporous weak base anion exchange resin	Pb: 96%; Zn: 98%	High selectivity for lead and zinc	Requires frequent resin replacement	(Marszałek et al., 2023)
Mycoremediation	Fungal remediation	Pleurotus ostreatus	Pb: 91%; Zn: 90%	Effective in removing multiple contaminants	Limited field studies and requires further research	(Ahmad Zakil et al., 2022)
Mycoremediation	Fungal remediation	Pleurotus ostreatus	Pb: 91%; Zn: 90%	Effective in removing multiple contaminants	Limited field studies and requires further research	(Wu et al., 2023)
Bioaugmentation	Microbial augmentation	Micrococcus sp., Bacillus sp., and Pseudomonas sp.	Pb: 80%; Zn: 75%	Increases microbial activity and enhances remediation efficiency	Limited effectiveness in highly contaminated soils	(Govarthanan et al., 2013)
Bioremediation	Biosorption	Bacterial biomass, e.g. Pseudomonas putida	Pb: 90%; Zn: 95%	Cost-effective and easy to implement	May require a long treatment time and biosorption capacity may be limited	(Xiao et al., 2021)

- **Soil testing and analysis:** Regular soil testing and analysis can help identify areas of soil contamination and determine the levels of lead and zinc present (Barhoum et al., 2023).
- **Land use management:** Land use management practices, such as limiting access to contaminated areas, can help reduce exposure to contaminated soil (Cappucci et al., 2020; H. Yu et al., 2023a, 2023b).
- **Personal protective equipment:** Individuals working in or around contaminated soil should wear appropriate PPE, such as gloves and masks, to reduce the risk of exposure (Q. Li et al., 2023a, 2023b).
- **Remediation:** Soil remediation techniques, such as phytoremediation and soil washing, can be used to reduce the levels of lead and zinc in contaminated soil (Song et al., 2017).
- **Health monitoring:** Regular health monitoring of individuals exposed to contaminated soil can help detect and manage any adverse health effects (P. Yu et al., 2023a, 2023b).
- **Education and outreach:** Education and outreach programs can help raise awareness of the risks associated with soil contamination and promote safe practices for managing exposure (Z. Wang et al., 2023a, 2023b, 2023c, 2023d).
- **Regulatory measures:** Government regulations and policies can help prevent soil contamination and ensure that contaminated areas are properly managed and remediated (Soni et al., 2022).

6 New Techniques and Approaches for Lead and Zinc Pollution Control

6.1 Innovative Appproaches for Mining Waste Management and Remediation

Mining waste management and remediation are critical aspects of sustainable mining practices. The management of mining waste involves several challenges, including the need to reduce the environmental impact of waste, minimize the risks to human health (Csavina et al., 2014) and the environment, and ensure the efficient use of resources (H. Li et al., 2023a, 2023b). Innovative approaches to mining waste management and remediation have emerged in recent years, driven by the need to address these challenges. As Table 15 presents, the approaches of mineral waste management in different countries, one of the most common innovative approaches to mining waste management is the beneficial use of waste (Bhatnagar et al., 2022). This approach involves finding new uses for mining waste, such as using coal ash as a substitute for cement in construction materials or using iron ore tailings in road construction. By finding new uses for waste, the amount of waste that needs to be stored or disposed of can be reduced, which can help to minimize the environmental impact of mining activities. Another innovative approach to mining waste management is the use of biological treatments (Mikula et al., 2021).

This approach involves using living organisms, such as bacteria or fungi, to break down or remove contaminants from mining waste. For example, bioleaching is a biological treatment process used to extract metals from low-grade ores or mining waste. This approach can reduce the amount of waste that needs to be stored or disposed of and can help to minimize the environmental impact of mining activities.

Integrated waste management is another innovative approach to mining waste management (Cappucci et al., 2020). This approach involves the use of a combination of waste management strategies to minimize the environmental impact of mining activities. For example, the Canadian Dam Association (CDA) guidelines for mine tailings management promote the use of integrated waste management strategies that include the use of tailings ponds, the incorporation of dry-stack tailings technology, and the use of cemented paste backfill (Z. Wang et al., 2023a, 2023b, 2023c, 2023d).

6.2 Green Chemistry and Sustainable Practices in the Mining Industry

Green chemistry and sustainable practices are becoming increasingly important in the mining industry as society demands more environmentally friendly processes and products (Soni et al., 2022). Green chemistry focuses on the design of chemical products and processes that minimize or eliminate the use and generation of hazardous substances (Milori et al., 2023). In the mining industry, this means reducing the use of toxic chemicals and finding alternative methods for processing minerals and waste. As shown in Fig. 5, some of the sustainable practices that are being implemented in the mining industry include:

Table 14 Comparison of various phytoremediation techniques for heavy metal remediation

Approach	Plant Species	Removal Efficiency	Advantages	Limitations	Reference
Phytoremediation	Brassica napus	Pb: up to 94%; Zn: up to 80%	Sustainable and low cost; can be used on-site; fast process	Dependent on plant species and growth conditions; not effective for deep contamination	(Dikšaitytė et al., 2023)
Phytoremediation	Brassica juncea	Pb: up to 91%; Zn: up to 95%	Sustainable and low cost; can be used on-site; fast process	Dependent on plant species and growth conditions; not effective for deep contamination	(Cui et al., 2021)
Phytoremediation	Festuca arundinacea	Pb: up to 80%; Zn: up to 70%	Can be used on-site; sustainable; effective for low-level contamination	Slow process; dependent on plant species and growth conditions; not effective for deep contamination	(Cui et al., 2021)
Phytoremediation	Pinus massoniana	Pb: up to 99%; Zn: up to 80%	Sustainable and low cost; can be used on-site; effective for low-level contamination	Slow process; dependent on plant species and growth conditions; not effective for deep contamination	(Yaqian Li et al., 2021a, 2021b, 2021c, 2021d)
Microbial-assisted	Bacillus subtilis	Pb: up to 78%; Zn: up to 66%	Sustainable and low cost; minimal soil disturbance; effective for low-level contamination	Dependent on microbial species and growth conditions; slow process; not effective for deep contamination	(Krucon et al., 2023)
Nano-based remediation	Zero-valent iron (nZVI)	Pb: up to 95%; Zn: up to 80%	Effective for low-level contamination; minimal soil disturbance	High cost; potential toxicity; not effective for deep contamination	(Yang et al., 2023)
Phytoremediation	Chelating peptides	Pb: 70–90%; Zn: 60–80%	Cost-effective; high removal efficiency	Limited to specific plant species; potential risk of heavy metal mobilization	(Yadav et al., 2023)
Microbe-assisted phytoremediation	Arbuscular mycorrhizal fungi	Pb: up to 96%; Zn: up to 95%	Improved plant growth and heavy metal accumulation	Dependent on specific microbial species and soil conditions; slow process	(Xi et al., 2022)
Phytostabilization	Biochar	Pb: up to 83%; Zn: up to 67%	Sustainable; low cost; can be used in situ or ex situ	Limited to surface contamination; slow process	(Tang et al., 2019)
Phytoremediation	Citric acid	Pb: up to 98%; Zn: up to 80%	Cost-effective; high removal efficiency	Potential for phytotoxicity; dependent on plant growth conditions	(Yaqian Li et al., 2021a, 2021b, 2021c, 2021d)
Phytoextraction	Sunflower (Helianthus annuus)	Pb: 67.7%; Zn: 53.4%	Sustainable and low-cost approach; can be used on-site	Limited effectiveness in high-metal content soils; potential for metal accumulation in plant tissues	(Xu et al., 2021)

Table 14 (continued)

Approach	Plant Species	Removal Efficiency	Advantages	Limitations	Reference
Rhizofiltration	Reed (Phragmites australis)	Pb: 97%; Zn: 94%	Effective in removing metals from waterlogged soils; promotes soil microbial activity	Limited effectiveness in dry soils; requires maintenance to prevent clogging of the roots	(Fediuc & Erdei, 2002)
Phytostabilization	Alfalfa (Medicago sativa)	Pb: 68–96%; Zn: 47–74%	Effective in reducing metal mobility; improves soil structure and fertility	Slow process; limited effectiveness in highly contaminated soils	(Elouear et al., 2016)
Phytoremediation	Perennial ryegrass (Lolium perenne)	Pb: 74%; Zn: 77%	Fast-growing; can be used on-site	Limited effectiveness in highly contaminated soils; potential for metal accumulation in plant tissues	(Han et al., 2021)
Phytostabilization	Robinia pseudoacacia	Pb: 68–85%	Prevents metal leaching; low cost; suitable for small areas	Limited metal removal; slow process	(Wang et al., 2018)
Phytoextraction	Indian mustard	Pb: 86%; Zn: 71%	Efficient for Pb and Zn removal; can treat large areas	May cause toxic effects to plants and soil organisms	(Duquène et al., 2009)
Phytostabilization	Vetiver grass	Pb: 59–70%; Zn: 56%	Reduces metal bioavailability; enhances soil quality	Limited to surface contamination; slow process	(Chen et al., 2004)
Rhizoremediation	Ryegrass	Pb: 80–90%; Zn: 70%	Reduces metal bioavailability; enhances plant growth	Limited to rhizosphere; requires plant growth	(Hoang et al., 2021)
Phytovolatilization	Fern	Pb: 25–50%; Zn: 40%	Efficient for Pb and Zn removal; can treat large areas	Requires frequent harvest; potential for phytotoxicity	(Fayiga & Saha, 2016)
Phytoextraction	Sedum alfredii	Pb: up to 99%; Zn: upto 90%	High efficiency; low cost; can remove large amounts of metals	Restricted to hyperaccumulating plants; slow process	(Chen et al., 2022)
Phytostabilization	Festuca arundinacea	Pb: up to 78%; Zn: upto 66%	Prevents leaching of metals; reduces bioavailability	Limited to shallow contamination; maintenance required	(Steliga & Kluk, 2020)
Phytostabilization	Vetiver grass (Chrysopogon zizanioides)	Pb: up to 80%; Zn: up to 70%	Low cost and maintenance; effective for shallow contamination	Limited effectiveness for deep contamination	(Gautam & Agrawal, 2017)
Rhizofiltration	Sunflower (Helianthus annuus)	Pb: up to 90%; Zn: up to 80%	Sustainable and low cost; can be used on-site	Dependent on plant growth conditions; may require pre-treatment of soil	(Singh et al., 2004)

Table 15 Mineral waste management approaches in various countries

Country	Type of Mineral Waste	Mineral Waste Management Approach	Main Pillar of the Standard	Reference
USA	Coal mining waste	Beneficial use	Resource Conservation and Recovery Act (RCRA)	(McCann & Nairn, 2022)
Canada	Mine tailings	Integrated waste management	Canadian Dam Association (CDA) Guidelines	(Rana et al., 2022)
China	Copper smelting waste	Biological treatment	Hazardous waste management standard	(Mikula et al., 2021)
Australia	Bauxite residue	Residue filtration and stacking	Global industry standard for bauxite residue management	(Kannan et al., 2021)
Brazil	Iron ore tailings	Dry stacking	National Mining Agency (ANM) Resolution	(Moura et al., 2022)
Chile	Copper mine waste	Bioleaching	ISO 14001 Environmental Management System standard	(Newbold, 2006)
USA	Coal mining waste	Land reclamation	Land use and water resources	(Feng et al., 2019)
Canada	Oil sands tailings	Consolidation	Geotechnical engineering	(da Silva et al., 2021)
Japan	Steelmaking slag	Recovery and reuse	Resource conservation	(Yu et al., 2022)
Germany	Phosphate waste	Solubilization and recovery	Resource efficiency	(Wen and Li, 2022)
Australia	Bauxite residue	Neutralization and revegetation	Environmental performance	(Scullett-Dean et al., 2023)
Canada	Tailings	Subaqueous Disposal	International Commission on Large Dams (ICOLD)	(Guimarães et al., 2022)
China	Red mud	Stabilization and solidification	National Hazardous Waste Management Standard	(Tongyuan Yang et al., 2022a, 2022b, 2022c)
Germany	Fly ash, bottom ash	Encapsulation	Technical Guidelines for Municipal Solid Waste Incineration	(Yuying Zhang et al., 2021a, 2021b)
India	Iron ore tailings	Utilization in construction materials	Indian Roads Congress (IRC)	(Shanmugasundaram & Shanmugam, 2023)
Norway	Sulphide-rich mine waste	Carbonate Apatite Permeable Reactive Barrier	Norwegian Pollution Control Authority (NPCA)	(Gauthier et al., 2021)
South Africa	Acid mine drainage	Biological treatment using sulfate-reducing bacteria	South African National Standards (SANS)	(Masindi, 2017)
USA	Coal ash	Beneficial reuse in construction materials	American Coal Ash Association (ACAA)	(Zierold et al., 2022)
Australia	Coal mine tailings	Phytostabilization with native vegetation	Net Acid Generation (NAG)	(Borden et al., 2022)
Canada	Gold mine tailings	Cemented Paste Backfill (CPB)	Paste Backfill Guide	(Benkirane et al., 2023)
South Africa	Platinum mine tailings	Plasma technology for metal recovery	National Environmental Management Act (NEMA)	(Ololade & Annegarn, 2013)

- **Recycling and reuse:** Many mining operations are implementing recycling programs to reduce waste and conserve resources (Lin et al., 2022b). For example, water can be treated and reused in mining operations to reduce the amount of fresh water required (Cappucci et al., 2020).
- **Energy efficiency:** Mining operations are also implementing energy-efficient practices, such

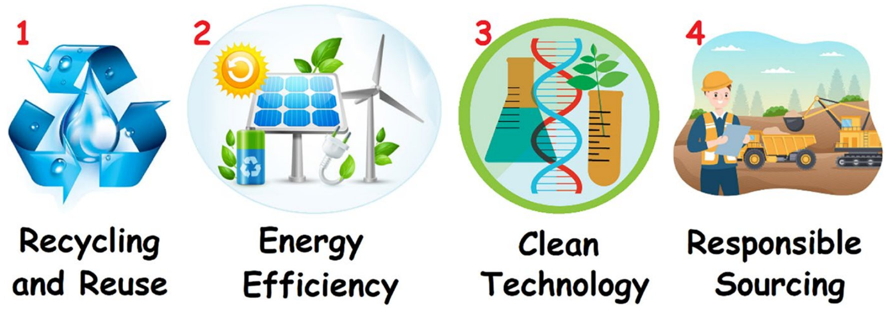

Fig. 5 Graphical abstract of some sustainable practices that rely on green chemistry in the mining industry

as using renewable energy sources like solar and wind power (Beni & Esmaeili, 2020a).

- **Clean technology:** New technologies are being developed that reduce the use of toxic chemicals in the mining process. For example, bioreactors are being used to extract metals from ores, reducing the need for chemical leaching (Beni & Esmaeili, 2020b).
- **Responsible sourcing:** Mining companies are also being held accountable for the impact of their operations on local communities and the environment (Parizanganeh et al., 2010). Many companies are implementing responsible sourcing practices to ensure that their products are ethically and sustainably sourced.

6.3 Use of Artificial Intelligence (AI)

Artificial intelligence (AI) can reduce lead and zinc soil pollution around mines through various approaches, including:

- **Predictive modeling:** AI can be used to develop models that predict the likelihood of soil pollution based on factors such as geological characteristics, mining activities, and weather conditions (Gautam et al., 2023; Wong et al., 2021). These models can be used to identify areas that are most at risk of pollution, allowing for targeted monitoring and remediation efforts (Wong et al., 2020a).
- **Monitoring:** AI-powered sensors and drones can be used to collect data on soil quality in real-time (Wong et al., 2021). This data can be analyzed using machine learning algorithms to identify patterns and anomalies, allowing for early detection of soil pollution and prompt remediation (Wang et al., 2019).
- **Optimization of remediation efforts:** AI can be used to optimize the design and implementation of remediation strategies (Wong et al., 2021). Machine learning algorithms can analyze data on soil characteristics and the effectiveness of different remediation methods to identify the most effective approach for a particular site (Ji et al., 2022; Wong et al., 2020a).

The use of AI in lead and zinc pollution control can improve the efficiency and effectiveness of soil monitoring and remediation efforts, leading to more targeted and cost-effective solutions (Ji et al., 2023; Wong et al., 2021).

7 Conclusion and Future Directions

The mining industry significantly contributes to environmental pollution, particularly through lead and zinc contamination of soil. This contamination arises from mining activities, production, waste management, and atmospheric deposition, impacting soil, water, plants, wildlife, and human health. Effective monitoring and assessment are vital for understanding the issue and developing solutions. Traditional soil remediation methods have limitations, necessitating innovative pollution control approaches. Green chemistry and sustainable practices are increasingly adopted to minimize environmental impact in mining. Policymakers should implement stricter environmental regulations, better waste management, emission control, and enhanced monitoring. Increased research funding for pollution control and remediation methods is also crucial. Ultimately, managing lead and zinc contamination is essential for safeguarding human health and the environment.

For innovative research in the field of evaluation and control of soil, water, and air pollution around factories and industries related to lead and zinc, you can pay attention to the following to conduct innovative and effective research: Using new technologies such as artificial intelligence sensors, remote imaging, and the Internet of Things (IoT) to collect accurate and continuous data from contaminated areas and environments around factories. These data can help to better analyze pollution and provide innovative solutions. Using advanced modeling and artificial intelligence algorithms to predict pollution and provide optimal solutions for pollution control. These models can help make better decisions and make more accurate predictions. Research and development of advanced treatment technologies to remove contaminants from soil, water, and air. This can include nanomaterials, photocatalytic technologies, and biological treatment technologies. research on strategies to prevent future pollution in industries related to lead and zinc. This can include designing more efficient manufacturing systems and processes and less polluting materials. Actively interacting with local communities and sharing information with them. This can help raise public awareness and identify new issues. Collaborating researchers with different specialties including environmental science, environmental engineering, data science, and public health to create multidisciplinary approaches to tackling pollution. using renewable and clean energies instead of polluting energy sources in industries related to lead and zinc. This can help reduce air pollution associated with fossil fuels.

Data Availability Data available on request from the authors.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

References

Acharki, S. (2022). Remote sensing applications : Society and environment planetscope contributions compared to sentinel-2, and Landsat-8 for LULC mapping. *Remote Sensing Applications: Society and Environment, 27*, 100774. https://doi.org/10.1016/j.rsase.2022.100774

Ackah, M. (2019). Soil elemental concentrations, geoaccumulation index, non-carcinogenic and carcinogenic risks in functional areas of an informal e-waste recycling area in Accra, Ghana. *Chemosphere, 235*, 908–917. https://doi.org/10.1016/j.chemosphere.2019.07.014

Acquah, A. A., D'Souza, C., Martin, B. J., Arko-Mensah, J., Botwe, P. K., Tettey, P., Dwomoh, D., Nti, A. A., Kwarteng, L., Takyi, S., Quakyi, I. A., Robins, T. G., & Fobil, J. N. (2021). A preliminary assessment of physical work exposures among electronic waste workers at Agbogbloshie Accra Ghana. *International Journal of Industrial Ergonomics, 82*, 103096. https://doi.org/10.1016/j.ergon.2021.103096

Adanu, S. K., Gbedemah, S. F., & Attah, M. K. (2020). Challenges of adopting sustainable technologies in e-waste management at Agbogbloshie Ghana. *Heliyon., 6*, e04548. https://doi.org/10.1016/j.heliyon.2020.e04548

Adedeji, O. H., Olayinka, O. O., Tope-Ajayi, O. O., & Adekoya, A. S. (2020). Assessing spatial distribution, potential ecological and human health risks of soil heavy metals contamination around a Trailer Park in Nigeria. *Science African, 10*, e00650. https://doi.org/10.1016/j.sciaf.2020.e00650

Adewumi, A. J., & Laniyan, T. A. (2020). Contamination, sources and risk assessments of metals in media from Anka artisanal gold mining area Northwest Nigeria. *Science of The Total Environment, 718*, 137235. https://doi.org/10.1016/j.scitotenv.2020.137235

Aghababai Beni, A., & Jabbari, H. (2022). Nanomaterials for environmental applications. *Results in Engineering, 15*, 100467. https://doi.org/10.1016/j.rineng.2022.100467

Aghababai Beni, A., Esmaeili, A., & Behjat, Y. (2021). Invent of a simultaneous adsorption and separation process based on dynamic membrane for treatment Zn(II), Ni(II) and Co(II) industrial wastewater. *Arabian Journal of Chemistry, 14*, 103231. https://doi.org/10.1016/j.arabjc.2021.103231

Ahmad Zakil, F., Mohd Isa, R., Mohd Sueb, M. S., & Isha, R. (2022). Growth performance and mineral analysis of Pleurotus ostreatus (oyster mushroom) cultivated on spent mushroom medium mixed with rubber tree sawdust. *Materials Today: Proceedings, 57*, 1329–1337. https://doi.org/10.1016/j.matpr.2022.01.112

Ahmed, B., Rizvi, A., Syed, A., Jailani, A., Elgorban, A. M., Khan, M. S., AL-Shwaiman, H. A., & Lee, J. (2021). Differential bioaccumulations and ecotoxicological impacts of metal-oxide nanoparticles, bulk materials, and metal-ions in cucumbers grown in sandy clay loam soil. *Environmental Pollution, 289*, 117854. https://doi.org/10.1016/j.envpol.2021.117854

Ahumada-Mexía, R., Murillo-Jiménez, J. M., Ortega-Rubio, A., Marmolejo-Rodríguez, A. J., & Nava-Sánchez, E. H. (2021). Identification of mining waste using remote sensing technique: A case study in El Triunfo town, BCS, México. *Remote Sensing Applications: Society and Environment., 22*, 100493. https://doi.org/10.1016/j.rsase.2021.100493

Aja, D., Okolo, C. C., Nwite, N. J., & Njoku, C. (2021). Environmental risk assessment in selected dumpsites in Abakaliki metropolis, Ebonyi state, southeastern Nigeria. *Environmental Challenges, 4*, 100143. https://doi.org/10.1016/j.envc.2021.100143

Albayrak, A., Çeven, S., & Bayır, R. (2021). Ecological informatics modeling of migratory beekeeper behaviors with machine learning approach using meteorological and environmental variables : The case of Turkey. *Ecological Informatics, 66*, 101470. https://doi.org/10.1016/j.ecoinf.2021.101470

Aliyu, A. A., Mudansiru, A., Obadiah, C. D., & Dharmendra, S. (2023). Accumulation of heavy metals in autochthonous plants around Bagega Artisanal Gold Mining Village and the remediation potential of selected plants. *Acta Ecologica Sinica*. https://doi.org/10.1016/j.chnaes.2023.02.005

Alonso Castillo, M. L., Vereda Alonso, E., Siles Cordero, M. T., Cano Pavón, J. M., & García de Torres, A. (2011). Fractionation of heavy metals in sediment by using microwave assisted sequential extraction procedure and determination by inductively coupled plasma mass spectrometry. *Microchemical Journal, 98*, 234–239. https://doi.org/10.1016/j.microc.2011.02.004

Alshetty, D., & Nagendra, S. M. S. (2022). Impact of vehicular movement on road dust resuspension and spatiotemporal distribution of particulate matter during construction activities. *Atmospheric Pollution Research, 13*, 101256. https://doi.org/10.1016/j.apr.2021.101256

Ambade, B., Sethi, S. S., Kurwadkar, S., Kumar, A., & Sankar, T. K. (2021). Toxicity and health risk assessment of polycyclic aromatic hydrocarbons in surface water, sediments and groundwater vulnerability in Damodar River Basin. *Groundwater for Sustainable Development, 13*, 100553. https://doi.org/10.1016/j.gsd.2021.100553

Anderson, J., Lévesque, N., Caron, F., Beckett, P., & Spiers, G. A. (2022). A review on the use of lichens as a biomonitoring tool for environmental radioactivity. *Journal of Environmental Radioactivity., 243*, 106797. https://doi.org/10.1016/j.jenvrad.2021.106797

Asadzadeh, S., Roberto, C., & Filho, D. S. (2020). Characterization of microseepage-induced diagenetic changes in the Upper- Red Formation, Qom region, Iran, Part I : Outcrop, geochemical, and remote sensing studies. *Marine and Petroleum Geology., 117*, 104149. https://doi.org/10.1016/j.marpetgeo.2019.104149

Aubineau, J., Parat, F., Elghali, A., Raji, O., Addou, A., Bonnet, C., Muñoz, M., Mauguin, O., Baron, F., Jouti, M. B., Yazami, O. K., & Bodinier, J. L. (2022). Highly variable content of fluorapatite-hosted CO32−in the Upper Cretaceous/Paleogene phosphorites (Morocco) and implications for paleodepositional conditions. *Chemical Geology., 597*, 120818. https://doi.org/10.1016/j.chemgeo.2022.120818

Awasthi, M. K., Liao, R., Ali, A., Mahar, A., Guo, D., Li, R., Xining, S., Awasthi, M. K., Wang, Q., & Zhang, Z. (2017). Spatial distribution and risk assessment of heavy metals in soil near a Pb/Zn smelter in Feng County China. *Ecotoxicology and Environmental Safety, 139*, 254–262. https://doi.org/10.1016/j.ecoenv.2017.01.044

Awasthi, A. K., Awasthi, M. K., Mishra, S., Sarsaiya, S., & Pandey, A. K. (2022). Evaluation of E-waste materials linked potential consequences to environment in India. *Environmental Technology and Innovation, 28*, 102477. https://doi.org/10.1016/j.eti.2022.102477

Azizi, K., Ayoubi, S., Nabiollahi, K., Garosi, Y., & Gislum, R. (2022). Predicting heavy metal contents by applying machine learning approaches and environmental covariates in west of Iran. *Journal of Geochemical Exploration, 233*, 106921. https://doi.org/10.1016/j.gexplo.2021.106921

Ba, J., Gao, F., Peng, C., & Li, J. (2022). Characteristics of nitrate and heavy metals pollution in Huixian Wetland and its health risk assessment. *Alexandria Engineering Journal, 61*, 9031–9042. https://doi.org/10.1016/j.aej.2022.02.045

Bansal, S., Kushwah, S. S., Garg, A., & Sharma, K. (2024). Materials Today : Proceedings Utilization of plastic waste in construction industry in India - A review. *Materials Today: Proceedings*. https://doi.org/10.1016/j.matpr.2023.03.693

Baran, A., Tack, F. M. G., Delemazure, A., Wieczorek, J., Tarnawski, M., & Birch, G. (2023). Metal contamination in sediments of dam reservoirs: A multi-facetted generic risk assessment. *Chemosphere, 310*, 136760. https://doi.org/10.1016/j.chemosphere.2022.136760

Barhoum, A., Hamimed, S., Slimi, H., Othmani, A., Abdel-Haleem, F. M., & Bechelany, M. (2023). Modern designs of electrochemical sensor platforms for environmental analyses: Principles, nanofabrication opportunities, and challenges. *Trends in Environmental Analytical Chemistry, 38*, e00199. https://doi.org/10.1016/j.teac.2023.e00199

Barut, I. F., Meriç, E., & Yokeş, M. B. (2016). Assessment of recent and chalcolithic period environmental pollution using Mytilus galloprovincialis Lamarck, 1819 from Yarimburgaz Cave, the northern Marmara Sea and Bosphorus coasts. *Oceanologia, 58*, 135–149. https://doi.org/10.1016/j.oceano.2016.01.001

Begum, F., Khajuria, A., Abdi, H., Williams, A., Jones, I., Leon-Villapalos, J., Collins, D., & Atkins, J. (2019). In hot water: The impact of burn injuries from hot water bottles — Experience of a UK burns unit and review of the literature. *Burns, 45*, 974–982. https://doi.org/10.1016/j.burns.2018.12.006

Behera, S. K., Mishra, D. P., Singh, P., Mishra, K., Mandal, S. K., Ghosh, C. N., Kumar, R., & Mandal, P. K. (2021). Utilization of mill tailings, fly ash and slag as mine paste backfill material: Review and future perspective. *Construction and Building Materials, 309*, 125120. https://doi.org/10.1016/j.conbuildmat.2021.125120

Beni, A. A., & Esmaeili, A. (2019). Design and optimization of a new reactor based on biofilm-ceramic for industrial wastewater treatment. *Environmental Pollution, 255*, 113298. https://doi.org/10.1016/j.envpol.2019.113298

Beni, A. A., & Esmaeili, A. (2020a). Fabrication of 3D hydrogel to the treatment of moist air by solar/wind energy in a simulated battery recycle plant salon. *Chemosphere, 246*, 125725. https://doi.org/10.1016/j.chemosphere.2019.125725

Beni, A. A., & Esmaeili, A. (2020b). Environmental Technology & Innovation Biosorption, an efficient method for removing heavy metals from industrial effluents : A Review. *Environmental Technology and Innovation, 17*, 100503. https://doi.org/10.1016/j.eti.2019.100503

Benkirane, O., Haruna, S., & Fall, M. (2023). Strength and microstructure of cemented paste backfill modified with nano-silica particles and cured under non-isothermal conditions. *Powder Technology, 419*, 118311. https://doi.org/10.1016/j.powtec.2023.118311

Bhatnagar, A., Khatri, P., Krzywonos, M., Tolvanen, H., & Konttinen, J. (2022). Techno-economic and environmental assessment of decentralized pyrolysis for crop residue management: Rice and wheat cultivation system in India. *Journal of Cleaner Production, 367*, 132998. https://doi.org/10.1016/j.jclepro.2022.132998

Biamont-Rojas, I. E., Cardoso-Silva, S., Figueira, R. C. L., Kim, B. S. M., Alfaro-Tapia, R., & Pompêo, M. (2023). Spatial distribution of arsenic and metals suggest a high ecotoxicological potential in Puno Bay Lake Titicaca Peru. *Science of The Total Environment., 871*, 162051. https://doi.org/10.1016/j.scitotenv.2023.162051

Biswas, T., Pal, S. C., Chowdhuri, I., Ruidas, D., Saha, A., Islam, A. R. M. T., & Shit, M. (2023). Effects of elevated arsenic and nitrate concentrations on groundwater resources in deltaic region of Sundarban Ramsar site Indo-Bangladesh Region. *Marine Pollution Bulletin, 188*, 114618. https://doi.org/10.1016/j.marpolbul.2023.114618

Borah, P., Rene, E. R., Rangan, L., & Mitra, S. (2023). Phytoremediation of nickel and zinc using Jatropha curcas and Pongamia pinnata from the soils contaminated by municipal solid wastes and paper mill wastes. *Environmental Research, 219*, 115055. https://doi.org/10.1016/j.envres.2022.115055

Borden, R. K., Brown, P. L., & Sturgess, S. (2022). Geochemical and hydrological evolution of mine impacted waters at the Argyle Diamond Mine Western Australia. *Applied Geochemistry, 139*, 105253. https://doi.org/10.1016/j.apgeochem.2022.105253

Bullock, L. A., Alcalde, J., Tornos, F., & Fernandez-Turiel, J. L. (2023). Geochemical carbon dioxide removal potential of Spain. *Science of the Total Environment, 867*, 161287. https://doi.org/10.1016/j.scitotenv.2022.161287

Bundschuh, J., Schneider, J., Alam, M. A., Niazi, N. K., Herath, I., Parvez, F., Tomaszewska, B., Guilherme, L. R. G., Maity, J. P., López, D. L., Cirelli, A. F., Pérez-Carrera, A., Morales-Simfors, N., Alarcón-Herrera, M. T., Baisch, P., Mohan, D., & Mukherjee, A. (2021). Seven potential sources of arsenic pollution in Latin America and their environmental and health impacts. *Science of The Total Environment., 780*, 146274. https://doi.org/10.1016/j.scitotenv.2021.146274

Burt, R., Wilson, M. A., Keck, T. J., Dougherty, B. D., Strom, D. E., & Lindahl, J. A. (2003). Trace element speciation in selected smelter-contaminated soils in Anaconda and Deer Lodge Valley, Montana USA. *Advances in Environmental Research, 8*, 51–67. https://doi.org/10.1016/S1093-0191(02)00140-5

Canavati, A., Toweh, J., Simon, A. C., & Arbic, B. K. (2022). The world's electronic graveyard: What is the solution to Ghana's e-waste dilemma? *World Development Perspectives, 26*, 100433. https://doi.org/10.1016/j.wdp.2022.100433

Cao, S., Wen, D., Chen, X., Duan, X., Zhang, L., Wang, B., Qin, N., & Wei, F. (2022). Source identification of pollution and health risks to metals in household indoor and outdoor dust: A cross-sectional study in a typical mining town China. *Environmental Pollution, 293*, 118551. https://doi.org/10.1016/j.envpol.2021.118551

Cappucci, G. M., Avolio, R., Carfagna, C., Cocca, M., Gentile, G., Scarpellini, S., Spina, F., Tealdo, G., Errico, M. E., & Ferrari, A. M. (2020). Environmental life cycle assessment of the recycling processes of waste plastics recovered by landfill mining. *Waste Management, 118*, 68–78. https://doi.org/10.1016/j.wasman.2020.07.048

Castillo-Michel, H. A., Larue, C., Pradas del Real, A. E., Cotte, M., & Sarret, G. (2017). Practical review on the use of synchrotron based micro- and nano- X-ray fluorescence mapping and X-ray absorption spectroscopy to investigate the interactions between plants and engineered nanomaterials. *Plant Physiology and Biochemistry, 110*, 13–32. https://doi.org/10.1016/j.plaphy.2016.07.018

Castro-Bedriñana, J., Chirinos-Peinado, D., Ríos-Ríos, E., Machuca-Campuzano, M., & Gómez-Ventura, E. (2021). Dietary risk of milk contaminated with lead and cadmium in areas near mining-metallurgical industries in the Central Andes of Peru. *Ecotoxicology and Environmental Safety, 220*, 112382. https://doi.org/10.1016/j.ecoenv.2021.112382

Chauhan, S., Dahiya, D., Sharma, V., Khan, N., Chaurasia, D., Nadda, A. K., Varjani, S., Pandey, A., & Bhargava, P. C. (2022). Advances from conventional to real time detection of heavy metal(loid)s for water monitoring: An overview of biosensing applications. *Chemosphere, 307*, 136124. https://doi.org/10.1016/j.chemosphere.2022.136124

Chen, Y., Shen, Z., & Li, X. (2004). The use of vetiver grass (Vetiveria zizanioides) in the phytoremediation of soils contaminated with heavy metals. *Applied Geochemistry, 19*, 1553–1565. https://doi.org/10.1016/j.apgeochem.2004.02.003

Chen, A., Lin, C., Lu, W., Wu, Y., Ma, Y., Li, J., & Zhu, L. (2007). Well water contaminated by acidic mine water from the Dabaoshan Mine, South China: Chemistry and toxicity. *Chemosphere, 70*, 248–255. https://doi.org/10.1016/j.chemosphere.2007.06.041

Chen, Z., Liu, Q., Chen, S., Zhang, S., Wang, M., Mujtaba Munir, M. A., Feng, Y., He, Z., & Yang, X. (2022). Roles of exogenous plant growth regulators on phytoextraction of Cd/Pb/Zn by Sedum alfredii Hance in contaminated soils. *Environmental Pollution, 293*, 118510. https://doi.org/10.1016/j.envpol.2021.118510

Chen, D., Wang, X., Luo, X., Huang, G., Tian, Z., Li, W., & Liu, F. (2023). Delineating and identifying risk zones of soil heavy metal pollution in an industrialized region using machine learning ☆. *Environmental Pollution, 318*, 120932. https://doi.org/10.1016/j.envpol.2022.120932

Chera-Anghel, I. A., & Stefan-van Staden, R. I. (2023). Extraction of heavy metals by cooking/preserving of seafood, tuna and poultry from Romania – A source of contamination with heavy metals. *Food Chemistry, 407*, 135158. https://doi.org/10.1016/j.foodchem.2022.135158

Chi, Y., Peng, L., Tam, N. F. Y., Lin, Q., Liang, H., Li, W. C., & Ye, Z. (2022). Effects of fly ash and steel slag on cadmium and arsenic accumulation in rice grains and soil health: A field study over four crop seasons in Guangdong China. *Geoderma, 419*, 115879. https://doi.org/10.1016/j.geoderma.2022.115879

Chirinos-Peinado, D. M., Castro-Bedriñana, J. I. (2020). Lead and cadmium blood levels and transfer to milk in cattle reared in a mining area. *Heliyon 6*, 0–4. https://doi.org/10.1016/j.heliyon.2020.e03579

Coman, A., Chereches, R. M., Ungureanu, M. I., Marton-Vasarhelyi, E. O., Valentine, M. A., Sabo-Attwood, T., & Gray, G. C. (2015). An assessment of the occupational and environmental health needs in seven Southeastern European and West-Central Asian countries. *Journal of Epidemiology and Global Health, 5*, 375–384. https://doi.org/10.1016/j.jegh.2015.04.004

Cooray, T., Zhang, J., Zhong, H., Zheng, L., Wei, Y., Weragoda, S. K., Jinadasa, K. B. S. N., & Weerasooriya, R. (2021). Profiles of antibiotic resistome and microbial community in groundwater of CKDu prevalence zones in Sri Lanka. *Journal of Hazardous Materials, 403*, 123816. https://doi.org/10.1016/j.jhazmat.2020.123816

Csavina, J., Taylor, M. P., Félix, O., Rine, K. P., Eduardo Sáez, A., & Betterton, E. A. (2014). Size-resolved dust and aerosol contaminants associated with copper and lead smelting emissions: Implications for emission management and human health. *Science of the Total Environment, 493*, 750–756. https://doi.org/10.1016/j.scitotenv.2014.06.031

Cui, E., Cui, B., Fan, X., Li, S., & Gao, F. (2021). Ryegrass (Lolium multiflorum L.) and Indian mustard (Brassica juncea L.) intercropping can improve the phytoremediation of antibiotics and antibiotic resistance genes but not heavy metals. *Science of The Total Environment, 784*, 147093. https://doi.org/10.1016/j.scitotenv.2021.147093

da Silva, M. A., Lopes Motta, F., & Soares, J. B. P. (2021). Recovery of residual bitumen, dewatering, and consolidation of oil sands tailings with poly(acrylamide-co-lauric acid). *Minerals Engineering, 174*, 107248. https://doi.org/10.1016/j.mineng.2021.107248

da Silva, G. J., Borges, A. C., Moreira, M. C., & Rosa, A. P. (2022). Statistical process control in assessing water quality in the Doce river basin after the collapse of the Fundão dam (Mariana, Brazil). *Journal of Environmental Management., 317*, 115402. https://doi.org/10.1016/j.jenvman.2022.115402

Dai, X., Wang, Z., Liu, S., Yao, Y., Zhao, R., Xiang, T., Fu, T., Feng, H., Xiao, L., Yang, X., & Wang, S. (2022). Hyperspectral imagery reveals large spatial variations of heavy metal content in agricultural soil - A case study of remote-sensing inversion based on Orbita Hyperspectral Satellites (OHS) imagery. *Journal of Cleaner Production, 380*, 134878. https://doi.org/10.1016/j.jclepro.2022.134878

Darroudi, S., Saberi-karimian, M., Tayefi, M., Tayefi, B., Khashyarmanesh, Z., Gonoodi, K., Esmaeili, H., Mohammadpour, A.H., Ferns, G.A. (2018). Association between hypertension in healthy participants and zinc and copper status : a population-based study.

Dembele, S., Akcil, A., & Panda, S. (2022). Technological trends, emerging applications and metallurgical strategies in antimony recovery from stibnite. *Minerals Engineering, 175*, 107304. https://doi.org/10.1016/j.mineng.2021.107304

Deng, W., Wang, F., & Liu, W. (2023). Identification of factors controlling heavy metals/metalloid distribution in agricultural soils using multi-source data. *Ecotoxicology and Environmental Safety, 253*, 114689. https://doi.org/10.1016/j.ecoenv.2023.114689

Dikšaitytė, A., Kniuipytė, I., & Žaltauskaitė, J. (2023). Drought-free future climate conditions enhance cadmium phytoremediation capacity by Brassica napus through improved physiological status. *Journal of Hazardous Materials, 452*, 131181. https://doi.org/10.1016/j.jhazmat.2023.131181

Dold, B., Wade, C., & Fontboté, L. (2009). Water management for acid mine drainage control at the polymetallic Zn-Pb-(Ag-Bi-Cu) deposit Cerro de Pasco. *Journal of Geochemical Exploration, 100*, 133–141. https://doi.org/10.1016/j.gexplo.2008.05.002

Duquène, L., Vandenhove, H., Tack, F., Meers, E., Baeten, J., & Wannijn, J. (2009). Enhanced phytoextraction of uranium and selected heavy metals by Indian mustard and ryegrass using biodegradable soil amendments. *Science of the Total Environment, 407*, 1496–1505. https://doi.org/10.1016/j.scitotenv.2008.10.049

Durkalec, M., Martínez-Haro, M., Nawrocka, A., Pareja-Carrera, J., Smits, J. E. G., & Mateo, R. (2022). Factors influencing lead, mercury and other trace element exposure in birds from metal mining areas. *Environmental Research., 212*, 113575. https://doi.org/10.1016/j.envres.2022.113575

Dutta Dey, S., & Singh, R. (2021). Mapping precarious energy geographies: Exploring the lived experience of coal mining in Jharia India. *Energy Research & Social Science, 82*, 102298. https://doi.org/10.1016/j.erss.2021.102298

El-Dib, F. I., Mohamed, D. E., El-Shamy, O. A. A., & Mishrif, M. R. (2020). Study the adsorption properties of magnetite nanoparticles in the presence of different synthesized surfactants for heavy metal ions removal. *Egyptian Journal of Petroleum, 29*, 1–7. https://doi.org/10.1016/j.ejpe.2019.08.004

El-Ghamry, A. M., Huang, C. Y., & Xu, J. M. (2002). Environmental effect of metsulfuron-methyl on the size of microbial biomass and N-mineralization in a loamy sand soil. *Developments in Soil Science, 28*, 147–156. https://doi.org/10.1016/S0166-2481(02)80013-7

Elouear, Z., Bouhamed, F., Boujelben, N., & Bouzid, J. (2016). Application of sheep manure and potassium fertilizer to contaminated soil and its effect on zinc, cadmium and lead accumulation by alfalfa plants. *Sustainable Environment Research, 26*, 131–135. https://doi.org/10.1016/j.serj.2016.04.004

Enyoh, C. E., & Isiuku, B. O. (2021). Current research in green and sustainable chemistry competitive biosorption and phytotoxicity of chlorophenols in aqueous solution to Canna indica L. *Current Research in Green and Sustainable Chemistry, 4*, 100094. https://doi.org/10.1016/j.crgsc.2021.100094

Eze, C. T. G., Otitoloju, A. A., Eze, O. O., Ugochukwu, T. E., Onodugo, C., Ali, A. M., Lyche, J. L., Karlsen, O. A., & Goksøyr, A. (2023). West African e-waste-soil assessed with a battery of cell-based bioassays. *Science of The Total Environment., 856*, 159068. https://doi.org/10.1016/j.scitotenv.2022.159068

Faiza Amin, K., Gulshan, F., Asrafuzzaman, D. H., Rashid, R., & Hoque, S. M. (2023). Synthesis of mesoporous

silica and chitosan-coated magnetite nanoparticles for heavy metal adsorption from wastewater. *Environmental Nanotechnology, Monitoring & Management., 20*, 100801. https://doi.org/10.1016/j.enmm.2023.100801
Faraji, M., Alizadeh, I., Oliveri Conti, G., & Mohammadi, A. (2023). Investigation of health and ecological risk attributed to the soil heavy metals in Iran: Systematic review and meta-analysis. *Science of the Total Environment, 857*, 158925. https://doi.org/10.1016/j.scitotenv.2022.158925
Fasrjana, S. H., Huda, N., & Mahmud, M. A. P. (2019). Impacts of aluminum production: A cradle to gate investigation using life-cycle assessment. *Science of the Total Environment, 663*, 958–970. https://doi.org/10.1016/j.scitotenv.2019.01.400
Fathizad, H., Ardakani, M. A. H., Heung, B., Sodaiezadeh, H., Rahmani, A., Fathabadi, A., Scholten, T., & Taghizadeh-Mehrjardi, R. (2020). Spatio-temporal dynamic of soil quality in the central Iranian desert modeled with machine learning and digital soil assessment techniques. *Ecological Indicators, 118*, 106736. https://doi.org/10.1016/j.ecolind.2020.106736
Fayiga, A. O., & Saha, U. K. (2016). Arsenic hyperaccumulating fern: Implications for remediation of arsenic contaminated soils. *Geoderma, 284*, 132–143. https://doi.org/10.1016/j.geoderma.2016.09.003
Fediuc, E., & Erdei, L. (2002). Physiological and biochemical aspects of cadmium toxicity and protective mechanisms induced in Phragmites australis and Typha latifolia. *Journal of Plant Physiology, 159*, 265–271. https://doi.org/10.1078/0176-1617-00639
Feitosa, M. M., Alvarenga, I. F. S., Jara, M. S., Lima, G. J. E. de O., Vilela, F. J., Resende, T., Guilherme, L. R. G. (2021). Environmental and human-health risks of As in soils with abnormal arsenic levels located in irrigated agricultural areas of Paracatu (MG) Brazil. Ecotoxicology and Environmental Safety. 226. https://doi.org/10.1016/j.ecoenv.2021.112869
Feng, Y., Wang, J., Bai, Z., & Reading, L. (2019). Effects of surface coal mining and land reclamation on soil properties: A review. *Earth-Science Reviews, 191*, 12–25. https://doi.org/10.1016/j.earscirev.2019.02.015
Filonchyk, M., & Peterson, M. P. (2023). An integrated analysis of air pollution from US coal-fired power plants. *Geoscience Frontiers, 14*, 101498. https://doi.org/10.1016/j.gsf.2022.101498
Flem, B., Eggen, O. A., Torgersen, E., Kongsvik, M. K., & Ottesen, R. T. (2018). Urban geochemistry in Kristiansand Norway. *Journal of Geochemical Exploration, 187*, 21–33. https://doi.org/10.1016/j.gexplo.2017.03.004
Fujimori, T., Itai, T., Goto, A., Asante, K. A., Otsuka, M., Takahashi, S., & Tanabe, S. (2016). Interplay of metals and bromine with dioxin-related compounds concentrated in e-waste open burning soil from Agbogbloshie in Accra Ghana. *Environmental Pollution, 209*, 155–163. https://doi.org/10.1016/j.envpol.2015.11.031
Gared, O., & Gaur, A. (2020). Feasibility study of Jarosite as cement replacement in rigid pavement. *Materials Today: Proceedings, 44*, 4337–4341. https://doi.org/10.1016/j.matpr.2020.10.554
Gautam, M., & Agrawal, M. (2017). Phytoremediation of metals using vetiver (Chrysopogon zizanioides (L.) Roberty) grown under different levels of red mud in sludge amended soil. *Journal of Geochemical Exploration, 182*, 218–227. https://doi.org/10.1016/j.gexplo.2017.03.003
Gautam, K., Sharma, P., Dwivedi, S., Singh, A., Gaur, V. K., Varjani, S., Srivastava, J. K., Pandey, A., Chang, J. S., & Ngo, H. H. (2023). A review on control and abatement of soil pollution by heavy metals: Emphasis on artificial intelligence in recovery of contaminated soil. *Environmental Research, 225*, 115592. https://doi.org/10.1016/j.envres.2023.115592
Gauthier, P. T., Blewett, T. A., Garman, E. R., Schlekat, C. E., Middleton, E. T., Suominen, E., & Crémazy, A. (2021). Environmental risk of nickel in aquatic Arctic ecosystems. *Science of the Total Environment, 797*, 148921. https://doi.org/10.1016/j.scitotenv.2021.148921
Gebhart, K. A., Farber, R. J., Hand, J. L., Eatough, D. J., Schichtel, B. A., Vimont, J. C., Green, M. C., & Malm, W. C. (2021). Long-term trends in particulate sulfate at Grand Canyon National Park. *Atmospheric Environment, 253*, 118339. https://doi.org/10.1016/j.atmosenv.2021.118339
Ghayoraneh, M., & Qishlaqi, A. (2017). Concentration, distribution and speciation of toxic metals in soils along a transect around a Zn/Pb smelter in the northwest of Iran. *Journal of Geochemical Exploration, 180*, 1–14. https://doi.org/10.1016/j.gexplo.2017.05.007
Goodarzi, R., Beirami, B. A., Sahebi, M. R., & Mokhtarzade, M. (2023). ScienceDirect Evaluation of regression modes' accuracy for estimating soil heavy metals content from topographic rectified satellite imagery (Case study : Irankouh from Iran). *Advances in Space Research*. https://doi.org/10.1016/j.asr.2023.03.025
Goswami, R., Bhagat, C., Lollen, I., Neog, N., Barache, U. B., Thakur, R., Mahlknecht, J., & Kumar, M. (2023). Potential arsenic–chromium–lead Co-contamination in the hilly terrain of Arunachal Pradesh, north-eastern India: Genesis and health perspective. *Chemosphere, 323*, 138067. https://doi.org/10.1016/j.chemosphere.2023.138067
Govarthanan, M., Lee, K.-J., Cho, M., Kim, J. S., Kamala-Kannan, S., & Oh, B.-T. (2013). Significance of autochthonous Bacillus sp. KK1 on biomineralization of lead in mine tailings. *Chemosphere, 90*, 2267–2272. https://doi.org/10.1016/j.chemosphere.2012.10.038
Green, R. E., Pain, D. J., & Krone, O. (2022). The impact of lead poisoning from ammunition sources on raptor populations in Europe. *Science of the Total Environment, 823*, 154017. https://doi.org/10.1016/j.scitotenv.2022.154017
Gu, J., Liu, X., & Zhang, Z. (2023). Road base materials prepared by multi-industrial solid wastes in China: A review. *Construction and Building Materials, 373*, 130860. https://doi.org/10.1016/j.conbuildmat.2023.130860
Guimarães, R. N., Moreira, V. R., Cruz, J. R. A., Saliba, A. P. M., & Amaral, M. C. S. (2022). History of tailings dam failure: Impacts on access to safe water and influence on the legislative framework. *Science of the Total Environment., 852*, 158536. https://doi.org/10.1016/j.scitotenv.2022.158536

Guo, K., Xiang, W., Zhou, W., Zhao, Y., Cheng, Y., & He, M. (2021). In situ plant bionic remediation of cadmium-contaminated soil caused by a high geological background in Kaihua, Zhejiang Province China. *Chemosphere, 269*, 128693. https://doi.org/10.1016/j.chemosphere.2020.128693

Haghighizadeh, A., Aghababai Beni, A., Haghmohammadi, M., Adel, M. S. S., & Farshad, S. (2023). Green Synthesis of ZnO-TiO2 Nano-Photocatalyst Doped with Fe(III) Ions Using Bitter Olive Extract to Treat Textile Wastewater Containing Reactive Dyes. *Water, Air, and Soil Pollution, 234*, 1–17. https://doi.org/10.1007/s11270-023-06374-w

Haghmohammadi, M., Sajjadi, N., Aghababai, A., Mostafa, S., Nezarat, A., & Delnabi, S. (2023). Journal of water process engineering synthesis of activated carbon / magnetite nanocatalyst for sono-Fenton-like degradation process of 4-chlorophenol in an ultrasonic reactor and optimization using response surface method. *Journal of Water Process Engineering, 55*, 104216. https://doi.org/10.1016/j.jwpe.2023.104216

Hakim, L., Asmara, A. A., Priambodo, R. Y., & Wong, Y. J. (2023). Microplastic pollution profile in the Indian Ocean of the Southern Java Island, Indonesia. *Environmental Challenges, 13*, 100786. https://doi.org/10.1016/j.envc.2023.100786

Han, Y., Zveushe, O. K., Dong, F., Ling, Q., Chen, Y., Sajid, S., Zhou, L., & Resco de Dios, V. (2021). Unraveling the effects of arbuscular mycorrhizal fungi on cadmium uptake and detoxification mechanisms in perennial ryegrass (Lolium perenne). *Science of the Total Environment, 798*, 149222. https://doi.org/10.1016/j.scitotenv.2021.149222

Hao, C., Chen, B., Sánchez de la Campa, A. M., & de la Rosa, J. D. (2020). Increased industry contribution and atmospheric heavy metals from economic recovery in Spain. *Journal of Cleaner Production, 246*, 119024. https://doi.org/10.1016/j.jclepro.2019.119024

Haque, E., Thorne, P. S., Nghiem, A. A., Yip, C. S., & Bostick, B. C. (2021). Lead (Pb) concentrations and speciation in residential soils from an urban community impacted by multiple legacy sources. *Journal of Hazardous Materials, 416*, 125886. https://doi.org/10.1016/j.jhazmat.2021.125886

Hien, T. T., Chi, N. D. T., Huy, D. H., Le, H. A., Oram, D. E., Forster, G. L., Mills, G. P., & Baker, A. R. (2022). Soluble trace metals associated with atmospheric fine particulate matter in the two most populous cities in Vietnam. *Atmospheric Environment: X, 15*, 100178. https://doi.org/10.1016/j.aeaoa.2022.100178

Hoang, S. A., Lamb, D., Seshadri, B., Sarkar, B., Choppala, G., Kirkham, M. B., & Bolan, N. S. (2021). Rhizoremediation as a green technology for the remediation of petroleum hydrocarbon-contaminated soils. *Journal of Hazardous Materials, 401*, 123282. https://doi.org/10.1016/j.jhazmat.2020.123282

Horváth, A., Kalicz, P., Farsang, A., Balázs, P., Berki, I., & Bidló, A. (2018). Science of the total environment in fl uence of human impacts on trace metal accumulation in soils of two Hungarian cities. *Science of the Total Environment, 637–638*, 1197–1208. https://doi.org/10.1016/j.scitotenv.2018.05.033

Hu, B., Shao, S., Ni, H., Fu, Z., Hu, L., Zhou, Y., Min, X., She, S., Chen, S., Huang, M., Zhou, L., Li, Y., & Shi, Z. (2020). Current status, spatial features, health risks, and potential driving factors of soil heavy metal pollution in China at province level. *Environmental Pollution, 266*, 114961. https://doi.org/10.1016/j.envpol.2020.114961

Huang, Ya., Huang, Y., Hou, J., Wu, L., Christie, P., & Liu, W. (2023). Microbial community assembly of the hyperaccumulator plant Sedum plumbizincicola in two contrasting soil types with three levels of cadmium contamination. *Science of the Total Environment, 863*, 160917. https://doi.org/10.1016/j.scitotenv.2022.160917

Huynh, T. L., Le, T. K. O., Wong, Y. J., Phan, C. T., & Trinh, T. L. (2023). Towards sustainable composting of source-separated biodegradable municipal solid waste—insights from long an Province Vietnam. *Sustain., 15*, 13243. https://doi.org/10.3390/su151713243

Jafarian, A., & Alehashem, M. (2013). Heavy metal contamination of vegetables in Isfahan Iran. *Research in Pharmaceutical Science, 8*, 51–58.

Jara-Baeza, F., Rajagopalan, P., & Andamon, M. M. (2023). A holistic assessment of indoor environmental quality perception in Australian high-rise social housing. *Energy and Buildings, 284*, 112859. https://doi.org/10.1016/j.enbuild.2023.112859

Ji, M., AL-Huqail, A. A., Majdi, A., Liu, H., Ali, I., & Marzouki, R. (2022). Remediation of mine polluted soil with nano-enhanced materials: Development of extreme learning machine approaches. *Chemosphere, 307*, 135772. https://doi.org/10.1016/j.chemosphere.2022.135772

Ji, M., Li, B., Majdi, A., Alkhalifah, T., Alturise, F., & Ali, H. E. (2023). Application of nano remediation of mine polluted in acid mine drainage water using machine learning model. *Chemosphere, 311*, 136926. https://doi.org/10.1016/j.chemosphere.2022.136926

Jiang, Q., He, Y., Wu, Y., Dian, B., Zhang, J., Li, T., & Jiang, M. (2022a). Solidification/stabilization of soil heavy metals by alkaline industrial wastes: A critical review. *Environmental Pollution, 312*, 120094. https://doi.org/10.1016/j.envpol.2022.120094

Jiang, X., Guo, Y., Li, H., Li, X., & Liu, J. (2022b). Ecological evolution during the three-year restoration using rhizosphere soil cover method at a Lead-Zinc tailing pond in Karst areas. *Science of the Total Environment, 853*, 158291. https://doi.org/10.1016/j.scitotenv.2022.158291

Jibiri, N. N., Isinkaye, M. O., & Momoh, H. A. (2014). Assessment of radiation exposure levels at Alaba e-waste dumpsite in comparison with municipal waste dumpsites in southwest Nigeria. *Journal of Radiation Research and Applied Science, 7*, 536–541. https://doi.org/10.1016/j.jrras.2014.09.002

Jordanova, N., Jordanova, D., Tcherkezova, E., Georgieva, B., & Ishlyamski, D. (2021). Advanced mineral magnetic and geochemical investigations of road dusts for assessment of pollution in urban areas near the largest copper smelter in SE Europe. *Science of the Total Environment,*

792, 148402. https://doi.org/10.1016/j.scitotenv.2021.148402
Kamrath, B., & Yuan, Y. (2022). Streamflow duration curve to explain nutrient export in midwestern USA watersheds: implication for water quality achievements. *SSRN Electronic Journal, 336*, 117598. https://doi.org/10.2139/ssrn.4255039
Kannan, P., Banat, F., Hasan, S. W., & Abu Haija, M. (2021). Neutralization of Bayer bauxite residue (red mud) by various brines: A review of chemistry and engineering processes. *Hydrometallurgy, 206*, 105758. https://doi.org/10.1016/j.hydromet.2021.105758
Karnaeva, A., Kulikova, O., Mazlova, E., & Buryak, A. (2021). Aged diesel and heavy metal pollution in the Arctic tundra (Yamal Peninsula, Russia). *Science of the Total Environment, 792*, 148471. https://doi.org/10.1016/j.scitotenv.2021.148471
Karpinski, A. P., Serenyi, J. R. (2023). Secondary Batteries: zinc batteries: zinc–silver, 2nd ed, Energy. Elsevier B.V. https://doi.org/10.1016/B978-0-323-96022-9.00044-X
Kazapoe, R. W., Amuah, E. E. Y., & Dankwa, P. (2022). Sources and pollution assessment of trace elements in soils of some selected mining areas of southwestern Ghana. *Environmental Technology and Innovation, 26*, 102329. https://doi.org/10.1016/j.eti.2022.102329
Kennedy, S. A., & Kelloway, S. J. (2020). Identifying metallurgical practices at a colonial silver refinery in Puno, Peru, using portable X-Ray fluorescence spectroscopy (pXRF). *Journal of Archaeological Science: Reports, 33*, 102568. https://doi.org/10.1016/j.jasrep.2020.102568
Ketterer, M. E., Lowry, J. H., Simon, J., Humphries, K., & Novotnak, M. P. (2001). Lead isotopic and chalcophile element compositions in the environment near a zinc smelting-secondary zinc recovery facility, Palmerton, Pennsylvania, USA. *Applied Geochemistry, 16*, 207–229. https://doi.org/10.1016/S0883-2927(00)00029-9
Khan, M. Z., & Shoumik, B. A. A. (2022). Land degradation neutrality concerns in Bangladesh. *Soil Security., 9*, 100075. https://doi.org/10.1016/j.soisec.2022.100075
Khan, J., Singh, R., Upreti, P., & Kumar, R. (2022). Environmental technology & innovation geo-statistical assessment of soil quality and identification of Heavy metal contamination using Integrated GIS and Multivariate statistical analysis in Industrial region of Western India. *Environmental Technology and Innovation, 28*, 102646. https://doi.org/10.1016/j.eti.2022.102646
Khan, Z. A., Chowdhury, S. R., Mitra, B., Mozumder, M. S., Elhaj, A. I., Salami, B. A., Rahman, M. M., & Rahman, S. M. (2023). Analysis of industrial symbiosis case studies and its potential in Saudi Arabia. *Journal of Cleaner Production, 385*, 135536. https://doi.org/10.1016/j.jclepro.2022.135536
Kicińska, A., & Wikar, J. (2021). Ecological risk associated with agricultural production in soils contaminated by the activities of the metal ore mining and processing industry - example from southern Poland. *Soil and Tillage Research., 205*, 104817. https://doi.org/10.1016/j.still.2020.104817
Kim, J., Lin, S. Y., Singh, R. P., Lan, C. W., & Yun, H. W. (2021). Underground burning of Jharia coal mine (India) and associated surface deformation using InSAR data. *International Journal of Applied Earth Observation and Geoinformation, 103*, 102524. https://doi.org/10.1016/j.jag.2021.102524
Kolala, C., Polyakov, M., & Fogarty, J. (2020). Impacts of mining on property values in Kalgoorlie-Boulder Western Australia. *Resource Policy, 68*, 101777. https://doi.org/10.1016/j.resourpol.2020.101777
Koon, A. B., Kwame, G., Wullobayi, B., Daanoba, E., Agyare, A., & Gyamfi, C. (2023). Urban climate evaluation of groundwater vulnerability using GIS-based DRASTIC model in Greater Monrovia Montserrado. *Urban Climate, 48*, 101427. https://doi.org/10.1016/j.uclim.2023.101427
Krucon, T., Ruszkowska, Z., Pilecka, W., Szych, A., Drewniak, L. (2023). Bioprospecting of the antarctic bacillus subtilis strain for potential applications in leaching hydrocarbons and trace elements from contaminated environments based on functional and genomic analysis. *SSRN Electronic Journal. 227*. https://doi.org/10.2139/ssrn.4329659
Kumar, D., Kumar, G., & Kumari, A. (2021). High resolution geophysical and geospatial mapping of quaternary sediments for exploration and assessment of groundwater in Ghaziabad district, Uttar Pradesh india. *Groundwater for Sustainable Development, 14*, 100638. https://doi.org/10.1016/j.gsd.2021.100638
Kumar Singh, S., Pratap Banerjee, B., & Raval, S. (2022). A review of laser scanning for geological and geotechnical applications in underground mining. *International Journal of Mining Science and Technology, 33*, 133–154. https://doi.org/10.1016/j.ijmst.2022.09.022
Laidlaw, M. A. S., Filippelli, G. M., Brown, S., Paz-Ferreiro, J., Reichman, S. M., Netherway, P., Truskewycz, A., Ball, A. S., & Mielke, H. W. (2017). Case studies and evidence-based approaches to addressing urban soil lead contamination. *Appllied Geochemistry, 83*, 14–30. https://doi.org/10.1016/j.apgeochem.2017.02.015
Lei, T., Jiang, X., Zhou, Y., Chen, H., Bai, H., Wang, S., & Yang, X. (2023). A multifunctional adsorbent based on 2,3-dimercaptosuccinic acid/dopamine-modified magnetic iron oxide nanoparticles for the removal of heavy-metal ions. *Journal of Colloid and Interface Science, 636*, 153–166. https://doi.org/10.1016/j.jcis.2023.01.011
Lesnik, J. J. (2014). Termites in the hominin diet: A meta-analysis of termite genera, species and castes as a dietary supplement for South African robust australopithecines. *Journal of Human Evolution, 71*, 94–104. https://doi.org/10.1016/j.jhevol.2013.07.015
Li, J., Gan, J., & Hu, Y. (2016). Characteristics of heavy metal species transformation of Pb, Cu, Zn from Municipal Sewage Sludge by Thermal Drying. *Procedia Environmental Sciences, 31*, 961–969. https://doi.org/10.1016/j.proenv.2016.03.001
Li, W., Ni, P., & Yi, Y. (2019a). Comparison of reactive magnesia, quick lime, and ordinary Portland cement for stabilization/solidification of heavy metal-contaminated soils. *Science of the Total Environment, 671*, 741–753. https://doi.org/10.1016/j.scitotenv.2019.03.270
Li, Y., Zhang, H., Shao, L., Zhou, X., & He, P. (2019b). Impact of municipal solid waste incineration on heavy metals in the surrounding soils by multivariate analysis and lead

isotope analysis. *Journal of Environmental Sciences (china), 82*, 47–56. https://doi.org/10.1016/j.jes.2019.02.020

Li, M. M., Gao, Z. Y., Dong, C. Y., Wu, M. Q., Yan, J., Cao, J., Ma, W. J., Wang, J., Gong, Y. L., Xu, J., Cai, S. Z., Chen, J. Y., Xu, S. Q., Tong, S., Tang, D., Zhang, J., & Yan, C. H. (2020a). Contemporary blood lead levels of children aged 0–84 months in China: A national cross-sectional study. *Environment International, 134*, 105288. https://doi.org/10.1016/j.envint.2019.105288

Li, Y., Hu, J., Liu, H., Zhou, C., & Tian, S. (2020b). Electrochemically reversible foam enhanced flushing for PAHs-contaminated soil: Stability of surfactant foam, effects of soil factors, and surfactant reversible recovery. *Chemosphere, 260*, 127645. https://doi.org/10.1016/j.chemosphere.2020.127645

Li, M., Yang, J., Liang, S., Hou, H., Wang, J., Hu, G., Li, Z., Hu, J., Xiao, K., & Liu, B. (2021a). Ammonia chloride assisted air-chlorination recovery of tin from pyrometallurgical slag of spent lead-acid battery. *Resources, Conservation and Recycling, 170*, 105611. https://doi.org/10.1016/j.resconrec.2021.105611

Li, Y., Ma, Q., Chen, J. M., Croft, H., Luo, X., Zheng, T., Rogers, C., & Liu, J. (2021c). Remote sensing of environment fine-scale leaf chlorophyll distribution across a deciduous forest through two-step model inversion from Sentinel-2 data. *Remote Sensing of Environment, 264*, 112618. https://doi.org/10.1016/j.rse.2021.112618

Li, Y., Wang, Y., Khan, M. A., Luo, W., Xiang, Z., Xu, W., Zhong, B., Ma, J., Ye, Z., Zhu, Y., Duan, L., & Liu, D. (2021d). Effect of plant extracts and citric acid on phytoremediation of metal-contaminated soil. *Ecotoxicology and Environmental Safety, 211*, 111902. https://doi.org/10.1016/j.ecoenv.2021.111902

Li, J., Xia, C., Cheng, R., Lan, J., Chen, F., Li, X., Li, S., Chen, J., Zeng, T., & Hou, H. (2022a). Passivation of multiple heavy metals in lead–zinc tailings facilitated by straw biochar-loaded N-doped carbon aerogel nanoparticles: Mechanisms and microbial community evolution. *Science of the Total Environment, 803*, 149866. https://doi.org/10.1016/j.scitotenv.2021.149866

Li, S. P., Zeng, L. S., & Zhongliang, S. U. (2022b). Wheat growth, photosynthesis and physiological characteristics under different soil Zn levels. *Journal of Integrative Agriculture, 21*, 1927–1940. https://doi.org/10.1016/S2095-3119(21)63643-2

Li, X., Liu, H., Meng, W., Liu, N., & Wu, P. (2022c). Accumulation and source apportionment of heavy metal(loid)s in agricultural soils based on GIS, SOM and PMF: A case study in superposition areas of geochemical anomalies and zinc smelting Southwest China. *Process Safety and Environmental Protection, 159*, 964–977. https://doi.org/10.1016/j.psep.2022.01.072

Li, Y. J., Zhang, R. Q., Ji, H., Wang, C., Tan, J., & Wei, J. H. (2022d). Chemistry and U-Pb geochronology of cassiterite in the Xiasai deposit, central Yidun Terrane (SW China): Link between Sn and Ag–Pb–Zn mineralisation. *Ore Geology Reviews, 149*, 105106. https://doi.org/10.1016/j.oregeorev.2022.105106

Li, H., Yao, J., Sunahara, G., Min, N., Li, C., & Duran, R. (2023a). Quantifying ecological and human health risks of metal(loid)s pollution from non-ferrous metal mining and smelting activities in Southwest China. *Science of the Total Environment, 873*, 162364. https://doi.org/10.1016/j.scitotenv.2023.162364

Li, Q., Lesseur, C., Srirangam, P., Kaur, K., Hermetz, K., Caudle, W. M., Fiedler, N., Panuwet, P., Prapamontol, T., Naksen, W., Suttiwan, P., Baumert, B. O., Hao, K., Barr, D. B., Marsit, C. J., & Chen, J. (2023b). Associations between prenatal organophosphate pesticide exposure and placental gene networks. *Environmental Research, 224*, 115490. https://doi.org/10.1016/j.envres.2023.115490

Li, C., Li, M., Zeng, J., Yuan, S., Luo, X., Wu, C., & Xue, S. (2024). Migration and distribution characteristics of soil heavy metal(loid)s at a lead smelting site. *Journal of Environmental Sciences (china), 135*, 600–609. https://doi.org/10.1016/j.jes.2023.02.007

Li, P., Cai, M. F. (2021). Challenges and new insights for exploitation of deep underground metal mineral resources. Transactions of Nonferrous Metals Society of China. China (English Ed. 31, 3478–3505. https://doi.org/10.1016/S1003-6326(21)65744-8

Liang, X., Wang, C., Song, Z., Yang, S., Bi, X., Li, Z., & Li, P. (2021). Soil metal(loid)s pollution around a lead/zinc smelter and source apportionment using isotope fingerprints and receptor models. *Applied Geochemistry, 135*, 105118. https://doi.org/10.1016/j.apgeochem.2021.105118

Liang, J., Liu, Z., Tian, Y., Shi, H., Fei, Y., Qi, J., & Mo, L. (2023). Research on health risk assessment of heavy metals in soil based on multi-factor source apportionment: A case study in Guangdong Province China. *Science of the Total Environment., 858*, 159991. https://doi.org/10.1016/j.scitotenv.2022.159991

Lin, S., Ali, M. U., Zheng, C., Cai, Z., & Wong, M. H. (2022a). Toxic chemicals from uncontrolled e-waste recycling: Exposure, body burden, health impact. *Journal of Hazardous Materials, 426*, 127792. https://doi.org/10.1016/j.jhazmat.2021.127792

Lin, S., Chen, X. W., Cai, Z., Shi, J., Fu, J., Jiang, G., & Wong, M. H. (2022b). Remediation of emerging contaminated sites due to uncontrolled e-waste recycling. *Chemical Engineering Journal, 430*, 133169. https://doi.org/10.1016/j.cej.2021.133169

Liu, J., Li, C., Jing, J., Zhao, P., Luo, Z., Cao, M., Ma, Z., Jia, T., & Chai, B. (2018). Ecological patterns and adaptability of bacterial communities in alkaline copper mine drainage. *Water Research, 133*, 99–109. https://doi.org/10.1016/j.watres.2018.01.014

Liu, S., Wang, X., Guo, G., & Yan, Z. (2021). Status and environmental management of soil mercury pollution in China: A review. *Journal of Environmental Management, 277*, 111442. https://doi.org/10.1016/j.jenvman.2020.111442

Liu, L., Nian, H., & Lian, T. (2022a). Plants and rhizospheric environment: Affected by zinc oxide nanoparticles (ZnO NPs) A Review. *Plant Physiology and Biochemistry, 185*, 91–100. https://doi.org/10.1016/j.plaphy.2022.05.032

Liu, L., Xu, X., Han, J., Zhu, J. M., Li, S., Liang, L., Wu, P., Wu, Q., & Qiu, G. (2022b). Heavy metal(loid)s in agricultural soils in the world's largest barium-mining area:

Pollution characteristics, source apportionment, and health risks using PMF model and Cd isotopes. *Process Safety and Environment Protection, 166*, 669–681. https://doi.org/10.1016/j.psep.2022.08.061
Liu, W., Zhang, X., Zhang, W., He, S., Luo, S., Han, J., & Shen, D. (2023a). Metal-driven bacterial community variation in urban and suburban park soils of Shanghai China. *European Journal of Soil Biology, 115*, 103475. https://doi.org/10.1016/j.ejsobi.2023.103475
Liu, Y., Zhou, J., Sun, D., Chen, H., Qin, J., Chen, G., & Qiu, R. (2023b). Polyaspartic acid assisted-phytoremediation of cadmium-contaminated farmland: Phytoextraction efficiency, soil quality, and rhizosphere microbial community. *Science of the Total Environment, 862*, 160736. https://doi.org/10.1016/j.scitotenv.2022.160736
Lobo, G. P., Laraway, J., & Gadgil, A. J. (2022). Identifying schools at high-risk for elevated lead in drinking water using only publicly available data. *Science of the Total Environment, 803*, 150046. https://doi.org/10.1016/j.scitotenv.2021.150046
Long, Z., Zhu, H., Bing, H., Tian, X., Wang, Z., Wang, X., & Wu, Y. (2021). Contamination, sources and health risk of heavy metals in soil and dust from different functional areas in an industrial city of Panzhihua City, Southwest China. *Journal of Hazardous Materials., 420*, 126638. https://doi.org/10.1016/j.jhazmat.2021.126638
Lu, X., Zhang, Y., Liu, Y., & Fan, Y. (2022). Differences in planktonic and benthic diatoms reflect water quality during a rainstorm event in the Songhua River Basin of northeast China. *Ecological Indicators, 144*, 109547. https://doi.org/10.1016/j.ecolind.2022.109547
Luo, J., Xing, W., Ippolito, J. A., Zhao, L., Han, K., Wang, Y., Qiu, K., & Li, L. (2022). Bioaccessibility, source and human health risk of Pb, Cd, Cu and Zn in windowsill dusts from an area affected by long-term Pb smelting. *Science of the Total Environment, 842*, 156707. https://doi.org/10.1016/j.scitotenv.2022.156707
Luo, X., Wu, C., Lin, Y., Li, W., Deng, M., Tan, J., & Xue, S. (2023). Soil heavy metal pollution from Pb/Zn smelting regions in China and the remediation potential of biomineralization. *Journal of Environmental Sciences (china), 125*, 662–677. https://doi.org/10.1016/j.jes.2022.01.029
Ma, W., Tang, Y., Wu, P., & Xia, Y. (2019). Sewage sludge incineration ash for coimmobilization of lead, zinc and copper: Mechanisms of metal incorporation and competition. *Waste Management, 99*, 102–111. https://doi.org/10.1016/j.wasman.2019.08.029
Mackay, A. K., Taylor, M. P., Munksgaard, N. C., Hudson-Edwards, K. A., & Burn-Nunes, L. (2013). Identification of environmental lead sources and pathways in a mining and smelting town: Mount Isa Australia. *Environmental Pollution, 180*, 304–311. https://doi.org/10.1016/j.envpol.2013.05.007
Maity, S., Roy, S., Bhattacharya, S., & Chaudhury, S. (2011). Metallothionein responses in the earthworm Lampito mauritii (Kinberg) following lead and zinc exposure: A promising tool for monitoring metal contamination. *European Journal of Soil Biology, 47*, 69–71. https://doi.org/10.1016/j.ejsobi.2010.10.001
Mandal, J., Bakare, W. A., Rahman, M. M., Rahman, M. A., Siddique, A. B., Oku, E., Wood, M. D., Hutchinson, S. M., & Mondal, D. (2022). Varietal differences influence arsenic and lead contamination of rice grown in mining impacted agricultural fields of Zamfara State Nigeria. *Chemosphere, 305*, 135339. https://doi.org/10.1016/j.chemosphere.2022.135339
Mao, W., Watkins, D., Sabin, M. L., Huang, K., Langlois, E., Ogundeji, Y., Fogstad, H., Schäferhoff, M., & Yamey, G. (2023). Articles Effects of public financing of essential maternal and child health interventions across wealth quintiles in Nigeria : an extended cost-effectiveness analysis. *The Lancet Global Health, 11*, 597–605. https://doi.org/10.1016/S2214-109X(23)00056-6
Mapodzeke, J. M., Adil, M. F., Sehar, S., Karim, M. F., Saddique, M. A. B., Ouyang, Y., & Shamsi, I. H. (2021). Myriad of physio-genetic factors determining the fate of plant under zinc nutrient management. *Environmental and Experimental Botany, 189*, 104559. https://doi.org/10.1016/j.envexpbot.2021.104559
Marafatto, F. F., Dähn, R., Grolimund, D., Göttlicher, J., & Voegelin, A. (2021). Thallium sorption by soil manganese oxides: Insights from synchrotron X-ray micro-analyses on a naturally thallium-rich soil. *Geochimica Et Cosmochimica Acta, 302*, 193–208. https://doi.org/10.1016/j.gca.2021.03.011
Markowitz, G. (2016). The childhood lead poisoning epidemic in historical perspective. *Endeavour, 40*, 93–101. https://doi.org/10.1016/j.endeavour.2016.03.006
Marsili, L., Casini, S., Mori, G., Ancora, S., Bianchi, N., D'Agostino, A., Ferraro, M., & Fossi, M. C. (2009). The Italian wall lizard (Podarcis sicula) as a bioindicator of oil field activity. *Science of the Total Environment, 407*, 3597–3604. https://doi.org/10.1016/j.scitotenv.2009.01.035
Marszałek, M., Knapik, E., Piotrowski, M., & Chruszcz-Lipska, K. (2023). Removal of cadmium from phosphoric acid in the presence of chloride ions using commercially available anion exchange resins. *Journal of Industrial and Engineering Chemistry, 118*, 488–498. https://doi.org/10.1016/j.jiec.2022.11.032
Masindi, V. (2017). Recovery of drinking water and valuable minerals from acid mine drainage using an integration of magnesite, lime, soda ash, CO2 and reverse osmosis treatment processes. *Journal of Environmental Chemical Engineering, 5*, 3136–3142. https://doi.org/10.1016/j.jece.2017.06.025
Mathieu, L., Riller, U., Gibson, L., & Lightfoot, P. (2021). Data on the geology and structure of the Copper Cliff embayment and offset dyke, Sudbury Igneous Complex Canada. *Data in Brief., 35*, 106957. https://doi.org/10.1016/j.dib.2021.106957
McCann, J. I., & Nairn, R. W. (2022). Characterization of residual solids from mine water passive treatment oxidation ponds at the tar creek superfund site, Oklahoma, USA: Potential for reuse or disposal. *Cleaner Waste Systems, 3*, 100031. https://doi.org/10.1016/j.clwas.2022.100031
Mendonça-Santos, R. G., Antoniazzi, R., Camarota, F., dos Reis, Y. T., & Viana-Junior, A. B. (2023). Scattered

trees as crucial elements in maintaining urban diversity: A case study with canopy ants in a biodiversity hotspot. *Acta Oecologica, 118*, 103894. https://doi.org/10.1016/j.actao.2023.103894
Meshesha, T. W., Wang, J., & Melaku, N. D. (2020). Modelling spatiotemporal patterns of water quality and its impacts on aquatic ecosystem in the cold climate region of Alberta Canada. *Journal of Hydrology, 587*, 124952. https://doi.org/10.1016/j.jhydrol.2020.124952
Metcheva, R., Teodorova, S., & Topashka-Ancheva, M. (2003). A comparative analysis of the heavy metal loading of small mammals in different regions of Bulgaria I: Monitoring points and bioaccumulation features. *Ecotoxicology and Environmental Safety, 54*, 176–187. https://doi.org/10.1016/S0147-6513(02)00051-9
Mezned, N., Alayet, F., Dkhala, B., & Abdeljaouad, S. (2022). Heliyon Field hyperspectral data and OLI8 multispectral imagery for heavy metal content prediction and mapping around an abandoned Pb – Zn mining site in northern Tunisia. *Heliyon, 8*, e09712. https://doi.org/10.1016/j.heliyon.2022.e09712
Miao, X., Xie, H., Ackley, S. F., Perovich, D. K., & Ke, C. (2015). Object-based detection of Arctic sea ice and melt ponds using high spatial resolution aerial photographs. *Cold Regions Science and Technology, 119*, 211–222. https://doi.org/10.1016/j.coldregions.2015.06.014
Mikula, K., Izydorczyk, G., Skrzypczak, D., Moustakas, K., Witek-Krowiak, A., & Chojnacka, K. (2021). Value-added strategies for the sustainable handling, disposal, or value-added use of copper smelter and refinery wastes. *Journal of Hazardous Materials, 403*, 123602. https://doi.org/10.1016/j.jhazmat.2020.123602
Milori, D. M. B. P., Martin-Neto, L., Gollany, H. T., de Babos, D. V., Borduchi, L. C. L., Villas-Boas, P. R. (2023). Soil analysis using laser-induced breakdown spectroscopy, 2nd ed, Reference Module in Earth Systems and Environmental Sciences. Elsevier Inc. https://doi.org/10.1016/b978-0-12-822974-3.00211-1
Mir, M. A., Arya, S., & Kak, A. M. (2020). Health Risk Assessment of Heavy Metals for Population Via Consumption of Pulses and Cereals. *International Journal of Biological Innovations., 02*, 241–246. https://doi.org/10.46505/ijbi.2020.2222
Mohanty, S., Benya, A., Hota, S., Kumar, M. S., & Singh, S. (2023). Eco-toxicity of hexavalent chromium and its adverse impact on environment and human health in Sukinda Valley of India: A review on pollution and prevention strategies. *Environmental Chemistry and Ecotoxicology, 5*, 46–54. https://doi.org/10.1016/j.enceco.2023.01.002
Moreno, J. L., Bastida, F., Sánchez-Monedero, M. A., Hernández, T., & García, C. (2013). Response of soil microbial community to a high dose of fresh olive mill wastewater. *Pedosphere, 23*, 281–289. https://doi.org/10.1016/S1002-0160(13)60017-X
Morshdy, A. E. M. A., Darwish, W. S., Hussein, M. A. M., Mohamed, M. A. A., & Hussein, M. M. A. (2021). Lead and cadmium content in Nile tilapia (Oreochromis niloticus) from Egypt: A study for their molecular biomarkers. *Scientific African, 12*, e00794. https://doi.org/10.1016/j.sciaf.2021.e00794
Motomura, K., Horie, K., Ikehara, M., Sano, T., Takehara, M., & Kiyokawa, S. (2023). The nitrate-limited freshwater environment of the late Paleoproterozoic Embury Lake Formation, Flin Flon belt Canada. *Chemical Geology, 616*, 121234. https://doi.org/10.1016/j.chemgeo.2022.121234
Moura, A., Lutter, S., Siefert, C. A. C., Netto, N. D., Nascimento, J. A. S., & Castro, F. (2022). Estimating water input in the mining industry in Brazil: A methodological proposal in a data-scarce context. *The Extractive Industries and Society., 9*, 101015. https://doi.org/10.1016/j.exis.2021.101015
Muller, A., & Muller, D. (2014). Analysis of nodal point pollution, variability, and sustainability in mesohaline tidal creeks. *Marine Pollution Bulletin, 85*, 204–213. https://doi.org/10.1016/j.marpolbul.2014.05.048
Munanku, T., Banda, K., Nyimbili, P. H., Mhlongo, S. E., & Masinja, J. (2023). Development of a multi-criteria decision analysis tool for the assessment of the potential pollution risk of tailings dumps to the environment – An approach validated using selected Zambian Mine tailings. *Journal of the African Earth Sciences, 200*, 104880. https://doi.org/10.1016/j.jafrearsci.2023.104880
Mwaanga, P., Silondwa, M., Kasali, G., & Banda, P. M. (2019). Preliminary review of mine air pollution in Zambia. *Heliyon, 5*, e02485. https://doi.org/10.1016/j.heliyon.2019.e02485
Nabuyanda, M. M., Kelderman, P., Sankura, M. G., Rousseau, D., & Irvine, K. (2022). Investigating the effect of Eh and pH on binding forms of Co, Cu, and Pb in wetland sediments from Zambia. *Journal of Environmental Management, 319*, 115543. https://doi.org/10.1016/j.jenvman.2022.115543
Neo, E. R. K., Yeo, Z., Low, J. S. C., Goodship, V., & Debattista, K. (2022). A review on chemometric techniques with infrared, Raman and laser-induced breakdown spectroscopy for sorting plastic waste in the recycling industry. *Resources, Conservation and Recycling, 180*, 106217. https://doi.org/10.1016/j.resconrec.2022.106217
Newbold, J. (2006). Chile's environmental momentum: ISO 14001 and the large-scale mining industry - Case studies from the state and private sector. *Journal of Cleaner Production, 14*, 248–261. https://doi.org/10.1016/j.jclepro.2004.05.010
Ng, J. C., Ciminelli, V., Gasparon, M., & Caldeira, C. (2019). Health risk apportionment of arsenic from multiple exposure pathways in Paracatu, a gold mining town in Brazil. *Science of the Total Environment, 673*, 36–43. https://doi.org/10.1016/j.scitotenv.2019.04.048
Nieberl, M., Hornung, A., Sajdak, M., Majewski, A. J., & Ouadi, M. (2023). Application and recycling of tantalum from waste electric and electronic equipment–A review. *Resources, Conservation and Recycling, 190*, 106866. https://doi.org/10.1016/j.resconrec.2023.106866
Nodeh, Z. P., Beni, A. A., & Moghadam, A. J. (2023). Development of evaporation technique for concentrating lead acid wastewater from the battery recycling plant, by nanocomposite ceramic substrates and solar/wind energy. *Journal of Environmental Management, 328*, 116980. https://doi.org/10.1016/j.jenvman.2022.116980

Nwazelibe, V. E., Unigwe, C. O., & Egbueri, J. C. (2023). Catena Testing the performances of different fuzzy overlay methods in GIS-based landslide susceptibility mapping of Udi Province SE Nigeria. *Catena, 220*, 106654. https://doi.org/10.1016/j.catena.2022.106654

Obiri, S., Dodoo, D. K., Armah, F. A., Essumang, D. K., & Cobbina, S. J. (2010). Evaluation of lead and mercury neurotoxic health risk by resident children in the Obuasi municipality Ghana. *Environmental Toxicology and Pharmacology, 29*, 209–212. https://doi.org/10.1016/j.etap.2010.01.001

Ogarekpe, N. M., Nnaji, C. C., Oyebode, O. J., E100780kpenyong, M. G., Ofem, O. I., Tenebe, I. T., & Asitok, A. D. (2023). Groundwater quality index and potential human health risk assessment of heavy metals in water: A case study of Calabar metropolis, Nigeria. *Environmental Nanotechnology, Monitoring & Management, 19*, 100780. https://doi.org/10.1016/j.enmm.2023.100780

Ololade, O. O., & Annegarn, H. J. (2013). Contrasting community and corporate perceptions of sustainability: A case study within the platinum mining region of South Africa. *Resources Policy, 38*, 568–576. https://doi.org/10.1016/j.resourpol.2013.09.005

Orellana Mendoza, E., Cuadrado, W., Yallico, L., Zárate, R., Quispe-Melgar, H. R., Limaymanta, C. H., Sarapura, V., & Bao-Cóndor, D. (2021). Heavy metals in soils and edible tissues of Lepidium meyenii (maca) and health risk assessment in areas influenced by mining activity in the Central region of Peru. *Toxicology Reports, 8*, 1461–1470. https://doi.org/10.1016/j.toxrep.2021.07.016

Osinowo, O. O. (2016). Water quality assessment of the Asata River catchment area in Enugu Metropolis Southeast Nigeria. *Journal of African Earth Sciences, 121*, 247–254. https://doi.org/10.1016/j.jafrearsci.2016.06.009

Pal, S., Patel, N., Malik, A., Sharma, A., Pal, U., Rosin, K. G., & Singh, D. K. (2023). Eco-friendly treatment of wastewater and its impact on soil and vegetables using flood and micro-irrigation. *Agricultural Water Management, 275*, 108025. https://doi.org/10.1016/j.agwat.2022.108025

Parizanganeh, A., Hajisoltani, P., & Zamani, A. (2010). Assessment of heavy metal pollution in surficial soils surrounding Zinc Industrial Complex in Zanjan-Iran. *Procedia Environmental Sciences, 2*, 162–166. https://doi.org/10.1016/j.proenv.2010.10.019

Pérez-Vázquez, F. J., González-Martell, A. D., Fernández-Macias, J. C., Rocha-Amador, D. O., González-Palomo, A. K., Ilizaliturri-Hernández, C. A., González-Mille, D. J., & Cilia-Lopez, V. G. (2021). Health risk assessment in children living in an urban area with hydrofluorosis: San Luis Potosí Mexico case study. *Journal of Trace Elements in Medicine and Biology., 68*, 126863. https://doi.org/10.1016/j.jtemb.2021.126863

Perosa, F., Seitz, L. F., Zingraff-Hamed, A., & Disse, M. (2022). Flood risk management along German rivers – A review of multi-criteria analysis methods and decision-support systems. *Environmental Science & Policy, 135*, 191–206. https://doi.org/10.1016/j.envsci.2022.05.004

Peter, A. E., Shiva Nagendra, S. M., & Nambi, I. M. (2018). Comprehensive analysis of inhalable toxic particulate emissions from an old municipal solid waste dumpsite and neighborhood health risks. *Atmospheric Pollution Research, 9*, 1021–1031. https://doi.org/10.1016/j.apr.2018.03.006

Pfitzner, K., Bartolo, R., Whiteside, T., Loewensteiner, D., & Esparon, A. (2022). International Journal of Applied Earth Observations and Geoinformation Multi-temporal spectral reflectance of tropical savanna understorey species and implications for hyperspectral remote sensing. *International Journal of Applied Earth Observation and Geoinformation, 112*, 102870. https://doi.org/10.1016/j.jag.2022.102870

Piai, K. de A., Olympio, K. P. K. (2023). Children's blood lead levels in Latin America and the Caribbean – Recommendations to combat this well-known persistent public health problem. *Current Opinion in Environmental Science & Health*, 32, 100454. https://doi.org/10.1016/j.coesh.2023.100454

Pradhan, S. K., Singh, N. R., Kumar, U., Mishra, S. R., Perumal, R. C., Benny, J., & Thatoi, H. (2020). Illumina MiSeq based assessment of bacterial community structure and diversity along the heavy metal concentration gradient in Sukinda chromite mine area soils India. *Ecological Genetics and Genomics, 15*, 100054. https://doi.org/10.1016/j.egg.2020.100054

Prasad, P. S., & Ramana, G. V. (2016). Imperial smelting furnace (zinc) slag as a structural fill in reinforced soil structures. *Geotext. Geomembranes, 44*, 406–428. https://doi.org/10.1016/j.geotexmem.2016.01.009

Qin, S., Liu, H., Nie, Z., Rengel, Z., Gao, W., Li, C., & Zhao, P. (2020). Toxicity of cadmium and its competition with mineral nutrients for uptake by plants: A review. *Pedosphere, 30*, 168–180. https://doi.org/10.1016/S1002-0160(20)60002-9

Qin, H., Tao, Y., Niu, R., Han, B., & Qiao, L. (2023). Flower-like mesoporous Fe3O4@SiO2@F/NiO composites for magnetic solid-phase extraction of imidazole fungicides in tap water, milk and green tea. *Microchemical Journal, 185*, 108292. https://doi.org/10.1016/j.microc.2022.108292

Qu, M., Guang, X., Liu, H., Zhao, Y., & Huang, B. (2022). Additional sampling using in-situ portable X-ray fluorescence (PXRF) for rapid and high-precision investigation of soil heavy metals at a regional scale. *Environmental Pollution, 292*, 118324. https://doi.org/10.1016/j.envpol.2021.118324

Rainey, W., McHale, M., & Arabi, M. (2022). Characterization of co-benefits of green stormwater infrastructure across ecohydrologic regions in the United States. *Urban for Urban Green., 70*, 127514. https://doi.org/10.1016/j.ufug.2022.127514

Rajkumar, M., Sandhya, S., Prasad, M. N. V., & Freitas, H. (2012). Perspectives of plant-associated microbes in heavy metal phytoremediation. *Biotechnology Advances, 30*, 1562–1574. https://doi.org/10.1016/j.biotechadv.2012.04.011

Ramazanova, E., Lee, S. H., & Lee, W. (2021). Stochastic risk assessment of urban soils contaminated by heavy metals in Kazakhstan. *Science of the Total Environment, 750*, 141535. https://doi.org/10.1016/j.scitotenv.2020.141535

Rana, N. M., Ghahramani, N., Evans, S. G., Small, A., Skermer, N., McDougall, S., & Take, W. A. (2022). Global magnitude-frequency statistics of the failures and impacts of large water-retention dams and mine tailings impoundments. *Earth-Science Rev., 232*, 104144. https://doi.org/10.1016/j.earscirev.2022.104144

Rate, A. W., & McGrath, G. S. (2022). Data for assessment of sediment, soil, and water quality at Ashfield flats reserve Western Australia. *Data Brief, 41*, 107970. https://doi.org/10.1016/j.dib.2022.107970

Rathika, R., Srinivasan, P., Alkahtani, J., Al-Humaid, L. A., Alwahibi, M. S., Mythili, R., & Selvankumar, T. (2021). Influence of biochar and EDTA on enhanced phytoremediation of lead contaminated soil by Brassica juncea. *Chemosphere, 271*, 129513. https://doi.org/10.1016/j.chemosphere.2020.129513

Rebello, S., Anoopkumar, A. N., Aneesh, E. M., Sindhu, R., Binod, P., Kim, S. H., & Pandey, A. (2020). Hazardous minerals mining: Challenges and solutions. *Journal of Hazardous Materials., 402*, 123474. https://doi.org/10.1016/j.jhazmat.2020.123474

Reddy, S., & Osborne, W. J. (2020). Heavy metal determination and aquatic toxicity evaluation of textile dyes and effluents using Artemia salina. *Biocatalysis and Agricultural Biotechnology, 25*, 101574. https://doi.org/10.1016/j.bcab.2020.101574

Richardson, J. B., Donaldson, E. C., Kaste, J. M., & Friedland, A. J. (2015). Forest floor lead, copper and zinc concentrations across the northeastern United States: Synthesizing spatial and temporal responses. *Science of the Total Environment, 505*, 851–859. https://doi.org/10.1016/j.scitotenv.2014.10.023

Ringwald, P., Chapin, C., Iceman, C., Tighe, M. E., Sisk, M., Peaslee, G. F., Peller, J., & Wells, E. M. (2021). Characterization and within-site variation of environmental metal concentrations around a contaminated site using a community-engaged approach. *Chemosphere, 272*, 129915. https://doi.org/10.1016/j.chemosphere.2021.129915

Rojas-Rueda, D., Alsufyani, W., Herbst, C., AlBalawi, S., Alsukait, R., & Alomran, M. (2021). Ambient particulate matter burden of disease in the Kingdom of Saudi Arabia. *Environmental Research, 197*, 111036. https://doi.org/10.1016/j.envres.2021.111036

Rosas, S., Fontboté, L., & Tankard, A. (2007). Tectonic evolution and paleogeography of the Mesozoic Pucará Basin, central Peru. *Journal of South American Earth Sciences, 24*, 1–24. https://doi.org/10.1016/j.jsames.2007.03.002

Ros-Tonen, M. A. F., Aggrey, J. J., Somuah, D. P., & Derkyi, M. (2021). Human insecurities in gold mining: A systematic review of evidence from Ghana. *The Extractive Industries and Society, 8*, 100951. https://doi.org/10.1016/j.exis.2021.100951

Różański, S. Ł., Castejón, J. M. P., & McGahan, D. G. (2021). Child risk assessment of selected metal(loid)s from urban soils using in vitro UBM procedure. *Ecological Indicators., 127*, 107726. https://doi.org/10.1016/j.ecolind.2021.107726

Rueda-Avellaneda, J. F., Rivas-García, P., Gomez-Gonzalez, R., Benitez-Bravo, R., Botello-Álvarez, J. E., & Tututi-Avila, S. (2021). Current and prospective situation of municipal solid waste final disposal in Mexico: A spatio-temporal evaluation. *Renewable and Sustainable Energy Transition, 1*, 100007. https://doi.org/10.1016/j.rset.2021.100007

Sagan, V., Pasken, R., Zarauz, J., & Krotkov, N. (2018). SO2 trajectories in a complex terrain environment using CALPUFF dispersion model, OMI and MODIS data. *International Journal of Applied Earth Observation and Geoinformation, 69*, 99–109. https://doi.org/10.1016/j.jag.2018.03.003

Sakaa, B., Elbeltagi, A., Boudibi, S., Chaffaï, H., Islam, A. R. M. T., Kulimushi, L. C., Choudhari, P., Hani, A., Brouziyne, Y., & Wong, Y. J. (2022). Water quality index modeling using random forest and improved SMO algorithm for support vector machine in Saf-Saf river basin. *Environmental Science and Pollution Research, 29*, 48491–48508. https://doi.org/10.1007/s11356-022-18644-x

Samson, R., Rajput, V., Yadav, R., Shah, M., & Dastager, S. (2023). Science of the Total Environment Spatio-temporal variation of the microbiome and resistome repertoire along an anthropogenically dynamic segment of the Ganges River India. *Science of the Total Environment, 872*, 162125. https://doi.org/10.1016/j.scitotenv.2023.162125

Sanga, T. R., Maseka, K. K., Ponraj, M., Tungaraza, C., Mng'ong'o, M. E., & Mwakalapa, E. B. (2023). Accumulation and distribution of mercury in agricultural soils, food crops and associated health risks: A case study of Shenda gold mine-Geita Tanzania. *Environmental Challenges, 11*, 100697. https://doi.org/10.1016/j.envc.2023.100697

Sapkota, B., Verbuyst, B., Bain, J., Ptacek, C., Blowes, D., & Al, T. (2023). Geochemical and mineralogical investigation of cemented crusts in the tailings cover at Long Lake Gold Mine, Sudbury Canada. *Journal of Hazardous Materials, 451*, 131192. https://doi.org/10.1016/j.jhazmat.2023.131192

Schmitt, C. J., Brumbaugh, W. G., & May, T. W. (2007). Accumulation of metals in fish from lead-zinc mining areas of southeastern Missouri USA. *Ecotoxicology and Environmental Safety, 67*, 14–30. https://doi.org/10.1016/j.ecoenv.2006.11.002

Schulte, P., Hamacher, H., Lehmkuhl, F., & Esser, V. (2022). Initial soil formation in an artificial river valley - Interplay of anthropogenic landscape shaping and fluvial dynamics. *Geomorphology, 398*, 108064. https://doi.org/10.1016/j.geomorph.2021.108064

Schwanke, A. J., Silveira, D. R., SaorinPuton, B. M., Cansian, R. L., & Bernardo-Gusmão, K. (2022). Sustainable conversion of Brazilian Amazon kaolin mining waste to zinc-based Linde Type A zeolites with antibacterial activity. *Journal of Cleaner Production., 338*, 130659. https://doi.org/10.1016/j.jclepro.2022.130659

Scullett-Dean, G., Stockwell, K., Myers, L., Nyeboer, H., Moreira-Grez, B., & Santini, T. C. (2023). Coupling microbial and abiotic amendments accelerates in situ remediation of bauxite residue at field scale. *Science of the Total Environment, 877*, 162699. https://doi.org/10.1016/j.scitotenv.2023.162699

Setia, R., Dhaliwal, S. S., Singh, R., Singh, B., Kukal, S. S., & Pateriya, B. (2023). Ecological and human health risk assessment of metals in soils and wheat along Sutlej river (India). *Chemosphere, 312*, 137331. https://doi.org/10.1016/j.chemosphere.2022.137331

Shanmugasundaram, V., & Shanmugam, B. (2023). Application of cement treated magnesite mine tailings as subgrade. *Construction and Building Materials, 365*, 130064. https://doi.org/10.1016/j.conbuildmat.2022.130064

Shi, T., Ma, J., Zhang, Y., Liu, C., Hu, Y., Gong, Y., Wu, X., Ju, T., Hou, H., & Zhao, L. (2019). Status of lead accumulation in agricultural soils across China (1979–2016). *Environment International, 129*, 35–41. https://doi.org/10.1016/j.envint.2019.05.025

Shotyk, W., Rausch, N., Outridge, P. M., & Krachler, M. (2016). Isotopic evolution of atmospheric Pb from metallurgical processing in Flin Flon, Manitoba: Retrospective analysis using peat cores from bogs. *Environmental Pollution, 218*, 338–348. https://doi.org/10.1016/j.envpol.2016.07.009

Shukla, B. K., Gupta, A., Sharma, P. K., & Bhowmik, A. R. (2020). Pollution status and water quality assessment in pre-monsoon season: A case study of rural villages in Allahabad district, Uttar Pradesh India. *Materials Today: Proceedings, 32*, 824–830. https://doi.org/10.1016/j.matpr.2020.03.823

Shukla, M., Baksi, B., Mohanty, S. P., Mahanty, B., Mansi, A., Rene, E. R., & Behera, S. K. (2022). Remediation of chromium contaminated soil by soil washing using EDTA and N-acetyl-L-cysteine as the chelating agents. *Progress in Organic Coatings, 165*, 106704. https://doi.org/10.1016/j.porgcoat.2022.106704

Simmatis, B., Rühland, K. M., Evans, M., Meyer-Jacob, C., Kirk, J., Muir, D. C. G., & Smol, J. P. (2022). Metal contamination in alkaline Phantom Lake (Flin Flon, Manitoba, Canada) generates strong responses in multiple paleolimnological proxies. *Science of The Total Environment., 811*, 152299. https://doi.org/10.1016/j.scitotenv.2021.152299

Singh, S., Saxena, R., Pandey, K., Bhatt, K., & Sinha, S. (2004). Response of antioxidants in sunflower (Helianthus annuus L.) grown on different amendments of tannery sludge: Its metal accumulation potential. *Chemosphere, 57*, 1663–1673. https://doi.org/10.1016/j.chemosphere.2004.07.049

Singh, K. K., Tewari, G., Kumar, S., Busa, R., Chaturvedi, A., Rathore, S. S., Singh, R. K., & Gangwar, A. (2023). Understanding urban groundwater pollution in the Upper Gangetic Alluvial Plains of northern India with multiple industries and their impact on drinking water quality and associated health risks. *Groundwater for Sustainable Development, 21*, 100902. https://doi.org/10.1016/j.gsd.2023.100902

Siyar, R., Doulati Ardejani, F., Farahbakhsh, M., Norouzi, P., Yavarzadeh, M., & Maghsoudy, S. (2020). Potential of Vetiver grass for the phytoremediation of a real multi-contaminated soil, assisted by electrokinetic. *Chemosphere, 246*, 125802. https://doi.org/10.1016/j.chemosphere.2019.125802

Smuda, J., Dold, B., Friese, K., Morgenstern, P., & Glaesser, W. (2007). Mineralogical and geochemical study of element mobility at the sulfide-rich Excelsior waste rock dump from the polymetallic Zn-Pb-(Ag-Bi-Cu) deposit, Cerro de Pasco Peru. *Journal of Geochemical Exploration, 92*, 97–110. https://doi.org/10.1016/j.gexplo.2006.08.001

Soltani, N., Keshavarzi, B., Moore, F., Sorooshian, A., & Ahmadi, M. R. (2017). Distribution of potentially toxic elements (PTEs) in tailings, soils, and plants around Gol-E-Gohar iron mine, a case study in Iran. *Environmental Science and Pollution Research, 24*, 18798–18816. https://doi.org/10.1007/s11356-017-9342-5

Song, B., Zeng, G., Gong, J., Liang, J., Xu, P., Liu, Z., Zhang, Y., Zhang, C., Cheng, M., Liu, Y., Ye, S., Yi, H., & Ren, X. (2017). Evaluation methods for assessing effectiveness of in situ remediation of soil and sediment contaminated with organic pollutants and heavy metals. *Environment International, 105*, 43–55. https://doi.org/10.1016/j.envint.2017.05.001

Soni, A., Das, P. K., Hashmi, A. W., Yusuf, M., Kamyab, H., & Chelliapan, S. (2022). Challenges and opportunities of utilizing municipal solid waste as alternative building materials for sustainable development goals: A review. *Sustainable Chemistry and Pharmacy, 27*, 100706. https://doi.org/10.1016/j.scp.2022.100706

Soodan, R. K., Pakade, Y. B., Nagpal, A., & Katnoria, J. K. (2014). Analytical techniques for estimation of heavy metals in soil ecosystem: A tabulated review. *Talanta, 125*, 405–410. https://doi.org/10.1016/j.talanta.2014.02.033

Soufi, A., Hajjaoui, H., Elmoubarki, R., Abdennouri, M., Qourzal, S., & Barka, N. (2021). Spinel ferrites nanoparticles: Synthesis methods and application in heterogeneous Fenton oxidation of organic pollutants – A review. *Applied Surface Science Advances, 6*, 100145. https://doi.org/10.1016/j.apsadv.2021.100145

Steingräber, L. F., Ludolphy, C., Metz, J., Kierdorf, H., & Kierdorf, U. (2022). Uptake of lead and zinc from soil by blackberry plants (Rubus fruticosus L agg) and translocation from roots to leaves. *Environmental Advances., 9*, 100313. https://doi.org/10.1016/j.envadv.2022.100313

Steliga, T., & Kluk, D. (2020). Application of Festuca arundinacea in phytoremediation of soils contaminated with Pb, Ni, Cd and petroleum hydrocarbons. *Ecotoxicology and Environmental Safety, 194*, 110409. https://doi.org/10.1016/j.ecoenv.2020.110409

Stoneham, M., Edmunds, M., & Pollard, C. (2021). Local governments' decade of organisational change to promote child health and wellbeing: A Western Australian qualitative study. *Australian and New Zealand Journal of Public Health, 45*, 355–363. https://doi.org/10.1111/1753-6405.13128

Suer, J., Traverso, M., & Ahrenhold, F. (2021). Carbon footprint of scenarios towards climate-neutral steel according to ISO 14067. *Journal of Cleaner Production, 318*, 128588. https://doi.org/10.1016/j.jclepro.2021.128588

Sun, F., Dai, Y., & Yu, X. (2017). Air pollution, food production and food security: A review from the perspective of food system. *Journal of Integrative Agriculture., 16*, 2945–2962. https://doi.org/10.1016/S2095-3119(17)61814-8

Tale E., Pa, J., Wilke, F. D. H., Oroji, A., Andronikova, I. (2023). Source of gold and ore-forming processes in the Zarshuran gold deposit , NW Iran : Insights from in situ elemental and sulfur isotopic compositions of pyrite ,

fluid inclusions , and O − H isotopes 156. https://doi.org/10.1016/j.oregeorev.2023.105382
Tang, C., Chen, Y., Zhang, Q., Li, J., Zhang, F., & Liu, Z. (2019). Effects of peat on plant growth and lead and zinc phytostabilization from lead-zinc mine tailing in southern China: Screening plant species resisting and accumulating metals. *Ecotoxicology and Environmental Safety, 176*, 42–49. https://doi.org/10.1016/j.ecoenv.2019.03.078
Thatikayala, D., Noori, M. T., & Min, B. (2023). Zeolite-modified electrodes for electrochemical sensing of heavy metal ions – Progress and future directions. *Materials Today Chemistry, 29*, 101412. https://doi.org/10.1016/j.mtchem.2023.101412
Thummala, H., Venkata Raju, N., Manasa, B., Paritala, V., Srikanth, K., Nutalapati, V. (2022). Sublethal effects of zinc oxide nanoparticles induced toxicity and oxidative stress in Pila virens: A validation of homology modelling and docking. Materials Science and Engineering: B Solid-State Mater. *Advance Technology. 283*, 115842. https://doi.org/10.1016/j.mseb.2022.115842
Tian, X., Gong, Y., Wu, Y., Agyeiwaa, A., & Zuo, T. (2014). Management of used lead acid battery in China: Secondary lead industry progress, policies and problems. *Resources, Conservation and Recycling, 93*, 75–84. https://doi.org/10.1016/j.resconrec.2014.10.008
Tibane, L. V., & Mamba, D. (2022). Ecological risk of trace metals in soil from gold mining region in South Africa. *Journal of Hazardous Materials Advances, 7*, 100118. https://doi.org/10.1016/j.hazadv.2022.100118
Timalsina, H., Gyawali, T., Ghimire, S., & Paudel, S. R. (2022). Potential application of enhanced phytoremediation for heavy metals treatment in Nepal. *Chemosphere, 306*, 135581. https://doi.org/10.1016/j.chemosphere.2022.135581
Trannum, H. C., Pedersen, K. B., Renaud, P. E., Christensen, G. N., & Evenset, A. (2023). Recolonization and recovery of an Arctic benthic community subject to mine-tailings deposits. *Journal of Sea Research, 191*, 102327. https://doi.org/10.1016/j.seares.2022.102327
Tyagi, N., Upadhyay, M. K., Majumdar, A., Pathak, S. K., Giri, B., Jaiswal, M. K., & Srivastava, S. (2022). An assessment of various potentially toxic elements and associated health risks in agricultural soil along the middle Gangetic basin India. *Chemosphere, 300*, 134433. https://doi.org/10.1016/j.chemosphere.2022.134433
Usman, Q. A., Muhammad, S., Ali, W., Yousaf, S., & Jadoon, I. A. K. (2021). Spatial distribution and provenance of heavy metal contamination in the sediments of the Indus River and its tributaries, North Pakistan: Evaluation of pollution and potential risks. *Environmental Technology and Innovation, 21*, 101184. https://doi.org/10.1016/j.eti.2020.101184
Usman, M., Zia-ur-Rehman, M., Rizwan, M., Abbas, T., Ayub, M. A., Naeem, A., Alharby, H. F., Alabdallah, N. M., Alharbi, B. M., Qamar, M. J., & Ali, S. (2023). Effect of soil texture and zinc oxide nanoparticles on growth and accumulation of cadmium by wheat: A life cycle study. *Environmental Research, 216*, 114397. https://doi.org/10.1016/j.envres.2022.114397
Valenta, R. K., Lèbre, É., Antonio, C., Franks, D. M., Jokovic, V., Micklethwaite, S., Parbhakar-Fox, A., Runge, K., Savinova, E., Segura-Salazar, J., Stringer, M., Verster, I., & Yahyaei, M. (2023). Decarbonisation to drive dramatic increase in mining waste–Options for reduction. *Resources, Conservation and Recycling., 190*, 106859. https://doi.org/10.1016/j.resconrec.2022.106859
Vargas-Solano, S. V., Rodríguez-González, F., Martínez-Velarde, R., Morales-García, S. S., & Jonathan, M. P. (2022). Removal of heavy metals present in water from the Yautepec River Morelos México, using Opuntia ficus-indica mucilage. *Environmental Advances., 7*, 100160. https://doi.org/10.1016/j.envadv.2021.100160
Vodyanitskii, Y., Minkina, T., & Zamulina, I. (2020). Methodological aspects in the analysis of the content of mobile compounds of heavy metals in hydromorphic soils. *Appllied Geochemistry, 113*, 104493. https://doi.org/10.1016/j.apgeochem.2019.104493
von Osten, J. R., Benítez-Torres, J. A., Rojas-González, R. I., Morgado, F., & Borges-Ramírez, M. M. (2023). Microplastics in sediments from the southern Gulf of Mexico: Abundance, distribution, composition, and adhered pollutants. *Science of the Total Environment., 873*, 162290. https://doi.org/10.1016/j.scitotenv.2023.162290
Walls, D., Kinchy, A., Margalit, T., Ramírez-Andreotta, M. D., & Engel-Di Mauro, S. (2022). Confronting legacy lead in soils in the United States: Community-engaged researchers doing undone science. *Environmental Science & Policy, 128*, 165–174. https://doi.org/10.1016/j.envsci.2021.10.035
Walton-Day, K., & Mills, T. J. (2015). Hydrogeochemical effects of a bulkhead in the Dinero mine tunnel, Sugar Loaf mining district, near Leadville Colorado. *Applied Geochemistry, 62*, 61–74. https://doi.org/10.1016/j.apgeochem.2015.03.002
Wang, L., Lin, H., Dong, Y., He, Y., & Liu, C. (2018). Isolation of vanadium-resistance endophytic bacterium PRE01 from Pteris vittata in stone coal smelting district and characterization for potential use in phytoremediation. *Journal of Hazardous Materials, 341*, 1–9. https://doi.org/10.1016/j.jhazmat.2017.07.036
Wang, P., Yao, J., Wang, G., Hao, F., Shrestha, S., Xue, B., Xie, G., & Peng, Y. (2019). Exploring the application of artificial intelligence technology for identification of water pollution characteristics and tracing the source of water quality pollutants. *Science of the Total Environment, 693*, 133440. https://doi.org/10.1016/j.scitotenv.2019.07.246
Wang, Y., Duan, X., & Wang, L. (2020). Spatial distribution and source analysis of heavy metals in soils influenced by industrial enterprise distribution: Case study in Jiangsu Province. *Science of the Total Environment, 710*, 134953. https://doi.org/10.1016/j.scitotenv.2019.134953
Wang, Z., Shen, R., Ji, S., Xie, L., & Zhang, H. (2021). Effects of biochar derived from sewage sludge and sewage sludge/cotton stalks on the immobilization and phytoavailability of Pb, Cu, and Zn in sandy loam soil. *Journal of Hazardous Materials, 419*, 126468. https://doi.org/10.1016/j.jhazmat.2021.126468
Wang, J., Zhen, J., Hu, W., Chen, S., Lizaga, I., Zeraatpisheh, M., & Yang, X. (2023). International soil and water conservation research remote sensing of soil degradation : Progress and perspective. *International Soil and Water Conservation Research*. https://doi.org/10.1016/j.iswcr.2023.03.002

Wang, M., Wang, C., Ruan, J., Liu, W., Huang, Z., Chen, M., & Ni, B. (2023b). Pollution level mapping of heavy metal in soil for ground-airborne hyperspectral data with support vector machine and deep neural network : A case study of Southwestern Xiong ' an, China ☆. *Environmental Pollution, 321*, 121132. https://doi.org/10.1016/j.envpol.2023.121132

Wang, Y., Jiang, S., Huang, L., Lu, G., Kasemsan, M., Yaluk, E. A., Liu, H., Liao, J., Bian, J., Zhang, K., Chen, H., & Li, L. (2023). Differences between VOCs and NOx transport contributions, their impacts on O3, and implications for O3 pollution mitigation based on CMAQ simulation over the Yangtze River Delta, China. *Science of The Total Environment, 872*, 162118. https://doi.org/10.1016/j.scitotenv.2023.162118

Wang, Z., Chen, Z., & An, C. (2023d). A review on solid waste management in Canadian First Nations communities: Policy, practices, and challenges. *Cleaner Waste Systems, 4*, 100074. https://doi.org/10.1016/j.clwas.2022.100074

Wei, M., Wang, X., Zhou, K., & Yang, R. (2023). Binary adsorption and migration simulation of levofloxacin with zinc at concentrations simulating wastewater on silty clay and the potential environmental risk in groundwater. *Chemosphere, 311*, 136878. https://doi.org/10.1016/j.chemosphere.2022.136878

Wen, L., & Li, X. Y. (2022). Production of intracellular lipids from thermally hydrolyzed waste sludge by oleaginous yeast for energy and resource recovery. *Energy Conversion and Management, 252*, 115129. https://doi.org/10.1016/j.enconman.2021.115129

Wilder, S. M., & Simpson, S. J. (2022). A vertebrate, the fence skink, is a common but relatively low-quality prey for an invertebrate predator, the redback spider. *Food Webs, 32*, e00236. https://doi.org/10.1016/j.fooweb.2022.e00236

Wolkersdorfer, C., & Mugova, E. (2022). *Effects of Mining on Surface Water* (2nd ed.). Elsevier Inc. https://doi.org/10.1016/b978-0-12-819166-8.00036-0

Wong, Y. J., Arumugasamy, S. K., Chung, C. H., Selvarajoo, A., & Sethu, V. (2020a). Comparative study of artificial neural network (ANN), adaptive neuro-fuzzy inference system (ANFIS) and multiple linear regression (MLR) for modeling of Cu (II) adsorption from aqueous solution using biochar derived from rambutan (Nephelium lappaceum) pee. *Environmental Monitoring and Assessment, 192*, 439. https://doi.org/10.1007/s10661-020-08268-4

Wong, Y. J., Shimizu, Y., He, K., & Nik Sulaiman, N. M. (2020b). Comparison among different ASEAN water quality indices for the assessment of the spatial variation of surface water quality in the Selangor river basin Malaysia. *Environmental Monitoring and Assessment, 192*, 644. https://doi.org/10.1007/s10661-020-08543-4

Wong, Y. J., Shimizu, Y., Kamiya, A., Maneechot, L., Bharambe, K. P., Fong, C. S., & Nik Sulaiman, N. M. (2021). Application of artificial intelligence methods for monsoonal river classification in Selangor river basin Malaysia. *Environmental Monitoring and Assessment, 193*, 438. https://doi.org/10.1007/s10661-021-09202-y

Wong, Y. J., Shiu, H.-Y., Chang, J.H.-H., Ooi, M. C. G., Li, H.-H., Homma, R., Shimizu, Y., Chiueh, P.-T., Maneechot, L., & Nik Sulaiman, N. M. (2022). Spatiotemporal impact of COVID-19 on Taiwan air quality in the absence of a lockdown: Influence of urban public transportation use and meteorological conditions. *Journal of Cleaner Production, 365*, 132893. https://doi.org/10.1016/j.jclepro.2022.132893

Wong, Y. J., Yeganeh, A., Chia, M. Y., Shiu, H. Y., Ooi, M. C. G., Chang, J. H. W., Shimizu, Y., Ryosuke, H., Try, S., & Elbeltagi, A. (2023). Quantification of COVID-19 impacts on NO2 and O3: Systematic model selection and hyperparameter optimization on AI-based meteorological-normalization methods. *Atmospheric Environment, 301*, 119677. https://doi.org/10.1016/j.atmosenv.2023.119677

Wu, W., Liu, Y., Rogers, B. M., Xu, W., Dong, Y., & Lu, W. (2022). International Journal of Applied Earth Observations and Geoinformation Monitoring gas flaring in Texas using time-series sentinel-2 MSI and landsat-8 OLI images. *International Journal of Applied Earth Observation and Geoinformation, 114*, 103075. https://doi.org/10.1016/j.jag.2022.103075

Wu, W., Li, S., Xie, P., Li, X., Chang, H., & Ho, S. H. (2023). Algal-fungal interactions and biomass production in wastewater treatment: Current status and future perspectives. *Algal Research, 70*, 103021. https://doi.org/10.1016/j.algal.2023.103021

Xi, L., Shen, Y. Q., Zhao, X., Zhou, M., Mi, Y. D., Li, X. R., Chen, H. Y., Wei, Y., Su, H. L., & Hou, H. (2022). Effects of arbuscular mycorrhizal fungi on frond antimony enrichment, morphology and proteomics in Pteris cretica var nervosa during antimony phytoremediation. *Science of The Total Environment., 804*, 149904. https://doi.org/10.1016/j.scitotenv.2021.149904

Xiao, H., Shahab, A., Li, J., Xi, B., Sun, X., He, H., & Yu, G. (2019). Distribution, ecological risk assessment and source identification of heavy metals in surface sediments of Huixian karst wetland China. *Ecotoxicology and Environmental Safety, 185*, 109700. https://doi.org/10.1016/j.ecoenv.2019.109700

Xiao, B., Jia, J., Wang, W., Zhang, B., Ming, H., Ma, S., Kang, Y., & Zhao, M. (2023). A review on magnetic biochar for the removal of heavy metals from contaminated soils: Preparation, application, and microbial response. *Journal of Hazardous Materials Advances, 10*, 100254. https://doi.org/10.1016/j.hazadv.2023.100254

Xiao, C., Guo, S., Wang, Q., Chi, R., 2021. Enhanced reduction of lead bioavailability in phosphate mining wasteland soil by a phosphate-solubilizing strain of Pseudomonas sp., LA, coupled with ryegrass (Lolium perenne L.) and sonchus (Sonchus oleraceus L.). Environ. Pollut. 274, 116572. https://doi.org/10.1016/j.envpol.2021.116572

Xie, N., Chen, Z., Wang, H., & You, C. (2021). Activated carbon coupled with citric acid in enhancing the remediation of Pb-Contaminated soil by electrokinetic method. *Journal of Cleaner Production, 308*, 127433. https://doi.org/10.1016/j.jclepro.2021.127433

Xu, L., Li, J., Najeeb, U., Li, X., Pan, J., Huang, Q., Zhou, W., & Liang, Z. (2021). Synergistic effects of EDDS and ALA on phytoextraction of cadmium as revealed by biochemical and ultrastructural changes in sunflower (Helianthus annuus L.) tissues. *Journal of Hazardous Materials, 407*, 124764. https://doi.org/10.1016/j.jhazmat.2020.124764

Xu, L., Dai, H., Skuza, L., Xu, J., Shi, J., Wang, Y., Shentu, J., & Wei, S. (2022). Integrated survey on the heavy metal distribution, sources and risk assessment of soil in a commonly developed industrial area. *Ecotoxicology and Environmental Safety, 236*, 113462. https://doi.org/10.1016/j.ecoenv.2022.113462

Yadav, R., Singh, G., Santal, A. R., & Singh, N. P. (2023). Omics approaches in effective selection and generation of potential plants for phytoremediation of heavy metal from contaminated resources. *Journal of Environmental Management, 336*, 117730. https://doi.org/10.1016/j.jenvman.2023.117730

Yamazaki, J., Toyomaki, H., Nakayama, S. M. M., Yabe, J., Muzandu, K., Jelinek, J., Yokoyama, S., Ikenaka, Y., Takiguchi, M., & Ishizuka, M. (2021). Genome-wide DNA methylation analysis of dogs with high lead exposure living near a lead mining area in Kabwe Zambia. *Environmental Pollution, 286*, 117229. https://doi.org/10.1016/j.envpol.2021.117229

Yang, X., & Chen, Q. (2023). Mining violations, rent-seeking, and resource governance in China: Evidence from central environmental protection inspection. *The Extractive Industries and Society, 13*, 101218. https://doi.org/10.1016/j.exis.2023.101218

Yang, T., Zhang, Q., Wan, X., Li, X., Wang, Y., & Wang, W. (2020). Comprehensive ecological risk assessment for semi-arid basin based on conceptual model of risk response and improved TOPSIS model-a case study of Wei River Basin China. *Science of The Total Environment, 719*, 137502. https://doi.org/10.1016/j.scitotenv.2020.137502

Yang, T., Tang, G., Li, L., Ma, L., Zhao, Y., & Guo, Z. (2022a). Interactions between bacteria and eukaryotic microorganisms and their response to soil properties and heavy metal exchangeability nearby a coal-fired power plant. *Chemosphere, 302*, 134829. https://doi.org/10.1016/j.chemosphere.2022.134829

Yang, T., Xue, Y., Liu, X., & Zhang, Z. (2022b). Solidification/stabilization and separation/extraction treatments of environmental hazardous components in electrolytic manganese residue: A review. *Process Safety and Environment Protection, 157*, 509–526. https://doi.org/10.1016/j.psep.2021.10.031

Yang, Z., Yu, X., Dedman, S., Rosso, M., Zhu, J., & Yang, J. (2022c). Science of the total environment UAV remote sensing applications in marine monitoring : Knowledge visualization and review. *Science of the Total Environment, 838*, 155939. https://doi.org/10.1016/j.scitotenv.2022.155939

Yang, L., Jin, X., Lin, Q., Owens, G., & Chen, Z. (2023). Enhanced adsorption and reduction of Pb(II) and Zn(II) from mining wastewater by carbon@nano-zero-valent iron (C@nZVI) derived from biosynthesis. *Separation and Purification Technology, 311*, 123249. https://doi.org/10.1016/j.seppur.2023.123249

Yotova, G., Zlateva, B., Ganeva, S., Simeonov, V., Kudłak, B., Namieśnik, J., & Tsakovski, S. (2018). Phytoavailability of potentially toxic elements from industrially contaminated soils to wild grass. *Ecotoxicology and Environmental Safety, 164*, 317–324. https://doi.org/10.1016/j.ecoenv.2018.07.077

Yu, H., Lu, X., Miki, T., Matsubae, K., Sasaki, Y., & Nagasaka, T. (2022). Sustainable phosphorus supply by phosphorus recovery from steelmaking slag: A critical review. *Resources, Conservation and Recycling, 180*, 106203. https://doi.org/10.1016/j.resconrec.2022.106203

Yu, H., Zahidi, I., & Liang, D. (2023a). Spatiotemporal variation of vegetation cover in mining areas of Dexing City China. *Environmental Research, 225*, 115634. https://doi.org/10.1016/j.envres.2023.115634

Yu, P., Han, Y., Wang, M., Zhu, Z., Tong, Z., Shao, X. Y., Peng, J., Hamid, Y., Yang, X., Deng, Y., & Huang, Y. (2023b). Heavy metal content and health risk assessment of atmospheric particles in China: A meta-analysis. *Science of the Total Environment, 867*, 161556. https://doi.org/10.1016/j.scitotenv.2023.161556

Zacharopoulos, L., Thonemann, N., Dumeier, M., & Geldermann, J. (2023). Environmental optimization of the charge of battery electric vehicles. *Applied Energy, 329*, 120259. https://doi.org/10.1016/j.apenergy.2022.120259

Zerin, I., Farzana, N., Sayem, A. S. M., Anang, D. M., & Haider, J. (2020). Potentials of Natural Dyes for Textile Applications. *Encyclopedia of Renewable and Sustainable Materials, 2*, 873–883. https://doi.org/10.1016/b978-0-12-803581-8.11668-6

Zhan, H. Y., Jiang, Y. F., Yuan, J., Hu, X. F., Nartey, O. D., & Wang, B. L. (2014). Trace metal pollution in soil and wild plants from lead-zinc smelting areas in Huixian County Northwest China. *Journal of Geochemical Exploration, 147*, 182–188. https://doi.org/10.1016/j.gexplo.2014.10.007

Zhan, X., Wang, Y., Wang, L., Li, C., Xu, X., & Deng, R. (2023). Migration, solidification/stabilization mechanism of heavy metal in lightweight ceramisite from co-sintering fly ash and electrolytic manganese residue. *Process Safety and Environment Protection, 173*, 485–494. https://doi.org/10.1016/j.psep.2023.03.047

Zhang, K., Chai, F., Zheng, Z., Yang, Q., Zhong, X., Fomba, K. W., & Zhou, G. (2018). Size distribution and source of heavy metals in particulate matter on the lead and zinc smelting affected area. *Journal of Environmental Sciences (china), 71*, 188–196. https://doi.org/10.1016/j.jes.2018.04.018

Zhang, Y., McDermott, S., Davis, B., & Hussey, J. (2020). High incidence of brain and other nervous system cancer identified in two mining counties, 2001–2015. *Spatial and Spatio-temporal Epidemiology, 32*, 100320. https://doi.org/10.1016/j.sste.2019.100320

Zhang, Y., Wang, L., Chen, L., Ma, B., Zhang, Y., Ni, W., & Tsang, D. C. W. (2021b). Treatment of municipal solid waste incineration fly ash: State-of-the-art technologies and future perspectives. *Journal of Hazardous Materials, 411*, 125132. https://doi.org/10.1016/j.jhazmat.2021.125132

Zhang, H., Li, S., Lv, Z., He, J., Fan, Y., & Song, J. (2023a). The role of zinc sulfide in the electrochemical extraction of molybdenum. *Separation and Purification Technology, 311*, 123290. https://doi.org/10.1016/j.seppur.2023.123290

Zhang, Y., Song, B., & Zhou, Z. (2023b). Pollution assessment and source apportionment of heavy metals in soil from lead – Zinc mining areas of south China. *Journal* *of Environmental Chemical Engineering, 11*, 109320. https://doi.org/10.1016/j.jece.2023.109320

Zhang, Z., Li, J., Jiang, S., Xu, M., Ma, T., Sun, Z., & Zhang, J. (2023c). Lactobacillus fermentum HNU312 alleviated oxidative damage and behavioural abnormalities during brain development in early life induced by chronic lead exposure. *Ecotoxicology and Environmental Safety, 251*, 114543. https://doi.org/10.1016/j.ecoenv.2023.114543

Zhang, Ying, Zhang, T., Li, H. (2021). Application of laser-induced breakdown spectroscopy (LIBS) in environmental monitoring. Spectrochim. Acta - Part B At. Spectrosc. 181, 106218. https://doi.org/10.1016/j.sab.2021.106218

Zhao, B., Wu, J., Yang, F., Pilz, J., & Zhang, D. (2019). A novel approach for extraction of Gaoshanhe-Group outcrops using Landsat Operational Land Imager (OLI) data in the heavily loess-covered Baoji District Western China. *Ore Geology Reviews, 108*, 88–100. https://doi.org/10.1016/j.oregeorev.2018.01.034

Zheng, J., Noller, B., Huynh, T., Ng, J., Taga, R., Diacomanolis, V., & Harris, H. (2021). How the population in Mount Isa is living with lead exposure from mining activities. *The Extractive Industries and Society, 8*, 123–134. https://doi.org/10.1016/j.exis.2020.11.008

Zhou, Y., Jiang, D., Ding, D., Wu, Y., Wei, J., Kong, L., Long, T., Fan, T., & Deng, S. (2022). Ecological-health risks assessment and source apportionment of heavy metals in agricultural soils around a super-sized lead-zinc smelter with a long production history, in China. *Environmental Pollution, 307*, 119487. https://doi.org/10.1016/j.envpol.2022.119487

Zhu, Y., Yu, X., Pan, S., Nong, P., Kong, Q., Wang, X., Zhang, L., Tan, S., & Zhu, Z. (2022). Dissolution of the smithsonite–rhodochrosite (ZnCO3-MnCO3) solid solutions in aqueous solution at 25 °C. *Chemical Geology., 602*, 120886. https://doi.org/10.1016/j.chemgeo.2022.120886

Zhuk, A. Z., Borzenko, V. I., Buzoverov, E. A., Ivanov, P. P., & Shkolnikov, E. I. (2022). Comparative analysis of hydrogen production technologies: Hydrothermal oxidation of the "carbonless" aluminum and water electrolysis. *Renewable Energy, 197*, 1244–1250. https://doi.org/10.1016/j.renene.2022.08.023

Zia-ur-Rehman, M., Anayatullah, S., Irfan, E., Hussain, S. M., Rizwan, M., Sohail, M. I., Jafir, M., Ahmad, T., Usman, M., & Alharby, H. F. (2023). Nanoparticles assisted regulation of oxidative stress and antioxidant enzyme system in plants under salt stress: A review. *Chemosphere, 314*, 137649. https://doi.org/10.1016/j.chemosphere.2022.137649

Zielinska, M., Zapotoczny, P., Białobrzewski, I., Zuk-Golaszewska, K., & Markowski, M. (2012). Engineering properties of red clover (Trifolium pratense L.) seeds. *Industrial Crops and Products, 37*, 69–75. https://doi.org/10.1016/j.indcrop.2011.12.002

Zierold, K. M., Sears, C. G., Myers, J. V., Brock, G. N., Zhang, C. H., & Sears, L. (2022). Exposure to coal ash and depression in children aged 6–14 years old. *Environmental Research, 214*, 114005. https://doi.org/10.1016/j.envres.2022.114005