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REVIEW PAPER

Occurrence of cadmium in groundwater in China: a review

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Abstract
China has one of the world's fastest-growing economies due to its increase in various industrial activities. A side effect of economic growth is severe environmental problems such as heavy metal contamination of soil and groundwater. Anthropogenic activities are the main sources of cadmium which is highly mobile and toxic with the potential to bioaccumulate in the ecosystem. It can contaminate ground and river water consequently negatively impacting agriculture and water sources. Anthropogenic source of Cd concentrations in China is 0.002 mg/L in drinking water, 0.102 mg/kg in soil, and 0.23–0.96 mg/kg in paddy soil. Geological trends and health implications of cadmium contamination in Human, southern China were analyzed. Source, transportation, and various conventional remediation processes exist today and can be categorized as biological, physical, and chemical. Using nanoparticle technology, it has been found that adsorption capacities can be 3 to 4 times higher compared to using powdered activated carbon. From the experiment carried out, a maximum adsorption capacity of 10.86 mg/g for cadmium was obtained. Cadmium intake in south China populations occurred at an alarming rate and most children were at greater risk of being affected. Therefore, cadmium contamination should be taken seriously by the responsible authorities.

Keywords Cadmium · Contamination · Groundwater · Remediation · Bioaccumulation

Introduction

Water is vital for nearly all living creatures on the earth. Water is necessary for the survival of most living things, including humans. When water becomes contaminated, it has severe impacts on living beings (Maharjan et al. 2021; Ng and Elshikh 2021; Maharjan et al. 2021; Ng and Elshikh 2021). As a result of the rapid development of industry and agricultural operations, vast quantities of organic and inorganic pollutants have been manufactured (Al Farraj et al. 2019; Choong et al. 2021; Hadibarata et al. 2011; Kristanti et al. 2012; Liew et al. 2021; Nazifa et al. 2018).China is the most populous country on the globe and has one of the fastest economic growth rates. A combination of such factors has led to severe negative impacts on the environment and consequently on the general health and wellbeing of its citizens. Among the many environmental problems is the pollution and accumulation of heavy metal substances such as cadmium (Cd), arsenic (As), and lead (Pb) in the soil and groundwater which can pose very serious health risks. Cadmium is a metallic element with an oxidation state of + 2. It occurs naturally in sulfide ores along with lead and zinc. Cadmium is considered a toxic, carcinogenic element that is extremely mobile in the environment (Kubier and Pichler 2019). It can accumulate in organs and thus pose serious health risks to humans (Chen et al. 2018). Cadmium contamination across China has resulted from mainly anthropogenic industrial activities such as mining, smelting, agriculture, sewage irrigation, and waste recycling processes (Zhao et al. 2015). China is a major rice producer; however, it has been estimated that approximately 19.4% of all its agricultural land has been exposed to serious contamination (Chen et al. 2018). Hunan province in southern China is well known for its ferrous mining activities, which coexist with agricultural activities nearby. Significant amounts of cadmium have been detected in river water, soil, and crops. Most of the southern

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population is at high risk of cadmium intake by the direct exposure pathway which includes ingestion of contaminated food. According to the National Food Safety Standards in China, the maximum permitted limit of cadmium in produce is 0.6 mg/kg (Zhai et al. 2008). The main aim of this essay is to discuss the anthropogenic and natural sources of cadmium in southern China mainly over the past three decades since industrialization growth rates increased. Fate and transportation mechanisms, health effects associated with the short-term, and prolonged exposure to cadmium will be examined and mitigation strategies for the remediation of contaminated soil and water. The novelty part of the study is to investigate in detail the current cadmium pollution in China, the sources of these pollutions, the transportation ways of these pollutions, the risks that people who are exposed to this pollution may face, and finally the traditional and advanced technologies for the elimination of this pollution.

The current trend of cadmium pollution in China

According to a related study that collected samples across 19 provinces, the average cadmium concentration in 2015 was 0.45 mg/kg in the soil and 0.087 mg/kg in the samples of polished rice (Mu et al. 2019). It was also discovered that the highest concentration levels of cadmium in rice grains occurred in the south, showing a decreasing trend from south to north (Mu et al. 2019). Southern populations had higher dietary exposure compared to those in the north by a factor of 1.7–1.8 (Song et al. 2017). Mining and smelting are very prominent industrial activities in the south contributing to greater levels of PTE in the nearby soils (Yang et al. 2018). It has been observed that cadmium concentrations decreased further away from the mining sites. The Human province in Southern China has been regarded as one of the main non-ferrous mining regions of the country and is facing a major problem due to heavy metal pollution (J.-q. Chen et al. 2011). The average soil cadmium concentrations increased to 0.11 mg/kg from the background concentration of 0.07 mg/kg (J.-q. Chen et al. 2011). The average input rate was 0.004 mg/kg/year in 2005 and Luo et al. (2009) estimated then that at such a rate it could take less than 50 years to surpass the acceptable concentration limit. The true present-day value is likely to be higher. The Dong River which goes through Chenzhou City in Hunan further facilitates the transportation of cadmium along its bank, possessing a mean concentration of 7.6 mg/kg (Zhai et al. 2008). However, the highest total cadmium concentration of agricultural soil occurred in the northeast, likely due to other anthropogenic sources such as sewage irrigation and heavy fertilizer use (Luo et al. 2009). Furthermore, heavy metals such as cadmium are also present in livestock as background concentrations in their diets, as well as welfare supplements (Luo et al. 2009). This has a direct impact on the level of cadmium observed in animal manure. Cadmium concentrations in manure steadily increased by over 60% from 1990 to 2003 in chicken and pig manure, exceeding the acceptable limits (Luo et al. 2009). Moreover, China imports large amounts of phosphorus fertilizers which have been known to contain high levels of trace elements such as cadmium and chromium (Luo et al. 2009). For instance, in 2005 1.8×10^6 and 2.3×10^6 tons of diammonium phosphate (DAP) and NPK fertilizers were imported, with about 28% of the latter exceeding the national limits (Luo et al. 2009). According to an inventory carried out by Luo et al. (2009), cadmium inputs from livestock manure, atmospheric deposition, and fertilizers were 55%, 35%, and 8%, respectively. Zhang et al., in their study on the detection of different heavy metals in eight wastewater treatment plants in Wuhu city (China), determined that cadmium exhibited the highest pollution level and Cd showed a strong ecological risk due to the fact that the toxicity coefficients were much higher than those of other metals (Zhang et al. 2020). Cadmium concentrations varied in different plant parts such as the rice grain, the roots, and the shoots, and increased with the amount of soil extractable concentration of cadmium available (Mu et al. 2019). In a wastewater investigation study by Du et al. (2020a) in a region of China, cadmium heavy metals in the inlets and outlets were detected at concentrations up to 78 µg/L and 56 µg/L, respectively. Consequently, the availability of cadmium in the soil was influenced by soil properties such as pH, SOC, and clay content of the soil (Li et al. 2018). Mobility and availability of cadmium in the soil are enhanced by low pH conditions (Wang et al. 2006) and soil pH increased from south to north, explaining the trend observed (Mu et al. 2019). Table 1 shows the occurrence of Cd concentrations in China.

Table 1 Anthropogenic source of Cd concentrations in China

Location	Matrix analyzed	Concentration	Reference
Chatian	Drinking water	0.002 mg/L	(Sun et al. 2010)
	Paddy soil	1.06 µg/g	(Sun et al. 2010)
	Hair	0.17 µg/g	(Sun et al. 2010)
Changsha	Soil	0.102 mg/kg	(Wang et al. 2010)
Jiangsu	Paddy soil	0.23 mg/kg	(Wang et al. 2015)
Guizhou	Paddy soil	0.68 mg/kg	(Huang et al. 2020)
Hunan	Paddy soil	0.96 mg/kg	(Zhang et al. 2019)
Guangdong	Paddy soil	0.69 mg/kg	(Zheng et al. 2015)

Source of cadmium contamination

Anthropogenic sources

Cadmium contamination of groundwater is mostly the result of anthropogenic activities such as mining and smelting, agriculture, sewage irrigation, and traffic. In Changsha, the capital city of Hunan province in southern China, the main source of cadmium contamination originated from the non-ferrous mining and smelting beside the Xiangjiang river (Chen et al. 2011). Over the years, demand for ferrous and non-ferrous metals in China has increased, asserting much pressure on the industrial mining/smelting areas. Acidic drainage and wastewater from mines, atmospheric deposition, and toxic slag have often been the main source of cadmium in the surrounding soil and water (Chen et al. 2011; Du et al. 2020b). Agricultural areas often coexist with mining areas in the Hunan province, providing a sink for the collection of cadmium in the rice-producing soils (Sun et al. 2010). Another major source of cadmium pollution of the groundwater is agriculture. Typical rice-growing regions of south China have double rice-cropping systems, whereby irrigation, atmospheric deposition, and use of organic manures and phosphate fertilizers have contributed to the increase of cadmium in the soil and water (Wang et al. 2019; Zhao et al. 2015). Even though the southern region comprises red soil which is naturally acidic (Yu et al. 2016), heavy use of nitrogen and phosphate fertilizers in farming has further decreased the soil pH, creating more favorable conditions for cadmium mobility (Wang et al. 2019). Furthermore, paddy soils have been irrigated with contaminated water, enhancing the redox potential of the soil. Electronic waste (e-waste) which refers to discarded electronics such as computers and printers has become one of the most rapidly growing waste products of industrialization as newer technologies emerge each year (Wong et al. 2007). Large amounts of e-waste usually end up in developing countries where labor is cheaper and environmental laws are more lenient such as China, Vietnam, and India (Wong et al. 2007). Irresponsible recycling methods such as open-air burning and disposal in fields and rivers contribute to the pollution of heavy metal contaminants since these electronics comprise a mixture of plastic and metals. Since 1995, Guiyu, a town in southeast China, has become an e-waste recycling center, leading to cadmium concentrations of up to 42.9 mg/kg which is very alarming (Wong et al. 2007). Due to such activities, cadmium has been traced in the paddy soils as well as the river sediments in the neighboring areas. Figure 1 shows the geochemical cycle of cadmium.

Natural/geogenic sources

In many cases, it is not straightforward to determine if groundwater and soil are contaminated since cadmium can also be derived from natural sources and processes. Natural sources of cadmium include volcanic eruptions, weathering, natural fires, and dust storms (Hutton 1983; Wang et al. 2010). China is a wide, geochemically diverse country with many different climates and terrain types. Parent soil types and biogeochemical processes such as pedogenesis specific to each region attribute to the variation in natural background concentration levels (Zhao et al. 2015; Reimann and de Caritat 2005). For instance, soils that originated from sedimentary limestone have been known to have greater cadmium concentrations. Previous studies conducted in the early 1980s discovered that the cadmium concentration in southwest China was significantly higher than in the rest of the country, indicating that there must have been natural background levels before industrialization (Zhao et al. 2015).

Fate and transport of cadmium

It is mainly solubility and partitioning between the solid and liquid phases which determine the fate and transport of trace elements through the soil. Many factors such as soil pH, chemical speciation, soil organic matter, redox potential, and soil clay content affect the fate and transport of heavy metals (Carrillo-González et al. 2006). Transportation routes for cadmium molecules include diffusion, metal complexes, and leaching (Carrillo-González et al. 2006). Soil pH condition is the main variable that affects the mobility of cadmium. Cadmium molecules favor low pH levels and are thus very mobile in oxic and acidic waters, forming soluble organic and inorganic complexes such as $CdCl^+$, $CdCl_2$, $CdSO_4$, $[Cd(CO_3)_2]^{2-}$,, and $CdOH^+$ (Kubier and Pichler 2019; Carrillo-González et al. 2006). Consequently, the soluble complexes formed can easily infiltrate the groundwater and increase the bioavailability of plants. Although cadmium is not considered to be redox sensitive, such changes in redox conditions can affect the release and absorption of cadmium in aquifers. Furthermore, acid rain which has become increasingly common across industrial areas has facilitated the transport of such heavy metals to rivers and groundwater (Wang et al. 2010).

Cadmium exposure pathways and human health risks

The main cadmium exposure pathways include direct and indirect exposures. Direct exposure involves a soil-crop-human body pathway whereby cadmium ingestion is utilizing polluted rice, vegetables, and other foods (Wang et al. 2010). On the other hand, indirect exposure involves the soil-human body pathway through dermal contact, ingestion, and inhalation of particulates from soil or pollutions (Z. Wang et al. 2010). These pathways are summarized in Fig. 2.

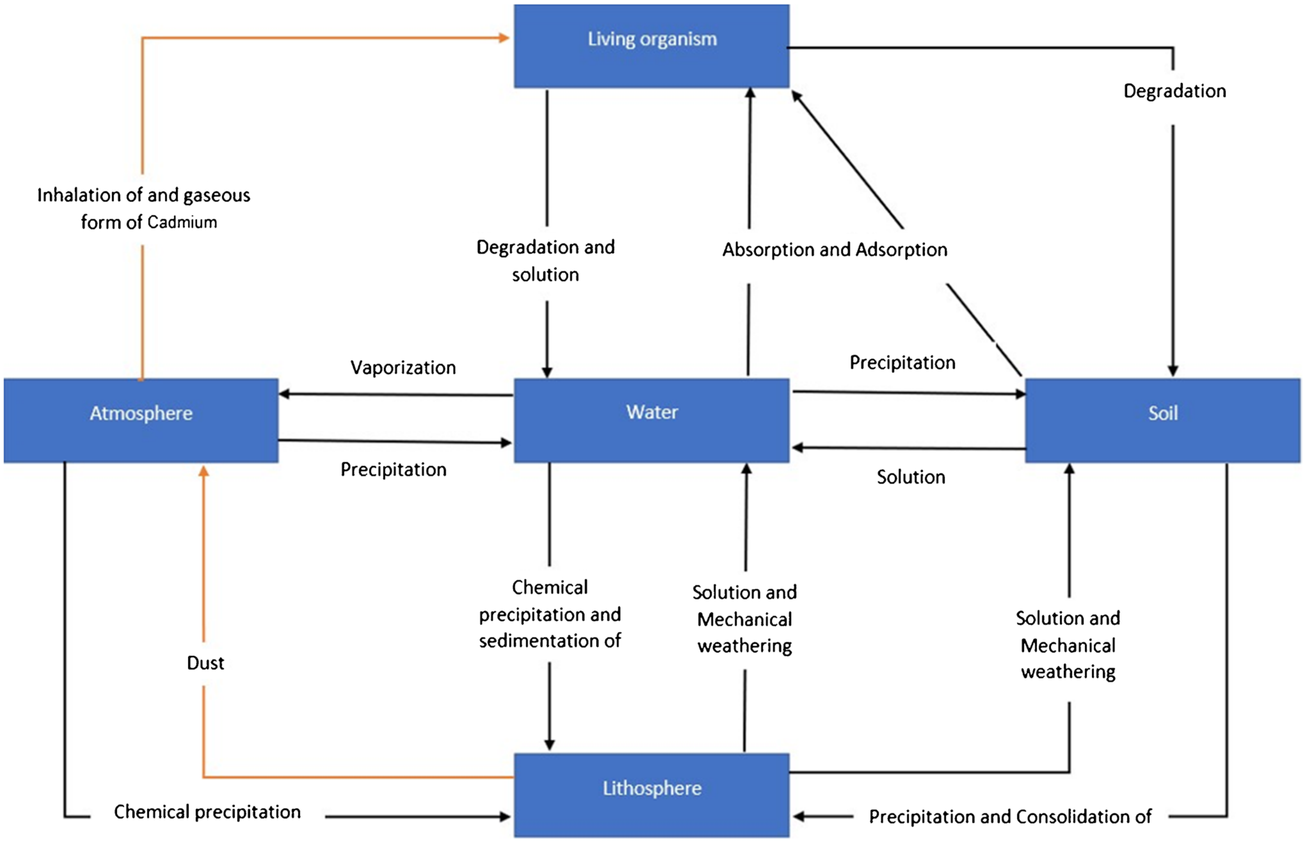
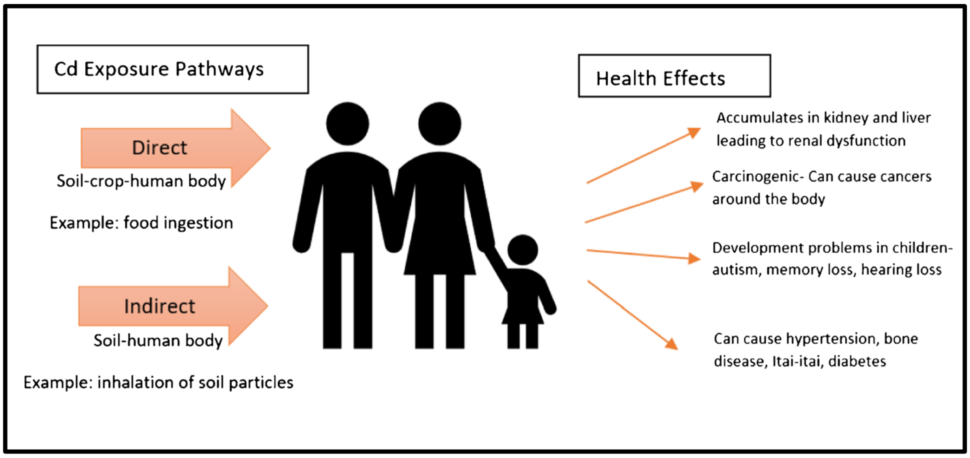


Fig. 1 The geochemical cycle of cadmium

Cadmium can induce serious intoxications in those who are occupationally exposed as well as the general public through food, water, and cigarette smoke (Matović et al. 2015). The World Health Organization and US Environmental Protection Agency advised that the maximum allowable intake of cadmium intake is 25 μg/(kg body weight)/month, and the allowable limit in polished rice is 0.4 mg/kg (Makino et al. 2007).

However, the dietary intake for the southern Chinese population ranged from 66.5 to 116 μg/kg body weight/month according to Chen et al. (2018). Cadmium is carcinogenic and can cause oxidative stress on organs and biological macromolecules even though it is not redox sensitive (Matović et al. 2015). One of the main target organs involved after prolonged cadmium intake is the liver and kidney where it accumulates and mimics other

Fig. 2 Cd exposure pathways and associated health risks for human



vital metallic molecules (Song et al. 2017). Diseases associated with short-term and prolonged cadmium exposure include hypertension, itai-itai, cancer, type 2 diabetes mellitus, renal dysfunction, and bone disease (Matović et al. 2015; Nogawa et al. 2004). Since cadmium has a half-life of typically 10–30 years (Song et al. 2017), children who are constantly developing are particularly at risk for the adverse, long-lasting effects of exposure. Children are mostly exposed to the indirect pathway due to their natural behavior, such as playing outdoors and close to potentially polluted soils (Wang et al. 2010). Health issues in children correlated to heavy metal exposure include memory loss, attention deficit, autism, hyperactive disorder, and learning difficulties (Heyer and Meredith 2017). In a recent study, Xu et al. (2020a) investigated the effects of cadmium and lead exposure on children living in e-waste recycling areas of China and concluded that there was a potential for suffering from hearing loss. Different heavy metals have different indicators and accumulate in different matrices. Urine, blood, and hair samples are usually analyzed to determine cadmium exposure levels in the body. Contaminant level in the blood usually reflects more recent exposure, and urinary and hair levels refer to the accumulation of heavy metal in the kidneys (Hellström et al. 2007). Food is the main source of cadmium intake excluding industrial workers.

Conventional strategies for remediation of cadmium from soil and water

As a result of the severe health risks associated with cadmium intake, management and mitigation in groundwater and soil are extremely important and should be carefully considered by the responsible authorities. Site characteristics, contaminant properties, and concentration are some of the major factors to be considered while selecting a remediation technique. Such techniques classified as either physical, chemical, or biological are discussed below and summarized in Table 2.

Physical remediation

Physical technologies for remediation of contaminated soils include physical barriers which isolate and immobilize contaminants, and also physical separation and removal from the soil (Kristanti et al. 2022; Mulligan et al. 2001). Isolation and containment-inert and resistant materials such as cement, bentonite, slurry walls, and grout are used to create vertical physical barriers between the surface and low-permeability bedrock or clay layer in the soil profile (Mulligan et al. 2001). This is essential to prevent the movement and mixing of contaminated groundwater in a specific area. Mechanical separation considers the size and contamination levels of the soil particles. Processes such as hydro-cyclones and fluidized bed separations can be used to separate the different-sized particles, and later chemical agents are added to make the contaminated particles float to the top, where they can then be removed (Mulligan et al. 2001). In addition, the magnetic characteristics of heavy metals can be applied to physically separate them from the soil. Pyro-metallurgical separation involves passing the contaminated soil through a high-temperature furnace of about 200–700 °C to volatile the contaminant, which can be recovered (Mulligan et al. 2001). Pre-treatment for cadmium-contaminated soil is often required and this is usually done ex situ due to the immobility of equipment. It is a suitable method for severely contaminated soils. Other solutions such as physically replacing contaminated soils with better quality material are costly and increasingly difficult to obtain (Makino et al. 2007). Farmers should adopt better agricultural practices to increase the soil pH and limit Cd mobility, and also select rice cultivar species with low Cd to avoid accumulation in food (Chen et al. 2018). In extreme cases, relocating people who live in highly contaminated areas has various socio-economic implications and ultimately leaves the problem of heavy metal contamination unsolved.

Chemical remediation

Solidification, in/ex situ extraction and electrokinetics, is certain chemical technology that can be implemented to remediate cadmium-contaminated soil and water (Wu et al. 2020; Mulligan et al. 2001). The latter use reverse osmosis, chemical precipitation, and ion exchange processes, but have usually high operating costs and usually impact the quality of the soil (Wu et al. 2020). Solidification is a method whereby chemicals are injected to trap the contaminants and hinder their mobility for later treatment or excavation (Mulligan et al. 2001). This method is cost-effective but inefficient for areas with boulders and bedrock, hence is only used in shallow soil contaminations (Mulligan et al. 2001). Electrokinetics involves cathode and anode electrodes fixed into contaminated soil, and the use of a small electric current to generate an electric gradient and consequently the migration of charged particles to their respective electrode (Mulligan et al. 2001). The metals can be obtained by electroplating, precipitation, or pumping at the electrodes. This method is useful both on and off site, low permeability soils, and careful consideration should be given for electrolysis details particular to the characteristics of each site. Permeable treatment wall is an in situ solution whereby a wall containing remedial substance is positioned across a contaminated area of soil. Groundwater

Table 2 Summary of conventional remediation approaches for cadmium contamination

Conventional method		Mechanism	Advantages	References
Physical	Isolation and containment	Physical barriers to immobilizing contaminants	Slurry walls are cheap	(Mulligan et al. 2001)
	Adsorption	Deposition of molecular species onto the surface	Cheap and fast	Salman et al. 2022
	Pyrometallurgical separation	Application of high temperatures to volatile contaminants	Effective for highly contaminated soils	(Mulligan et al. 2001)
	Mechanical separation	Separation based on particle size	Suitable for high cadmium concentration	(Mulligan et al. 2001)
Chemical	Surfactant and complexing chemical agents	Increases desorption of heavy metal from the soil surface	Efficient for various heavy metals, and a small quantity of chemicals is sufficient	(Doong et al. 1998)
	Soil washing	A chemical reagent ($CaCl_2$) was added to flush cadmium out of the soil, followed by water washing to remove the cadmium in aqueous form	Can be performed in situ and ex situ	(Makino et al. 2007)
	Solidification	Chemicals inject to solidify contaminants	Cost-effective and good for shallow contaminations	(Mulligan et al. 2001)
	Permeable treatment wall	A wall across the groundwater flow path containing remedial material	In situ solution and cost-effective	(Mulligan et al. 2001)
	Electrokinetics	Use of small electric current to separate ions	Suitable for low permeability soils	(Gnanasundar and Akshai 2020)
Biological	Bioleaching	Use of bacteria in acidic conditions to produce sulphuric acid for cadmium absorption	Natural process, in/ex situ	(Mulligan et al. 2001)
	Rhizofiltration	Absorption of cadmium by plants	Natural process, cost-effective	(Mulligan et al. 2001)
	Biosorption	Absorption from contaminated wastewater using biomass	Cost-effective, wide pH range	(Garg et al. 2008; Mohd Zain et al. 2022)
	Vermisorption	Uses earthworms to restore organically contaminated soils	Soil fertility, cheap	(Teh and Hadibarata 2014)

is remediated as it travels across the wall which absorbs the cadmium (Mulligan et al. 2001).

Anionic surfactants such as sodium dodecyl sulfate alongside complexing agents such as ethylenediaminetetraacetic acid (EDTA) are successful for heavy metal desorption due to the ionic exchange occurring on the surface of the soil particles (Doong et al. 1998). However, effectiveness is dependent upon the heavy metal in question and soil properties such as pH (Doong et al. 1998), and also EDTA can remain in the environment for long periods (Makino et al. 2007). Soil washing is another method used, whereby the contaminated soil is washed usually ex situ at treatment plants by adding chemical reagents to displace the cadmium from the soil to accumulate in an aqueous solution. On-site remediation methods have also been developed; for example, Makino et al. (2007) investigated the efficiency of chemical ($CaCl_2$) and water washing, followed by disposal of wastewater from the paddy soil. Even though this process had a certain effect on soil properties, overall rice production remained unaffected after the removal of cadmium (Makino et al. 2007).

Biological remediation

To date, many bioremediation techniques exist such as the use of plants, animals, and microorganisms for the absorption of pollutants (Hadibarata et al. 2007; Rubiyatno et al. 2022; Salman et al. 2022; Tang et al. 2020). Such methods are possible due to the tolerance of the organism, and the ability to accumulate heavy metals in their system. Garg et al. (2008) investigated biosorption and the removal of cadmium from wastewater using biomass such as sugarcane bagasse, maize corncob, and Jatropha oil cake which act as absorbents. Such biomass contains high levels of cellulose, lignin, carboxyl, and hydroxyl groups which are efficient over wide pH ranges. However, the ideal pH was 6.5 and dosage is an important factor in successful absorption (Garg et al. 2008). As noted by Mulligan et al. (2001), the contaminated plants should then be disposed of properly, for example, by incineration, pyrolysis, and gasification to name a few. Bioleaching is the process of using the activities of bacteria to oxidize metal sulfides to produce sulfuric acid, which can absorb metals from the surface of the contaminated soil particles. Conditions need to be anaerobic and acidic for the bacteria to thrive. This method is successful for shallow contaminations and can be implemented both on/off site (Mulligan et al. 2001). A study by Wu et al. (2020) related the combined use of earthworms, plants, and microorganisms to the effective, low-cost rhizofiltration of cadmium-contaminated soils. Rhizofiltration is the process whereby heavy metals are indirectly absorbed from the soil and water by plants and animals with high tolerance levels. Vetiver grass has been observed to have high cadmium tolerance (Wu et al. 2020). Earthworms can be considered "ecosystem engineers" since their activities in the soil increase porosity, fertility, and other microorganisms from their intestines which benefit plants (Wu et al. 2020). Earthworms also facilitate the movement of cadmium through the soil, therefore can be implemented alongside plants such as the Vetiver grass which also has a high tolerance (Wu et al. 2020). Xu et al. obtained promising results for the biological treatment of wastewater by using the new Pseudomonas sp. soy 375 to the aqueous solution contaminated with Cd^{2+} in their study (Xu et al. 2020b).

Advanced technologies

Novel nanofiber membrane

Another technology to resolve the problem of heavily contaminated groundwater is by filtering the contaminated water. This novel nanofiber membrane is manufactured by using chlorinated polyvinyl chloride which is then electrospun with high voltage. The result of this membrane, given the name M-1, can adsorb heavy metals from flowing through the structure of the membrane. When this is viewed on a large scale, it can be seen that this membrane functions as a physical barrier as it can filter off any particles which contain heavy metals (Sang et al. 2008). Micellar enhanced filtration (MEF) is found and experimented with to be a more effective method of removing heavy metals from the contaminated groundwater. The experimented result shows that the removal of heavy metals by MEF using the membrane designed named M-1 can provide good and desired results. The percentage removal of heavy metals from the MEF method is more than 70% for copper, more than 80% for lead, and more than 90% for cadmium (Sang et al. 2008). The advantage of using this method to treat the heavy metal–contaminated groundwater is that the preparation of the membrane through the process of electrospinning can be easily managed, formed in a shorter time, and at a low cost (Tlili and Tawfeeq 2019). Problems that are still arising when using this technology are that surfactant leakage might occur during the MEF process for groundwater (Landaburu-Aguirre 2012). Surfactant is important for the adsorption of heavy metal ion to occur, and hence when these surfactants permeate, they might go deeper into the soil and cause secondary pollution (Filipi et al. 1999). Table 3 shows advanced remediation technologies.

Electrocoagulation

Electrocoagulation is experimented with to be able to remove heavy metals and arsenic from contaminated groundwater. Electrocoagulation is a method where sacrificial metal at the anode is used to begin the electrochemical reactions between the heavy metal and the active cation. This reaction can coagulate and flocculate the heavy metal, arsenic, which in terms removes it from the water (Parga et al. 2005). There is an experimental result showing that by using the experimental electrocoagulation reactor, 99% of arsenic can be removed from the water. This is experimented with by using the contaminated groundwater collected from a well in La Comarca Lagunera; the results show that the water has an arsenic level in the range of 0.025 ppm to 0.05 ppm, which has decreased to a level of 0.002 ppm after the water is being treated using the electrocoagulation technology (Parga et al. 2005). The unresolved issue regarding this electrocoagulation with air injection technology to treat contaminated water is that its full potential is yet to be discovered in the future. Besides, the design of this electrocoagulation system is very complicated and none of the proposed designs is simplified and systematic enough for the whole process to operate (Kabdaşlı et al. 2012). The advantage of using electrocoagulation to treat contaminated groundwater is that no coagulants are needed to be added into the water after the treatment is completed. This is very much important as this will not arise the problem of secondary contamination. This technology in treating contaminated groundwater is also cost-effective. Besides, a wide range of heavy metals can be applied using this technology (Hashim et al. 2011).

Permeable reactive walls

In the case where groundwater is having a constantly flowing characteristic, scientists had designed reactive barriers to be placed into the aquifer of the contaminated groundwater. This modification and installation allow the heavy metals in the contaminated groundwater to be removed. This permeable reactive barrier is engineered to contain reactive solids which heavy metals will play a role to react with them. When contaminated groundwater containing heavy metal ions flows through these permeable reactive barriers, heavy metals ion will react with the reactive solids which these ions will turn into solid and these

Table 3 Advanced remediation technologies

Remediation technologies	Methods	Advantages	Distadvantages	References
Novel nanofiber membrane	Adsorption of heavy metals in flowing water using physical membrane walls	Preparation of membrane by electrospinning process is easily accessed and manageable	Surfactants leakage might occur during the process of remediation	(Sang et al. 2008; Tlili and Tawfeeq 2019; Landaburu-Aguirre 2012; Fillipi et al. 1999)
Electrocoagulation	Electrochemical process is undergone to accumulate heavy metals	No chemicals are needed to be added into the groundwater as electrodes were used in the process of electrochemical reaction	System and handling of the technology are complicated and lack of simplified design to be put into production	(Parga et al. 2005; Kabdaşlı et al. 2012; Hashim et al. 2011)
Permeable reactive walls	Physical barriers made for heavy metals to be reacted and heavy metals are immobilized on the reactive walls	The process of filtration is constantly ongoing as the flow of groundwater enables the reaction to happen without the need of pumping the groundwater	Efficiency will reduce when clogging occurs on the reactive walls	(Blowes et al. 1997; Phillips 2009; Martin and Kempton 2000)
Lime and calcium carbonate	Addition of chemicals to coagulate the heavy metals in the groundwater source	Cheap reagents and easy to handle during operation of remediation on contaminated site	Insoluble products formed might be mobilized and cause secondary pollution to the groundwater	(Lee et al. 2007; Hashim et al. 2011)
Nanoremediation	Involves the use of nanosized particles to undergo the adsorption process in groundwater	The process of filtration using nanosized particles will be faster and more efficient as a larger surface area increases the rate of reaction	The cost of manufacturing large-scale nanosized parts is high	(Rajan 2011; Savage and Mamadou 2005; Chung et al. 2021; Kristanti et al. 2021)

heavy metal ions are no longer mobile. Hence, this can reduce the contamination of groundwater (Blowes et al. 1997).

$$x\mathrm{Cr}^{3+}{}_{\mathrm{aq}} + (1-x)\mathrm{Fe}^{3+} + 3\mathrm{H_2O} \rightarrow \left(\mathrm{Cr}_x\mathrm{Fe}_{1-x}\right)(\mathrm{OH})_{3(s)} + 3\mathrm{H}^+ \quad (1)$$

From the experimental sights, results show that implementation of iron filings into the reactive barriers will be a suitable move to take. When iron fillings are used for the reactive barriers, they found that the concentration of chromium decreases to a range of less than 0.05 mg/L within a short time of 3 h. Compared to reductant solids, pyrite requires an hour more to reduce the concentration of chromium to a range of less than 0.05 mg/L compared to when iron fillings were used. This shows that iron filings are capable of reacting with heavy metals in a short time and allow the removal of heavy metals to occur more effectively (Blowes et al. 1997). The advantage of using this reactive barrier is that it can be installed as an impermeable layer that contains certain permeability. When groundwater is flowing, the reaction between the reactive solids and the heavy metals is constantly happening. Heavy metal reacted to form solid will remain on the reactive barriers and the treated groundwater will flow across the barrier. Besides, this reactive barrier is designed to be able to fit in the aquifer in both orientations, vertical and horizontal. This has attempted the removal of heavy metals in contaminated groundwater to be more effective (Blowes et al. 1997). Issues faced when this reactive barrier is planned to be installed the underground is that more problems or defects might arise when it comes to maintenance. It is also reported that when a clog happens on the reactive barriers, the effectiveness of it removing heavy metals will decrease (Phillips 2009). Hence, installation of these reactive walls on the site for remediation purposes might require regular excavation of the site and renewal of used reactive walls. Besides, these reactive walls are less effective in groundwater with a large scale of contamination, as they are more practical when it is used in concentrated groundwater contamination. More treatment studies regarding the permeable reactive barriers are to be put into research to increase the effectiveness of this technology when it is placed into the real test (Martin and Kempton 2000).

Lime and calcium carbonate

Removing heavy metals from groundwater can be accomplished also by adding coagulants to the groundwater source. This method of removing heavy metals from contaminated groundwater is by adding granulated lime mixed with calcium carbonate in a portable and moveable membrane into the groundwater. Using coagulants such as lime and calcium carbonate can change the heavy metal ions present in the groundwater into insoluble coagulates which are in the form of solids. This can reduce the mobility of the heavy metals and the solid waste can be removed easily when the solid waste is formed inside the portable and moveable membrane (Lee et al. 2007). From the experimental results, it is found that arsenic, nickel, and zinc can be removed from the contaminated groundwater. With the mixing of these two products which are lime and calcium carbonate in a ratio of 1 to 1, acting as coagulants, it can be seen that about more than 90% of the heavy metals, arsenic, nickel, and zinc are removed from a 12-L contaminated water. This method is reported to be successful even when the experiment is carried out on a larger scale which is at a volume of 200 L of contaminated groundwater (Lee et al. 2007). The advantage of using this method in remediating the heavy metal–contaminated groundwater is the production of lime and calcium carbonate is cheap and the production scale can be very big. Besides, the process of handling this remediation process is easy to manage. This could help in increasing the efficiency of removing heavy metals from groundwater (Hashim et al. 2011). Problems faced when using this method in remediating heavy metal–contaminated groundwater is that after the process of coagulation, some insoluble products might form, and when these insoluble products are mobile, they might cause secondary contamination to the groundwater. These mobilized coagulants will be hard to remove as they are located deep under the ground surface.

Nanoremediation technologies

Following the trend of increasing nanoparticle technology, nanomaterials are researched to be able to remediate heavy metal–contaminated groundwater. Nanoremediation is involving the use of reactive materials for the detoxification and transformation of the contaminants. The nanosized reactive materials can start the chemical reduction process and act as catalysts for the contaminant's removal process. Its large surface area enables its efficiency in the adsorption process to increase significantly (Rajan 2011). Research investigating the adsorption of certain heavy metals, lead, copper, and cadmium onto multiwalled carbon nanotubes (MWCNTs) achieves the ideal results. Using this nanoparticle technology, it is found that adsorption capacities can reach 3 to 4 times higher compared to the usage of activated carbon in powdered form. Maximum adsorption capacities of 97.08 mg/g for lead, 24.49 mg/g of copper, and 10.86 mg/g for cadmium were obtained from the experiment carried out. Besides this MWCNTs technology, other nanoparticle-sized technology that was used for the sorption efficiency of heavy metals also show positive and much more effective results such as cerium oxide designed on carbon nanotube technology (CeO_2-CNTs), akageneite nanocrystal technology (β-FeO(OH)), and many more (Savage and Mamadou 2005). The advantage of nanosized particles in the remediation process is the remediation of heavy metals in contaminated groundwater can be faster and more cost-effective. Besides, different chemical groups can carry out the adsorption process when these nanoparticles are used to increase the adsorption efficiency toward the contaminants in the targeted contaminated site (Rajan 2011). Although this nanosized technology is very effective in remediating heavy metals in contaminated groundwater, there will be a shortage of available nanomaterials for the development of nanoparticle remediation technology. Besides that, the cost of purchasing these nanomaterials might be a burden as nanomaterials are designed at a high cost. These obstacles had obstructed the manufacturing of nanoremediation technologies on large scale intending to remediate heavy metal–contaminated groundwater (Savage and Mamadou 2005).

Challenge of remediation

Remediation of heavy metal–contaminated groundwater faced many different challenges. In the context of achieving the success of implementing remediation technologies to treat the contamination of heavy metals in groundwater, selection and designing type of cleaning up techniques require a certain skill to be put into and some innovation that has to be taken. Groundwater contaminated sites are often existing with the complex situation of contamination as well as the features of the geological factor. Researchers do not only focus on methods or technologies that aim to remediate the contaminated groundwater; however, they also need to determine the method to provide this remediation in that targeted area. It is important to introduce the technologies based on their on-site effectiveness. These matters require lots of effort taken by researchers during any plan in remediating technologies into heavy metal–contaminated groundwater (Gavrilescu 2009; Wang et al. 2022). Besides, limited studies have been put into research aiming to remediate the contaminated groundwater due to heavy metals. This causes the continuous leakage and contamination of heavy metals into the environment by mining, industrial activities, and other activities involving the use of heavy metals. Even if some of the laboratory experiment shows good result in the remediation process, on-site field studies are needed to be taken into consideration to properly assess the real condition of the contaminated site. On-site field studies allow researchers to consider the landscape and possible sources of threat that might cause the installed remediation technologies to face failure. The effectiveness of the suggested remediation process is to be known when the researcher carries out on-site field studies (Arjoon et al. 2013).

Conclusion

Due to rapid urbanization, China has exploited its natural resources through industrial activities which have contributed to increasing environmental problems. Over the past three decades, Hunan province in southern China has been one of the major ferrous and non-ferrous mining sites in the country, giving rise to increased contamination of heavy metals in the surrounding agricultural lands. Although background concentrations existed prior due to natural processes, human activities have been the major source of heavy metals. Hunan is also one of the top rice-producing provinces and rice is a staple dietary food. Cadmium is very mobile especially in low pH conditions, using diffusion, solubility, and leaching as transport mechanisms. It has the potential to bioaccumulate in organisms as it travels up the food chain. Main cadmium intake was by ingestion and significantly increases the risks of contracting serious illnesses. Thus, the implementation of remediation techniques is extremely important to ensure that cadmium levels are maintained at a safe level. Many governments make decisions which are to favor economic prosperity and stability for their country. However, in the bottom-line human life is more important and it should be a priority to ensure their safety from environmental issues like heavy metal contaminations and the health risks associated. This study is important for people to be aware of this danger and take precautions. Ideally, stricter laws and regulations should be enforced to address the anthropogenic sources of pollution; meanwhile, remediation methods should be in constant implementation to manage the soil contaminants.

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Declarations

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