



Soil to Society: Heavy Metal Pollution in Soils and its Implications for Human Health - A Critical Review

Abstract: Heavy metal poisoning of soil presents serious dangers to the environment and public health on a global scale. Anthropogenic activities including mining, industrialization, the use of fertilizers and pesticides, and improper waste management have all contributed to the rise, in agricultural soils levels of heavy metals. Heavy metal concentrations in the soil, including lead, cadmium, mercury, and arsenic, have increased as a result of these activities. which, when present in excess of allowable limits, present serious toxicological hazards to plant life and human health. Following their introduction into the soil, heavy metals can be easily absorbed by plants, which allows them to enter the food chain and impact the metabolic processes of both humans and animals that eat the polluted plants. Even while the soil naturally contains tiny levels of heavy metals, concentrations above safe limits can have harmful effects, such as interfering with enzyme processes, damaging cellular structures, and with vital biological functions. According to studies, children who grow up in urban and industrial settings are especially susceptible to heavy metal exposure, which can lead to developmental delays, cognitive impairments, and other health problems. Furthermore, chronic illnesses like cancer, renal failure, and cardiovascular issues can result from prolonged exposure to these metals. Therefore, resolving this environmental issue is essential to maintaining ecological balance, protecting public health, and advancing sustainable development. This article highlights the origins, bioavailability, and soil accumulation of heavy metals while offering a thorough summary of the toxicological impacts of these metals on human health. It draws attention to the dangers that metals including arsenic, cadmium, chromium, lead, and mercury pose to human health.

**Pawanjot Kaur ¹, Dr. Charan Kamal Sekhon ²,
Monika Airi ³**

Affiliation

¹ Research Scholar, Sri Guru Granth Sahib World University, Fatehagrh Sahib, Punjab India.

² Head and Assistant Professor, Sri Guru Granth Sahib World University, Fatehagrh Sahib, Punjab India.

³ Assistant Professor, Sri Guru Granth Sahib World University, Fatehagrh Sahib, Punjab India.

Article History:

Received Date : Dec 13, 2025

Revised Date : Dec 30, 2025

Accepted Date : Dec 30, 2025

Published Date : Jan 12, 2026

Introduction

Heavy metals are naturally occurring elements with a high-density present in the

ecosystem. India has several environmental problems, including heavy metal contamination. They are popularly known as metals of environmental concern (Laoye et al., 2025). Heavy metal pollution or contamination in soil is one of the most consequential environmental issues. Heavy metals are stable and do not break down into less toxic products. Heavy metals bio accumulates in the food chain and can therefore have debilitating impacts on the health of human. The complex metabolic machinery in our body is affected by heavy metal pollution or toxicity, leading to negative health manifestations such as hemolytic anemia, nerve damage, nausea, diarrhea, and fetomaternal bleeding (Teschke, 2024, Khalaf et al., 2024, Acharya, 2024)

4)). The addition of hazardous materials to the environment is referred to as pollution. Both living and non-living things are impacted by these dangerous chemical agents, which also ruin the ecosystem. When these

chemicals are added, the soils composition changes. The problem of soil pollution is not restricted. These days, it is a worldwide concern. The natural habitat of the soil is being harmed by the heavy metals that are present in it. To guarantee food security and end hunger, attention has been focused on identifying and eliminating heavy metal pollution worldwide. Persistent pollutants known to have negative impacts on human and environmental health include heavy metals like cadmium, chromium, lead, arsenic, mercury (Bhuiyan et al., 2010, Wang et al., 2020). The ecology and public health are under serious risk due to the buildup of harmful compounds in different environmental compartments caused by industrial activity, urbanization, and poor waste management methods (Xu et al., 2020).

Significant volumes of heavy metals were released into the environment as a result of India's industrial boom, which was driven by industries including mining, manufacturing, and energy generation. The levels of contamination have also been made worse by uncontrolled mining operations, inappropriate industrial waste management, and the use of heavy metals in fertilizers and pesticides in agriculture (Guan et al., 2019, Kharazi et al., 2021). The issue has also been made worse by rapid urbanization and population growth, which have raised demand for consumer goods, transportation, and infrastructure, which in turn has boosted metal consumption and trash production (Li et al., 2021).

In India, the effects of heavy metal pollution are extensive and multifaceted (Palit and Hussain, 2022). These harmful compounds can contaminate drinking water supplies and aquatic ecosystems by entering water bodies through inappropriate waste disposal, agricultural runoff, and industrial effluents (Wang et al., 2020). According to Tóth et al., 2016, Fei et al., 2019, heavy metals can build up in soil and impact crop quality and food

safety. Consuming contaminated food can result in a number of health problems, such as kidney damage, neurological disorders, respiratory issues, and even cancer (Xing et al., 2020). Furthermore, heavy metals have the ability to linger in the environment for extended periods of time, bioaccumulating in the food chain and endangering both people and wildlife. The ecosystem of farmland is essential to human life, development, and evolution (Li et al., 2015, Xu et al., 2020). The origins and effects of HMs on humans via the food chain are shown in Figure 1. Long-term exposure to heavy metals by inhalation, contaminated food consumption, and skin contact can cause a variety of illnesses in humans and other species (Anyanwu et al., 2018).

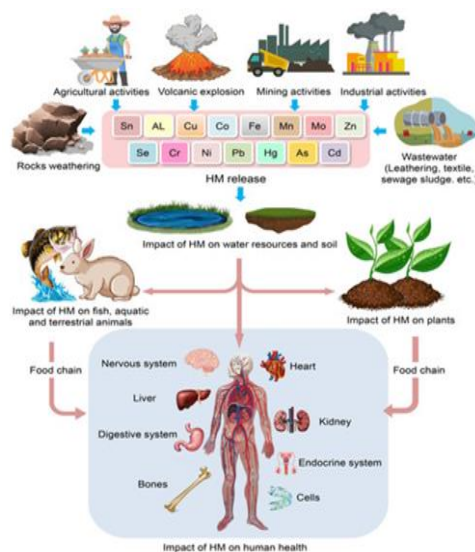


Figure 1. Origins and impacts of heavy metals on humans through the food chain.

The main source of environmental contamination is human activity, with vehicles, roads, and industrial emissions all contributing significantly to the release of dangerous heavy metals (HMs) such as cadmium (Cd), lead (Pb), and arsenic (As) into the environment (Nogueira and Hay, 2013) (Figure 2). Sludge discharge in agricultural fields can potentially lead to the accumulation of heavy metals in

plants and soil. One million tonnes of nickel (Ni) and five million tonnes of lead (Pb) are among the heavy metals the soil releases annually, according to Onat and Stakeeva (2013). Soil pollution is difficult in controlling than air and water pollution. soil contamination was previously viewed as less significant than these two types of pollution. But in developed nations, soil contamination has gotten worse in recent years. It has consequently gained increasing attention and become as a major global environmental protection concern.

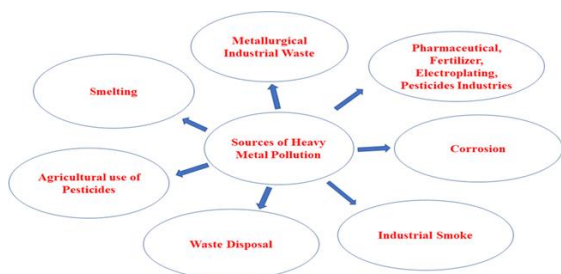


Figure 2: Natural and Anthropogenic sources of heavy metals

Toxic metals are poisonous, persistent, and can build up in humans, animals, and plants through the food chain, heavy metals constitute a major environmental hazard. They do not easily breakdown once they are in the soil, which makes soil cleansing challenging and expensive. Heavy metal-induced soil pollution has become a major worldwide problem in many developed nations in recent decades. The primary natural and man-made sources of heavy metals, their environmental dispersion, and their detrimental impacts on human health are examined in this overview. In order to safeguard people and ecosystems, it also emphasizes the necessity of enhanced monitoring, more environmental regulations, and better techniques for cleaning contaminated soils.

Heavy metal pollution or toxicity in agricultural soils

It is commonly recognized that plants and soil are affected by high levels of heavy metals. The World Health Organization (WHO) has established permissible limits or maximum residue levels (MRLs) for these metals in soil and plant tissues, measured in $\text{mg}\cdot\text{Kg}^{-1}$ (Table. 1)

Table 1: Provides the acceptable thresholds values for heavy metal levels in soil (FAO, 2001; WHO, 2011).

Heavy metals	Permissible limits(mg/kg)
Arsenic (As)	10
Cadmium (Cd)	3
Chromium (Cr)	100
Copper (Cu)	100
Iron (Fe)	425
Nickel (Ni)	50
Lead (Pb)	50
Mercury (Hg)	1
Zinc (Zn)	300

The Keshopur Effluent Irrigation Scheme (KEIS) periurban agricultural fields in Dehli, India, were chosen for the heavy metal assessment. Results indicated that sewage irrigation increases soil fertility by enriching it with organic matter as well as essential minerals, but it also contributes to a significant accumulation over time of many harmful metals, including, Fe, Ni, Cu, Pb and Zn. However, in order to avoid any human health risk from these metals' accumulation, so regular monitoring was required (Rattan et al., 2005). In Ludhiana, Punjab, farmers have used sewage and untreated industrial effluents to irrigate their crops. Initially this method appeared helpful because the soils were fertile and rich in organic matter which allowing crops to grow even under tough conditions. But



behind this seeming achievement, an unidentified threat gradually accumulated. The soils absorbed harmful heavy metals like Cadmium, Chromium, Nickel and lead along with nutrients during each irrigation year. These metals slowly began to build up in bioavailable forms and gradually seeped into the plants that were supposed to provide food for humans (Dheri et al., 2007). Cadmium, Nickel, and Zinc contamination in Bangladeshi soils originated primarily from tannery wastes, city sewage, and industrial discharges from pharmaceutical and paper mills. This investigation showed that metal concentrations declined significantly with depth, particularly in soils contaminated by municipal sewage, where deeper layers cause Cd and Zn concentrations to nearly quadruple. According to sequential extraction, mobility factors decreased with increased depth, with Cd exhibited the maximum mobility, Zn having intermediate mobility, and Ni having the lowest. The highest possible health risk is associated with city sewage soils because of their higher mobility and higher concentrations of Cd and Zn, which increase the possibility of contaminating groundwater and agricultural crops (Kashem et al., 2007). Mostly due to the accumulation of non-biodegradable heavy metals in the air, soil, water, and food, India growing urban population has made environmental pollution and related health issues worse. Despite the existence of rules and regulations, heavy metal contamination has persisted due to unofficial activities and lax enforcement, posing long-term risks to both human and animal health. Although it is impossible to totally stop heavy metals from entering the food chain, their effects can be greatly lessened by using mitigation techniques including switching to non-edible crops and changing land uses. India environmental governance needs to be strengthened by eschewing a policing-only strategy and adopting integrated strategies that incorporate sustainable land-use planning, public

awareness, and legislation (Ganeshamurthy et al., 2008). In Guiyu, Southeast (China) unregulated printed circuit board recycling had resulted in a significant lead and copper contamination of surface dust. The remarkably elevated levels detected in workshops and adjacent public spaces like streets, schoolyards, and marketplaces suggested that pollution affects more than just workers and poses a risk to community health. Children are particularly susceptible to these adverse effects. Guiyu serves as an urgent warning to other developing nations that recycle e-waste informally of the significance of sustainable and well-managed e-waste operations in preventing widespread contamination and health risks (Leung et al., 2008).

Because of the possible health risks, heavy metal contamination of soils from mining and smelting is a major problem. Cu, Cd, Pb, and Zn concentrations in food crops and soil in four villages (Zhongxin, Fandong, Liangqiao, and Shangba) were measured by the researchers. The findings showed that the Fandong village's Cu, Cd, Pb, and Zn concentrations were higher than allowed. By comparing the estimated dietary intake and target hazard quotient for lead and cadmium, this study also discovered that the local people may be at risk for health problems as a result of consuming contaminated food crops (Zhuang et al., 2009). The elements chromium (Cr), lead (Pb), iron (Fe), zinc (Zn), nickel (Ni), and copper (Cu) were measured in soil samples taken from residential, commercial, and traffic intersection sites along Hosur Road in South Bangalore. The geoaccumulation index revealed that residential soils were uncontaminated by Ni, Zn, and Fe but highly contaminated by Cr and Pb. Roadside and industrial regions had significantly higher levels of Fe, Pb, and Ni (Begum et al., 2009). The study that looked at 14 heavy metals in the soil of the southeast section of Ranga Reddy district was the first of its kind. According to the study, some metals come from



the rocks in the soil naturally, while others are the product of human activity like industrialization and the use of chemicals in agriculture. The findings demonstrated that both natural and man-made sources of heavy metals are found in the soil, with granite rock acting as the main natural source (Dantu, 2009).

India's largest leather production centers is located in the cities of Jajmau (Kanpur) and Unnao, which are located beside the sacred Ganga River. For the analysis of toxic metals, researchers collected 53 soil samples from the study area. Investigation revealed that Chromium, Copper, lead, Vanadium and Zinc were found in elevated amounts. The results identified that discriminate dumping of hazardous industrial waste as only the factor. Wind and rain water runoff also served as carriers dispersing these toxins outside of their original locations (Gowd *et al.*, 2010). In the previous several decades, hazardous metal pollutants have accumulated, and soil quality has declined as a result of India waste management plans not keeping up with the country rapid industrial growth and urbanization. The quality of the soil along the creek area in Mumbai is said to be impacted by a number of elements, including the discharge of agricultural, household, and industrial pollutants, land use practices, geological formation, rainfall patterns, and infiltration rate. The Thane Creek Wetland, situated near Mumbai had severely polluted from the large Thane- Belapur Industrial Complex. According to this study, the concentrations of heavy metals such as iron, mercury, cadmium, arsenic, zinc, nickel, and copper increased gradually during the dry season and peaked in the summer, but they sharply decreased during the rainy season and exceeded the allowable limits in the soil. These heavy metals significantly impact aquatic plants and animals, which then biomagnified their way into the food chain and eventually impact humans (Singare *et al.*, 2010). Because mine

wastes are released and spread throughout the environment, elevated quantities of hazardous metals are frequently found in food crops, stream systems, and agricultural soils. In order to evaluate the possible health risks and environmental dangers posed by contaminated agricultural products, several researches have looked into the spatial distribution and behavior of heavy metals in and near mining areas. For instance, surface soils from Spain's Almadén mining sector were shown to have enrichment of Cr and Ni due to mine tailings (Bueno *et al.*, 2009). Soils taken from southern Togo's mining regions also have elevated levels of Cr and Ni (Gnandi and Tobschall, 2002). According to Bi *et al.*, 2006, zinc smelting operations in Hezhang County, western Guizhou, China, caused Cr contamination of agricultural soils. The largest chromite mine in Vietnam is the Co Dinh mine. Heavy metal contamination in the mine area is clearly caused by mining, ore dressing, and tailings disposal. Chromium, cobalt, and nickel have seriously contaminated the surrounding paddy soils, sediments, and water as a result of chromite mining at the Co Dinh mine in Vietnam. The primary causes of this pollution were the mining area contaminated water outflow and the entry of contaminated sediments from a badly built dike. Agriculture, livestock, and human health are all seriously at risk from this kind of contamination (Kien *et al.*, 2010).

In China, the crops in Dunhua sewage irrigation area (DIA) have been irrigated with waste water for over 20 years instead of rivers or precipitation. Results showed that the surface soils contain higher levels of Cr, Cd and Pb. Cd was the most dangerous of them. This study also suggested that the accumulation of metals in plants was primarily seen in the roots, followed by stems, leaves, and fruits. Prolonged waste water irrigation raised high levels of toxic elements in soil and crops (Liang *et al.*, 2011). Soils surrounding metal scrap



dumps in Abraka and Agbor, Delta State, Nigeria had been contaminated with higher concentrations of heavy metals than control sites, specifically lead, copper, zinc, cobalt, and cadmium. The contamination predominantly originated from anthropogenic activities associated with scrap metal dumping with concentrations decreased with distance from the dumps. The contamination index revealed a considerable degree of pollution posed a substantial health risk to nearby communities (Akpoveta et al., 2011). In Nigerian cities, large areas of land, often over 5 hectares, are set aside for groups of small auto-mechanic businesses to operate workshops and repair yards. Bigger cities have more of these mechanic villages. Similarly, one more research was conducted in Ibadan, Nigeria, measured heavy metal levels in soil and groundwater near automobile mechanic villages. The soil showed much higher levels of metals like lead, cadmium, copper, chromium, and nickel as compared to a clean control area with some metals exceeded safe limits. The groundwater was mostly safe except for copper, which was above the safe level. The study recommended using plants to clean the soil, following strict rules to control pollution, and enforcing environmental laws to stop further metal buildup (Adelekan and Abegunde, 2011). The soil around two large industrial areas in Gebze, Turkey, is highly contaminated with metals such as cadmium, chromium, copper, arsenic, lead, manganese, zinc, and mercury. According to this study, heavy traffic and industrial operations are the primary causes of these elevated metal levels. Hazardous waste from manufacturers is transported by wind and rain, which contributes to pollution. Compared to soil situated further away, the soil around industrial regions is significantly more polluted (Yaylali-Abanuz, 2011).

The Dhaka Export Processing Zone (DEPZ), currently the second largest Export Processing Zone (EPZ) and the biggest industrial hub in

Bangladesh, contained 92 industrial units that are recognized as major sources of pollution. These industrial units encompass sectors such as cap and accessories manufacturing, clothing, weaving, fabrics, metal, plastics, leather-based footwear, electronics, paper, chemicals, fertilizers, and a variety of other different products. By increasing the amounts of pollutants like heavy metals, the industrial operations' discharge of untreated or insufficiently treated wastewater, effluents, and sludge into the environment can deteriorate the quality of the soil. This contamination negatively impacts macrophytes, soil organisms, and human health. Samples of agricultural soil were taken in the dry and rainy seasons from 20 different locations close to DEPZ. Results showed that elevated levels of heavy metals in soils near industrial sites was primarily due to human activities, specifically the uncontrolled release of solid waste and the discharge of untreated or inadequately treated liquid waste from these industries (Rahman et al., 2012). The sources of heavy metal contamination in the environment are both natural soil materials and human activities such the use of fertilizers, pesticides, and cars. Near Pune, automobile pollution is getting worse and hurting the surrounding farms. In this study soil samples were examined from six locations along highways in various seasons for the presence of heavy metals. Results reveals that soil was contaminated with chromium, lead, copper, nickel and zinc (Delbari et al., 2012).

In Tamil Naidu, scientists collected soils samples from seven industries like welding, steel, cement, printing, textile, paint and tannery. Analysis showed that organic carbon, salts and heavy metals was present in high concentrations of Pb, Cr and Cu in soils near to industries. High concentrations of Cu were found near tanneries soil. Overall Cd, Pb and Zn were found to be the dominant pollutant across the industrial zones. Local residents,



mainly children and workers are at greater risk of heavy metal toxicity (Dheeba and Kumar, 2012). One more research conducted in the industrial area of China in 2013. Higher levels of As, Pb, Cd, Cu, and Zn were present in soil samples of Tiexi industrial district of Shanyang, China due to the long term industrial and anthropogenic activities (Li et al., 2013). The spatial distribution of metals like iron, nickel, manganese, zinc, copper, chromium, lead, and cadmium were analyzed in urban soils of Ghaziabad district, an industrial city. According to this study, there is significant heavy metal contamination in the urban soils of Ghaziabad, primarily driven by industrial and urban activities, posing potential non-cancer health risks to children particularly for chromium and lead exposure. It was discovered that the amounts of Pb, Zn, Cu, Ni, Mn, Cd, and Cr were higher than allowed. Manganese had the most effect on human toxicity, but nickel was the main contributor to aquatic ecotoxicity (Chabukdhara and Nema, 2013). Tiruchirappalli, popularly known as Trichy, is the fourth largest Tamil Nadu municipal corporation and the fourth largest metropolitan area. It is situated alongside the Cauvery River. According to a study conducted at the Ariyamangalam municipal waste dumpsite in Tiruchirappalli, Tamil Nadu, heavy metals in the order of manganese, lead, copper, and cadmium are present in the soil close to the open dump. This indicated that there is observable soil pollution due to leachate from the disposed of garbage. Without action, these metals may continue to percolate in the soil and eventually contaminated the groundwater (Kanmani and Gnadhimathi, 2013).

In the next year, a study conducted in auto mechanic workshops in Ikare Akoko located in the Ondo state of Nigeria. The findings showed that soil was highly contaminated from waste dump mechanic workshop. Moderate to high pollution was confirmed by pollution indices.

The elevated levels of metals pose a significant environmental risk (Ololade et al., 2014). Due to their lack of access to wastewater treatment facilities, many Pakistani small-scale leather manufacturers release their waste into ditches or open fields. Heavy metal poisoning has rendered large tracts of land in the Kasur area unfit for farming. There is substantial heavy metal contamination in the soil and groundwater in the Pakistani leather manufacturing region of Kasur. Extremely high chromium concentrations, as well as high Cd, Co, Ni, Fe, Pb, Mn and Zn levels, suggested widespread pollution mostly from industrial effluents from leather manufacturing facilities (Afzal et al., 2014). China and India have a long history of using gray waste and other waste water for irrigation (Vigneswaran & Sundaravadivel, 2004). In Kano and Yola, Nigeria, grey waste water used for irrigation. Although grey wastewater is considered to be a rich source of organic matter and other nutrients, the receiving soils also contain high concentrations of heavy metals such as Co, Cd, Cr, Mn, Fe, Ni, Cu, Zn (Muhammad et al., 2008). Samples of soil, wastewater, and vegetables were taken from the Shinko and Fagge irrigation sites in Yola and Kano in order to analyze the heavy metal concentrations. The amounts of copper in soil and the concentrations of Cu, Fe, Mn, and Zn in irrigation waters were higher than allowed. Heavy metal contamination was higher in the Kano farm soils than in the Yola farm soils (Chiroma et al., 2014). In the Mandoli industrial area of Delhi, informal e-waste recycling has led to severe contamination of surface soils, vegetation, and groundwater by hazardous heavy metals including Pb, Cu, Zn, As, Cd, and Se. The detected metal levels greatly surpass the limits set by the EPA, Indian Standards, and WHO, posed a significant risk to environmental health and human safety. Indigenous plants in the area have absorbed large amounts of these metals, suggested that contaminants could enter the local food chain,



while the quality of groundwater pollution directly threatens nearby residents. Multivariate analysis and pollution assessment indices had clearly demonstrated a strong link between e-waste recycling operations and the heightened concentrations of these toxic metals (Kumar et al., 2014).

Likewise, a study to identify metals in agricultural soil and cassava leaves was carried out in Nigeria's Abia state. Investigation revealed that the soils and cassava leaves present along highway were contained higher amount of Cr, Fe and Pb as compared to the sites far away from the road (Nnaji, 2015). Soil samples were collected from various sites, including dumping grounds, roads, and agricultural regions for the assessment of soil pollution in Uttar Pradesh, India's Varanasi region. Results revealed that the majority of heavy metal concentrations, with the exception of lead (Pb) and copper (Cu) in soils close to roadways and disposal sites, were within allowable limits set by soil quality standards. Soil contamination was measured using the pollution index (PI), integrated pollution index (IPI), and geoaccumulation index (Igeo), showed that the highest pollution levels were found in soils from dumping areas and along roads. (Singh et al., 2015). Industrial solid wastes, such as fly ash and slag cement from interconnected iron and steel industries and coal-based thermal power plants, was dumped uncontrolled in the industrial area of Chhattisgarh (India) posed a significant environmental threat. Heavy metals that contaminate the soil and may percolate into adjacent water sources are present in the leachate from these waste dumps. Certain heavy elements, including lead, manganese, iron, chromium, and cadmium, had levels above permissible limits when the soil samples were examined. The results demonstrated that improper disposal of industrial solid wastes caused soils to become contaminated with heavy metals, which can have negative effects

on the ecosystem and human health (Tiwari et al., 2015). Arsenic contamination was a serious and growing problem affected large areas and many people in India. It spreads through soil, sediments, and groundwater, mainly from natural sources and anthropogenic activities. Although groundwater toxicity from arsenic is widely recognized, soil pollution impacts was less understood. Arsenic in soil can contaminate crops and vegetables, which then enter the food chain, posing health risks to humans. Various methods have been developed to remove arsenic, but physical and chemical treatments are often costly, less effective, and create toxic waste. Bioremediation, using living organisms to degrade or absorb arsenic, offers a promising, eco-friendly alternative for cleaning contaminated soils and water (Srivastava et al., 2015).

Researchers evaluated the level of metal contamination in the surface soils surrounding the Tunebilek thermal power plant (TTPP) in Turkey. As, Cr, Ni, Hg, and Pb levels in soil ranged from low to extremely highly contaminated, according to the assessment. These findings suggested that the TTPP coal-based operations had significantly increased the buildup of metals in nearby soils, raised possible human health and environmental concerns (Ozkul, 2016). In the same year, researchers collected 75 samples of soil taken from several locations in the Jharia coal field in Jharkhand, India. Results from enrichment factor indicated that the soil was polluted with Cadmium, Copper, Lead, Nickel and Lead. The contamination factor and pollutant load index were proposed for soils close to coal mines. The main causes of soil contamination in this region were wind-blown dust, mine fires, and coal mining operations (Pandey et al., 2016). Significant contamination by potentially dangerous elements was found in the soils from Kazipalli, Hyderabad, where concentrations of Cu, Cr, Zn, Ni, Pb and As above the permissible



levels. Enrichment factor geoaccumulation factor, contamination factor and pollution indices all continuously showed high to very high contamination, with lead and arsenic being the most concerning. While health risk assessment based on USEPA models showed possible non-carcinogenic and carcinogenic concerns for the local population, particularly through soil ingestion and skin contact, ecological risk assessment further identified As and Pb as the main contributors to overall risk (Krishna and Mohan, 2016). Agriculture is the main source of income for the people of Punjab, one of India's most fertile regions. In Punjab, agrochemicals are used to support intensive agriculture all year round. Two significant crops grown in Punjab during the Kharif season are sugarcane and sorghum. Due to intensive cultivation and various human activities, the soil in these areas faces a high risk of heavy metal contamination. Therefore, A study was conducted to look at the heavy metals and physicochemical properties of agricultural soils in a number of communities along Punjab's Sutlej and Beas rivers. According to analysis, the soil samples exhibited a sandy texture, minimal organic matter, a slightly acidic pH, and safe amounts of the heavy metals Cr, Cu, Cd, Co, and Pb. However, it was shown that the maximum allowable values for lead, cadmium, and chromium were surpassed in sorghum and sugarcane plants. Consequently, steps need to be taken to guarantee the adoption of more environmentally friendly farming methods (Bhatti et al., 2016). Over the past few decades, Baghdad, the capital of Iraq, has seen a sharp increase in both population and urbanization. The soils close to the Bagdad city roadway were evaluated for the presence of the heavy metal pollutants Cd, Pb, Zn, and Ni. According to the findings, the soil's concentration of heavy metals was higher than that of the control soils and went as follows: $Ni > Zn > Pb > Cd$. As the distance from the roadway rose, the values of the pollutant load index and enrichment factor

decreased. This means that soils located close to the road, especially within 1.5 to 10 meters, were more affected by vehicle exhaust emissions. (jibury and Essa, 2016). Soil pollution had emerged as a significant issue in Guwahati city, Assam, over the past several decades. In order to evaluate the impact of emissions from automobiles and industries, researchers measured eight heavy metals and sixteen different types of polycyclic aromatic hydrocarbons (PAHs) in soil samples collected from 15 different locations. The findings demonstrated that compared to locations with high traffic, industrial areas had greater concentrations of heavy metals and total PAHs. The variation in pollutant levels between contaminated and clean sites confirms that human activities are the main source of soil pollution in the region (Das et al., 2016).

In Turabah Province, Saudi Arabia, agricultural soils and well waters were used for irrigation and drinking purposes. Investigation revealed that trace elements like Al, As, Cr, Mn, Ni and Pb were found in soil and water samples. Accumulation of these elements in human body caused various types of health risks like cancer, cardiovascular diseases, hair loss, and kidney diseases (Elsheikh et al., 2017). Heavy metal pollution in soil and crops were assessed in Southern Yangtze River Delta, China and also evaluated associated health risks. Results showed that soil were at safe levels, but the overall soil pollution index was close to the warning level (Hu *et al.*, 2017). Many dangerous chemicals and heavy metals build up on agricultural land close to businesses, which is frequently overlooked. Agricultural soils near Hindustan Zinc Limited (HZL), particularly those exposed to industrial effluents in Mindi area, Visakhapatnam, Andhra Pradesh. Mindi industrial area is known for its zinc metal industry. Toxic elements like Cu, Zn, Pb, and Cd was exceeded safe limits in agricultural soil near this industrial area. According to these results, ongoing industrial effluent discharge



deteriorates the chemical and biological characteristics of soil, endangering food safety and agricultural output (Pushpanjali et al., 2017). Long-term exposure to surface dirt and street dust can have harmful consequences on human health through ingestion, inhalation, and absorption through the skin because of the accumulated potentially toxic metals (Yuan et al., 2014). Street dust in Tehran's central district is heavily contaminated with traffic-related metals such as Cu, Sb, Pb, and Zn, largely from brake wear, tire degradation, road abrasion, and fossil fuel combustion. Dust pollution in the southwest is considerably worsened by industrial emissions, according to geographical patterns. Pb is the sole element that clearly poses a health danger in both street dust and surface soil samples, according to health hazard evaluation, which also showed that consumption is the main exposure route for children and skin contact is significant for adults with Cr, Cd, and Sb (Dehghani et al., 2017). The government of Cameroon has prioritized addressing food insecurity by boosting agricultural output to satisfy the expanding population's need for food. However, pesticides and fertilizers used in agriculture, such as those applied regularly in the banana plantations around the Mussaka landfill, often contain heavy metals. The Mussaka landfill, which receives unsorted municipal waste from residential, commercial, institutional, medical, and construction sources, has poor hydrogeological conditions and lacks proper side-sealing systems. Consequently, the combined impact of agricultural activities and landfill operations poses a significant risk of toxic metals contamination in the Mussaka area. Soil samples collected from landfill and its surrounding areas of Mussaka landfill. The highest heavy metal concentrations in soil were copper, zinc, cadmium, and mercury with site SS1 showed the most contamination. Some sites were uncontaminated or moderately contaminated while the landfill showed

moderate to heavy pollution. The landfill is moderately polluted and could worsen due to ongoing human activities. This study is an important reference for environmental toxicology research (Fonge et al., 2017). The amounts of heavy metals in soil during the rainy and dry seasons were examined in a study conducted close to a municipal trash dumpsite in Uyo, Nigeria. The soil near the dumpsite had higher amounts of metals like lead, zinc, nickel, chromium, cadmium, and manganese as compared to a clean control site. The soil was especially polluted with cadmium, which caused most of the ecological risk. While no immediate health risks were found, children were more vulnerable to heavy metal contamination than adults (Ihedioha et al., 2017). High concentrations of various heavy metals, mostly from human activities like mining, were found in agricultural soils in the Singhbhum copper belt, Jharkhand, which is known to be rich in mineral resources like copper, iron, uranium, gold, and kyanite. Approximately 50% of the samples had moderate to extremely high ecological risk. For human health, most individual metals had not posed significant non-cancer risks, except that children could face higher overall risks when all metals and exposure routes are combined. The risk of cancer from arsenic and chromium was within safe limits. The research area's Hazard Index, which considered all of the metals and routes that were examined, was determined to be 0.71 for adults and 5.16 for children. These values, respectively, suggested that the locals were seriously concerned about their health (Giri and Singh, 2017).

As per the one more study, street dust in Lanzhou, China contained elevated concentrations of toxic metals particularly Cu, Cd, Cr, and Pb linked mainly to anthropogenic sources such as traffic emissions and industrial activities. According to an ecological risk assessment, Lanzhou's urban dust presented a significant risk to the city ecosystem. Human



health risk analysis indicated that the primary exposure pathway for both adults and children is ingestion, which is followed by skin contact. However, the hazard index values are still below the safe threshold, and the carcinogenic risks for Cd and Cr are within acceptable bounds, suggesting that there is little overall health risk from exposure to street dust (Jiang et al., 2018).

Industrial operations have obviously impacted the quality of the soil, a study on soil from five industrial sites: the thermal power plant in Mettur, Tamil Nadu; SIDCO-1, SIDCO-2, SIDCO-3, and Chemplast Sanmar Limited. According to findings amount of arsenic were highest near the thermal power plant, lead was highest in the chemplast region and copper was high at SIDCO-1 as a result of electroplating and smelting. SIDCO-1 area was the most contaminated according to the pollution load index. Overall findings indicated that industrial operations significantly affect the soil quality that improved waste management and monitoring was required (Kumar, 2018). On the other hand, researchers who worked in Chandigarh and Ludhiana's e-waste recycling industries examined the impact of heavy metals on adults and children. Samples of dust and dirt were gathered for this purpose from the locations of recycling operations. In soil and dust samples, higher concentrations of Ba, Cu, Pb, and Zn were found. When dust and soil were consumed, these pollutants presented major health risks. The primary metal of concern that posed a risk to both adults and children was lead. According to Singh et al., (2018), exposure to certain metals has been linked to a lifetime risk of cancer in adults. In northern Telangana soil was moderately contaminated with heavy metals. Chromium was showed concentrations above the recommended limits in most samples. The high chromium concentration was a serious environmental and health concern, even though the amount of arsenic, copper, zinc, lead, and nickel were all within safe limits.

However, arsenic and chromium lifetime cancer risk values were higher than the allowable limit, suggested that the local population may be at risk for cancer (Adimalla and Wang, 2018). The evaluation of soils from the Sukinda chromite mining region, Odisha, indicated that it is very clear that there is significant heavy metal contamination, especially from nickel, lead, cadmium, and chromium. The mine, agricultural, and roadside soils were categorized as heavily to extremely contaminated by the geo-accumulation index. According to health risk assessment, non-cancer hazard indices also surpassed acceptable levels, and there was a significant cancer risk in both adults and children at mining locations. The main causes of these hazards were hexavalent chromium, nickel, and lead (Naz et al., 2018). Large cities like Delhi, Kolkata, Mumbai, Bangalore, and Chennai were the center of India's e-waste recycling until a few years ago. However, with the recycling facilities have begun to develop in nearby cities and towns due to the rise in e-waste output and rising land costs in large cities. One such instance is the city of Moradabad, where recyclers purchase printed circuit boards (PCBs) from other major cities. Known as "Peetal nagri," or the Brass City, this city has long been famous for its brass jewelry and bangles. The investigation was carried out in Moradabad, India, at the former industrial waste and e-waste processing sites Peetal Nagri and Nawabpura, respectively. The primary hub for the processing, burning, and acid leaching of e-waste is Nawabpura. The findings demonstrate that the surface soil of the e-waste burning and acid leaching sites still contained considerable concentrations of heavy metals from burning and recycling printed circuit boards, including Pb, Cd, Cr, Zn, Ni, Cu, and Fe. Additionally, industrial waste has impacted the surrounding communities, posing a possible environmental danger (Singh et al., 2018).



As the per the study of agricultural soils in the Amritsar district, the levels of Cu, Cr, Pb and Zn exceeded the safety limits. If these metals accumulate in soils, there is a chance that they will find their way into food crops which might be harmful to local's health (Kaur et al., 2019). Surface soil was examined later in the year in the Karba Basin, India's largest coal-burning region. An analysis of pollution indices revealed extremely high levels of contamination, especially with regard to arsenic, lead, nickel, and arsenic content, which were determined to be over the safety limits in both arsenite and arsenate forms (Sharma et al., 2019). The level of heavy metal contamination in northern Telangana's agricultural soils has been assessed through a study. Northern Telangana's agricultural soils had varying degrees of heavy metal contamination, with levels of Ba, V, Zn, and Cu exceeding advised limits. Copper has the greatest geo-accumulation index, suggested significant contamination. Overall, low to moderate soil pollution was indicated by the pollution indices (Adimalla, 2019). In order to determine the degree of pollution from heavy metals soil samples collected from Nalagarh Valley, Himachal Pradesh by using chemometric analysis and geochemical indices to determine the ecological risks and sources of pollution. Cadmium, lead, and copper all progressively contributed to soil deterioration, offering a low to moderate ecological danger, according to the geochemical indices. According to Principal Component Analysis, there was three major origins of pollution in this: industrial and human activities that affect copper, lead, and zinc; geological processes like weathering that affect chromium and manganese and a mixed natural-anthropogenic source that influenced the accumulation of arsenic, cadmium, chromium, iron, manganese, and lead (Rajkumar et al., 2019). Numerous harmful substances were present in the soils around the Central Elbe River in Germany, particularly in the topsoil. Chromium, copper, nickel, and zinc

concentrations were above the acceptable ranges for sandy soils. Concerning levels of vanadium, lead, and arsenic were also discovered. The majority of metals were more concentrated in the topmost layer than in the lowermost layer and overall contamination was moderate to high. Children are exhibited to significantly higher quantities of arsenic, chromium, lead, and vanadium than adults, per the health risk assessment. (Rinklebe et al., 2019). Turkey largest city, Konya, has served as the seat of numerous civilizations. High concentrations of many trace elements, especially arsenic, chromium, and nickel exceeded both national and international safety limits in the soils of the Konya region of Turkey. Both natural geological formations and human activity like mining, manufacturing, farming, and waste disposal were associated with the occurrence of these elements. Concerning concentrations of cobalt, molybdenum, lead, antimony, and strontium was also found in some places, which could be harmful to human health (Horasan and Arik, 2019). The soils contained trace amounts of heavy metals in Istanbul's Tuzla District, with low to moderate contamination found in the majority of places. In broad terms, soils were categorized as uncontaminated to mildly contaminated using the geo-accumulation index (Igeo). Moderate enrichment by elements like copper, lead, zinc, cadmium, and mercury was indicated by the enrichment factor (EF). With the exception of two sites (SL1 and SL2), According to the estimated ecological risk and risk index, most sampling locations had low ecological risk, while some had intermediate ecological risk. (Sezgin et al., 2019). Toxic elements like Cd and Hg were highly contaminated in the agricultural soils close to the Jiyuan smelter in China posed serious threats to people well-being and the nature. Metal concentrations showed the substantial influence of industrial emissions maximum close to the smelter and declining with distance. Every sampling location was deemed to be extremely



contaminated and to pose a significant ecological risk. According to health risk evaluations, Children are more vulnerable to both cancer-causing and non-cancerous dangers than adults, primarily as a result of exposure to arsenic (Wu et al., 2019).

Similarly, in 2020, scientists evaluated the contamination caused by heavy metals in the urban soils of India's Medak Province. With the exception of zinc, the levels of As, Cd, Cr, Cu, Ni, Pb, and Zn were higher than WHO guidelines. The geo accumulation index data indicated that there is moderate to heavy pollution for the majority of metals (Adimalla, 2020). The purpose of this study was to ascertain the levels of dangerous heavy metals in the soil from small-scale gold mining activities in Myanmar. The findings indicated that the soil at these mining locations had higher concentrations of heavy metals. Metal intake was found to be less than 1, indicated that ingestion was safe (Tun et al., 2020). Heavy metals included in factory wastewater can eventually build up in soil deposits along waste water routes and in the organisms that live there. Another study claims that soil and wastewater samples were taken from open drainage ditches in Kenya's Nairobi industrial region. Hg, Pb, Cr, Cd, and Ni levels in soil samples were higher than WHO recommendations for agricultural soils and wastewater samples suggested significant pollution. This demonstrated that the soils in open trash channels had accumulated hazardous metals (Kinuthua et al., 2020). Human health is seriously impacted by the ongoing rise in heavy metal concentrations in soils brought on by careless farming methods. Researchers looked into the levels of heavy metals, including soil, in Sinop Province, Turkey. The findings showed that the amounts of Cr, Ni, As, and Pb were greater than usual limits, indicated that localized enrichment that was probably caused by human activity. Furthermore, multivariate statistical analysis

showed that anthropogenic sources, including agricultural runoff and associated land-use practices, were the main source of As, Cr, Ni, Pb and Zn pollution. The non-carcinogenic hazards from exposure to these metals were found to be within safe limits for adults but over the acceptable range for children (Baltas et al., 2020). Heavy metals like Cadmium, copper, chromium, zinc and lead and was present in agricultural soils in Morocco northeast Tadla plain primarily as a result of human activity. These metals concentrations were higher above safety limits particularly for copper and zinc. Localized contamination was highlighted by the results, which indicated moderate to significant pollution for several metals even though the overall ecological danger was deemed low (Ennaji et al., 2020).

Sialkot, Pakistan, is a major center for the production of leather and surgical equipment's. These industries produced a lot of solid waste, the most of which is dumped in landfills. The results showed that the amounts of lead and copper in the soil were higher than allowed. Due to high exposure to these metals' health risks particularly children's more vulnerable than adults. Chromium exposure in children was near the dangerous threshold for lifelong cancer risk (Ahmad, 2021). Soil samples from SAS Nagar district of Punjab was analyzed for the investigation of heavy metals. Results showed soil predominated with Lead. Concentration of Cr, As and Pb was provided serious health concerns in this area. As per this study, children were more vulnerable than adults to both carcinogenic and non-carcinogenic hazards (Sonkar et al., 2021). In Uttar Pradesh, India, researchers collected the agricultural soil and crops that were irrigated by the Kali River.. Investigations showed that soil and crops samples are contaminated with cadmium, iron, zinc and manganese. The regions heavy metal contamination levels are generally modest to moderate. However, if such food is consumed over time, the



accumulation of cadmium, manganese, and zinc in crops may provide health hazards (Singh et al., 2021). Heavy metal contamination in China's agriculture and urban soils is well covered by the meta-analysis of 713 articles published between 2000 and 2019. Results revealed that cadmium (Cd) is the primary pollutant was shown double to triple increased over background levels with approximately one-third of farmland and nearly half of urban soils contaminated by Cd. Overall, heavy metal concentrations had remained relatively stable over the past two decades, but urban areas exhibited higher pollution levels than farmland, particularly in the middle Yangtze River region where industrialization is intense. Heavy metal pollution, especially Cd contamination, remains a significant environmental concern in China (Yuan et al., 2021). The characteristics of soil and the concentrations of harmful and critical metals are impacted by prolonged fertilizer application. Samples of soil and plants were gathered from the All India Coordinated Research Project on Long-Term Fertilizer Experiments' Bengaluru location, which is situated in India's subregion AESR 8.1. Several fertilizer treatments were used in the study, including 150% NPK, 100% NPK with lime, 100% NPK with farmyard manure (FYM), 100% NPK, 100% NPK, 100% NPK, 100% NPK, and 100% NPK with phosphorus and potassium (NPK). The results showed that applying higher amounts of nitrogen (100% N) had not changed the DTPA-extractable zinc (Zn) levels in the soil. Similarly, added N, NP and NPK fertilizers had little effect on the amount of available Zinc, iron, manganese, and copper. Because of the constant fertilizer application, heavy metals like cadmium (Cd), lead (Pb), nickel (Ni), cobalt (Co), and chromium (Cr) only marginally accumulated in the soil under the finger millet–maize cropping system. Due to the usage of fertilizer and lime, these metals were also found in the grains of finger millet and maize. A health risk assessment (Hazard

Quotient, HQ) was conducted to determine whether eating these grains could be harmful to people (Adhikari et al., 2021).

Investigations along Buddha Nullah in Ludhiana show that industrial and urban effluents are the main cause of the extensive heavy metal contamination in the water, soil, and crops. While soils indicated high cadmium (Cd) deposition and excessive levels of other metals, with rice and wheat grains surpassing allowed limits, water quality examinations revealed heavy metal pollution index (HPI) values above safe standards. Significant metal transport from soil to plants was confirmed by bioaccumulation factors, with chromium, nickel, and cadmium presenting the highest carcinogenic risks. Even though ecological risk evaluations only recommended low to moderate hazards, follow-up examination of roadside soils along Buddha Nullah revealed moderate to high metal concentrations. Multivariate analysis also linked metal sources to both natural and man-made activities. In order to safeguard environmental health and lower human exposure in the Buddha Nullah region, these findings collectively demonstrate the urgent need for stronger regulation of effluent discharge, routine soil and water quality monitoring, and focused remediation techniques (Dhaliwal et al., 2021, Kaur et al., 2022). Several environmental and health associations have categorized arsenic as toxic and dangerous for the environment. Approximately 200 million people worldwide are at serious risk of arsenic poisoning, according to multiple reports, as a result of potential exposure to deadly quantities of the metal in soil, drinking water, irrigation water, and edible plant tissues. Arsenic (As) poisoning of food crops, soils, and groundwater in Pakistan's Punjab and Sindh provinces is a serious environmental and public health issue. A major route for human exposure is created by the widespread distribution of arsenic in drinking and irrigation water, which raises the



possibility of bioaccumulation in soils and edible plants. Chronic exposure to arsenic even at low levels can cause serious health problems, such as cancer (Khalid et al., 2022). The effects of fly ash on the soil environment have drawn increased attention from experts in recent years. In industries, managing waste has become one of the biggest and most difficult challenges. The study around the Bandel Thermal Power Station (BTPS) in West Bengal showed that the levels of heavy metals and metalloids (zinc, iron, copper, manganese, lead, and arsenic) in nearby soil were mostly within safe limits suggested little contamination. Most of these elements, except arsenic and lead are important nutrients for plants, which means their current amounts are not likely to cause serious environmental harm (Mandal et al., 2022). Large regions in developing nations like Zambia have been impacted by previous and current mineral mining and smelting, which has led to long-term exposure to heavy metals in the soil, water, plants, animals, and people. Excessive exposure to heavy metals has been linked to a number of health concerns, including heart disease, skin blemishes, organ malignancies, and reproductive disorders. (Salem et al., 2020, Setia et al., 2021). Researchers measured the heavy metal pollution in soil near mine waste dumpsites in Kitwe and Mufulira, Zambia, close to residential areas. It found that copper and cobalt were the main pollutants with high soil contamination at some sites, but overall ecological risks were low. The polluted soils can spread contaminants through wind and water (Dusengemungu et al., 2022). Agricultural soils in the Rae Bareilly District of Uttar Pradesh was affected by varying levels of heavy metal contamination, largely due to human activities such as industry, agriculture, and mining. The Uchahaar site showed the highest pollution levels particularly for copper, zinc, lead, manganese, strontium, and arsenic while the Bacharawa site was the least contaminated. Pollution indices and GIS mapping revealed that the northern region of

Rae Bareilly faces higher ecological risk. Overall, the soils were slightly to moderately polluted with some areas showed severe contamination (Neeraj et al., 2022).

Next study conducted in Rampal Upazila, Bangladesh focused on analysis of levels of toxic metals in soil. The findings of this study suggested that amount of metals in soil was below the permissible limit, except the lead (Pb). Environmental indices confirmed this result, Pb only is the metal exhibited the high level beyond the safety limit. This area was particularly polluted with Lead (Parvez et al., 2023). Researchers found that the surface soils of Kerala state's Kollam area were heavily contaminated with Fe, Cu, Pb, and Zn (George et al., 2023). Shanghai's city has been at the center of China's industrialization for over a century. Samples of soil were taken from Shanghai's agricultural fields in order to evaluate the levels of toxic metals in the soil. Despite the Shanghai long history past. This study revealed that the amounts of metals in agricultural soil are often within the safe limits. According to spatial analysis, the amount of Cd, Cr and Hg were high in industrial areas. In some areas, use of excessive fertilizers may also be factor of contamination (Li et al., 2023). Similarly, Brazil continues to dispose of waste outside, which has led to worries about soil contamination in the neighborhoods around these disposal sites. Researchers assessed a deactivated dumpsite in Southern Brazil for potential environmental hazards. This study found that leaching and dispersion had caused soil pollution due to the dumpsite in this area. As per the findings of pollution index, the dumpsite area was contaminated with heavy metals. However, both environmental hazards and health threats were low (de Souza et al., 2023). In India, studies along the Satluj river was revealed more critical situation due to metal pollution. Groundwater, river and canals like the Beas and Satluj river are the major origin of irrigation (Setia et al., 2021). To



investigate the relationship between heavy metals and plants, soil and wheat grain samples were collected within 5km buffer zone of Satluj river in Punjab. Collected samplers were highly contaminated with Cd and Zn. Cadmium posed the highest ecological risk in soils and Zn showed greatest bioaccumulation in wheat grain. Based on the evaluation of health risks, Pb is the primary cause of non-carcinogenic risk, while Cd is the primary carcinogenic threat (Setia, 2023). Thermal power plants release fly ash containing toxic heavy metals such as As, Cd, Cr, Pb and Hg into the environment. Agricultural soils near thermal power plants often show elevated concentrations of Cadmium, chromium and lead were exceeded safe limits. Crops grown in contaminated soil accumulate heavy metals, posing risks of food-chain transfer and human exposure. In Jharkhand, fly ash from the Bokaro thermal power station was contaminated soil with toxic elements like cadmium, chromium and lead. Cadmium showed the highest contamination and geoaccumulation factor. According to health risk assessments, adults were more likely to experience non-carcinogenic consequences from their intake of Cd, Pb, and Cr, even if the child population was under safe levels ($HQ < 1$). Furthermore, the higher target carcinogenic risk values for Pb and Cr suggested that adults may be at risk for cancer (Singh et al., 2023). Agricultural soils near Buddha Nullah in Ludhiana, Punjab, are slightly alkaline but contaminated with heavy metals such as cadmium, chromium, cobalt, copper, and lead, often exceeded permissible limits (Sharma et al., 2023). In the same year, 30 agricultural areas in Punjab's Ferozepur District, the dangers to human health posed by soil pollution by arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, uranium, and zinc were evaluated. Toxic metals such as lead, zinc, arsenic, and cadmium from both natural and man-made sources was highly present in the research area soils.

Children was particularly susceptible to ingested arsenic, and ecological danger was ranging from minimal to significant. Residents was also at danger for long-term cancer from arsenic and chromium (Kaur et al., 2023). The purpose of the study was to evaluate how industrialization affected the levels of heavy metal contamination in the agricultural soils of Sonapat, a New Delhi satellite city in the state of Haryana. Heavy metal analysis was performed on 23 agricultural soil samples that were gathered from various sites within the study area. It was discovered that the agricultural soils were tainted with Cd, Pb, Mn, Ni, and Zn. The majority of the soil samples had a moderate potential ecological concern because of the presence of cadmium. The examination of enrichment factors revealed that whereas nickel and lead came from both natural and human sources, cadmium, manganese, and zinc in agricultural soils were mostly anthropogenic (Rani et al., 2023). Electronic garbage in underdeveloped nations is either processed in recycling facilities or disposed of in landfills where heavy metals seep into the surrounding environment. Heavy metals, especially Cu, Pb, and Cd, was present in the surface soils of Lahore's recycling facilities and disposal sites. The average levels of Copper, cadmium, lead and zinc in recycling facilities were higher than acceptable limits, while the levels of Cu in disposal sites were higher than WHO guidelines. According to a health risk assessment, children who lived close to recycling centers was not at risk for Pb cancer, while adults and children was at low but significant risk for Cu cancer (Shakil et al., 2023). It was discovered that different heavy metals from mining operations have contaminated the soils in the Oke-Ere mining area in Yagba West, Kogi State (Nigeria). Scandium, chromium, nickel, and arsenic were identified as major pollutants linked to human activities. The study revealed severe pollution caused by scandium and moderate pollution by tin while other metals showed slightly



moderate contamination. Although the non-carcinogenic risks were within safe limits, the cancer risk through consumption and skin contact was above acceptable levels, posing potential health concerns for residents (Oluwasola et al.,2023).

In Poland, Scientists collected total 30 samples from post -mining mounds in forest areas and the surroundings. Investigation showed that the post- mining mounds was moderately polluted with metals. The overall abundance of the nine elements under analysis followed the order Fe> Mn> Cr> Zn> Ni> Cu>Pb > Cd with only Fe and Mn was significantly above the allowable limits (Podgorske and Jozwiak, 2024). The Ministry of Environmental Protection and the Ministry of Land and Resources released the National Soil Pollution Survey Report in 2014, which stated that the Yangtze River Delta, Pearl River Delta, and the established industrial bases in Northeast China had significantly exceeded the allowable limits for inorganic pollutants, particularly heavy metals, as a result of insufficient control measures and uncontrolled discharges (Cheng et al.,2017). At the present time, the primary contaminants influencing the environmental condition of China's soil are heavy metals. From the decades, heavy metal pollution became major environmental and human health concern in China due to mining and smelting activities. This study suggested that pollution is linked to both natural and anthropogenic sources. In this area, children are especially at risk for both carcinogenic and non- carcinogenic health concern due to the accumulation of toxic elements (Adnan et al., 2024). In the same year, research conducted that concentrated on Jinchang City in northwest China, where a sizable smelter has long had an influence on the local ecology. The goal of the study was to investigate the accumulation of copper (Cu) and nickel (Ni) in wheat and surrounding soils. Their analysis revealed that both metals were found in agricultural soils at

concentrations higher than those considered safe. Upon thoroughly examining the wheat plants, they discovered an intriguing pattern, copper was concentrated in the roots, while nickel accumulated more in the leaves. fortunately, the edible grains only contained trace levels of these metals. According to the results of the health hazard evaluation, adults who ate the local wheat were not at serious risk. Nickel exposure, however, continued to be a problem for kids. The study conclusion provided a clear message, if heavy metal contamination is to be decreased and food safety is to be maintained in the area, targeted soil cleanup and ongoing monitoring are crucial (Xu et al., 2024). Another study was carried out in China to look at the sources of heavy metals and potential health hazards. Investigation revealed that soils was moderately contaminated with cadmium and arsenic. Cadmium poses the highest environmental hazard. Source apportionment using positive matrix factorization (PMF) identified three major contributors to heavy metal contamination: pesticide application (36.5%), fertilizer input and transportation (20.5%), and mining and metallurgical activities (43.1%) in this area. Human Health Risk Assessment model suggested that more than half of the samples (56%) posed a potential carcinogenic risk to children (Gao et al.,2024).

One more recent study highlighted the effects of mining on soils in Raniganj, India. According to this research coal mining, industrial operations and human activities are the main cause of metal pollution in soils of Raniganj. This study found that, are considerable ecological effects and significant carcinogenic health risks, especially for children. Soil were contaminated with Cd, Cr and As (Angon et al.,2024). Soil quality assessments in Hoshiarpur, Punjab, indicated that cobalt, chromium, and lead had remained within safe limits while zinc and manganese exceeded safety limits (Dadwal et al.,2024). Long-term



untreated effluent discharge from tanneries, textile units, electroplating, and other businesses has resulted in significant soil and groundwater contamination in Kanpur, Uttar Pradesh's industrial regions. Soils exhibit greater deposition of heavy metals than groundwater, and elevated levels of chromium, cadmium, lead, and nickel are frequently recorded, which is extremely dangerous for both the environment and human health (Upadhyay et al., 2024). Soil surrounding the four coal thermal power plants in Chennai, Korba, Rupnagar, and Udupi contained a variety of metals. The highest metal concentrations were found in Rupnagar soil samples, followed by Chennai, Korba, and Udupi. Hazard index (HI) scores for both non-cancerous and cancerous hazards stayed within USEPA limits despite the presence of numerous metals, indicated that there were not many acute health dangers to the residents (Ravindra et al., 2024). Soils in the Batala region of Punjab was moderately contaminated with metals such as Cd, Zn, and Ni, exceeded the permissible limits. Ecological risk assessments were indicated cadmium, nickel, and zinc as the main culprits and soil pollution indices identified that six highly contaminated locations. Children was more susceptible to exposure to metals (Bala et al., 2024). To evaluated the geology and hydrological characteristics, soil and water samples were collected from the Wariyana dumpsites in Kapurthala (Jalandhar) and the surrounding areas of the dumpsite. Analysis revealed that pollutants levels were found to be excessive, especially for heavy metals such as lead was the primary contributor. These results highlighted how urgently better waste management procedures, appropriate leachate treatment, and routine monitoring are needed to preserve the quality of soil and groundwater and protect human health (Sankalp et al., 2024). In Uşak, western Türkiye, Scientists measured the levels of arsenic, copper, mercury, nickel, and lead in 48 agricultural soil samples to check for

pollution and its sources. The results showed that arsenic and nickel levels were much higher than normal compared to Earth's crust and other countries. Various pollution indicators found that most of the area had some level of contamination, with about 38% of the land showed moderate to high ecological risks and 75% being moderately polluted. Pollution was mainly seen in the northeastern and southwestern parts. The main causes of this pollution were industrial activities and heavy use of fertilizers and pesticides (Yildiz and Ozkul, 2024). One more study conducted in Ernakulam district, India, found that farmlands near busy commercial areas had more microplastics and heavy metals in the soil compared to rural fields. The main types of microplastics found were polypropylene and polyethylene. The levels of pollution were high enough to be concerning. Heavy metals like copper, zinc, and arsenic were especially common in these commercial area farmlands, which could harm the agricultural environment. The study says urgent steps are needed to reduce this pollution to protect farming and food safety (Borah et al., 2024).

During the "Green Revolution," which promoted the use of agrochemicals such chemical fertilizers, insecticides, weed killers, and fungicides as well as intensive farming methods. Heavy metal poisoning of the soil resulted from the remarkable agronomic growth in the Indian state of Punjab. The distribution of heavy metals in Haryana roadside soils revealed that road distance and traffic intensity had an impact on the concentrations of Cd, Cu, Cr, Zn, Ni, Mn, and Pb. The findings showed that soils along the National highway had the highest levels of metals followed by those along the state highway, the levels decreased with increasing distance from the road. The higher amount near highways demonstrated that vehicles emissions continue to contribute to soil pollution (Kumar et al., 2025). In modern era,



open dumping is still a popular method of getting rid of municipal solid waste (MSW). The amount of MSW produced continues to grow yearly due to the fast growth of cities and changing consumer habits that result in higher consumption (Alam et al., 2020). Global trash is predicted by the World Bank to increase by 3.40 billion tonnes per year by 2050, outpacing the rate of population growth, which is predicted to double over that time (Maalouf and Agamuthu, 2023). According to new research, soil and groundwater was highly polluted with Cr, Ni and Pb due to open dumping of municipal waste in Bhandewadi dumpsite, Nagpur (India) and this pollution poses a grave threat to the wellbeing of residents in the vicinity (Drall et al., 2025). The Saldha River flows through a landscape of factories, farms, and villages in Gazipur, Bangladesh, which is an industrial center. As a result of fast industrialization, the Saldha River's waters are contaminated by wastewater from textile and dyeing plants. Researchers developed a new model that considers the effects on human health as well as environmental degradation in order to comprehend the dangers. They tested soil, wastewater, and plants samples for eight metals: Cu, Fe, Mn, Zn, Ni, Cr, Pb, and Cd. The findings were concerning, levels of cadmium, a dangerous element with no protective function in the body, were shown to be more than two thousand times greater than usual, indicated clear signs of industrial pollution. In Gazipur, health risk assessments revealed hazardous metal exposure for both adults and children. The structure of the study is equally applicable to industrial areas across the globe, including Europe, North America, and Southeast Asia (Sahen et al., 2025). Heavy metals in scrap metal recycling sites pose serious risks to human and environmental health. long-term metal recycling activities in the Vietnam location have resulted to severe contamination of both soil and crops, causing major health issues faced by residents. The soil is moderately to severely polluted, according to the pollution index

values, and crops, especially those that include manganese and zinc, have higher concentrations of heavy metals than is safe limits. Rice is the main exposure pathway, accounting for more than 80% of the total hazard and cancer risk, according to health risk assessment, which also shows increased non-cancer and cancer hazards. (Nhan et al., 2025). In Semi- arid areas of South Punjab region, mainly in the Bathinda district, researchers analyzed the contamination of agricultural soils. According to the results, cadmium is the main pollutant of concern because its concentrations in a number of soil tests are higher than international standards. The usage of phosphatic fertilizers is primarily responsible for cadmium contamination in this locality. Both the Ecological Risk Index and the Pollution Load Index suggested that increasing environmental stress on the agroecosystem and moderate to significant ecological risk. There are currently little health concerns, but future hazards could arise from ongoing metal accumulation, with eastern Bathinda showing higher levels of contamination (Kaur et al., 2025). According to pollution indices, arsenic and lead were found to be the main pollutants in the soils of Punjab. Principal component analysis revealed that both natural and human activities have an impact on the soil composition (Tiwari et al., 2025). Cadmium contamination in industrial areas like Bawana, Kasana and Okhla in New Delhi were exceeded WHO recommended limits in soil samples, which posed severe environmental and public health threat. The severity of the issue is highlighted by the fact that several pollution indices, such as the contamination factor, degree of contamination, heavy metal pollution index, and geo-accumulation index, all showed dangerously high levels of Cadmium (Sable et al., 2025). In Pakistan Hafizabad district, irrigation with inadequately treated wastewater causes a considerable buildup of potentially hazardous metals in soils and Basmati rice grains. Considering the moderate

to very high levels of soil pollution, there was no ecological risk. The results, however, highlighted the possibility of long-term accumulation because ongoing wastewater irrigation may raise potentially toxic metals concentrations in crops and soil, which could then pose health hazards (Younas and Younas, 2025). The Kashmir Valley saffron-growing soils are undergoing major geochemical changes as a result of human activity and industrial pollution. Areas affected by industrial activity have higher amounts of heavy metals, especially arsenic and chromium, with pollution indices shown moderate to severe contamination. These results showed that saffron cultivation and possibly other crops are directly threatened by industrial pollution and heavy metal deposition, which might damage the socioeconomic stability of the area (Ayoub et al., 2025). The analysis of agricultural soils near the coal power plant in Sahiwal, Pakistan, revealed that the concentrations of Cadmium, Copper, Chromium, Lead and Manganese were all within permissible limits, indicating no immediate threat to soil quality or agricultural productivity. Overall, the findings suggested that current coal power plant operations have not resulted in detectable adverse heavy metal contamination in the study area. However, continuous monitoring is recommended to ensure long-term soil health and to prevent potential risks associated with prolonged industrial activity (Ahmad et al., 2025). In the town of Novocheboksarsk in South Russia European region, Power stations that burn coal are a major source of pollution for the environment because the heavy metals that are deposited in the soil cause substantial ecosystem damage and exacerbate the negative effects of human activity. This study found that heavy metal concentrations, such as Pb, Zn, Cu, Ni, Mn, Cd, and Cr, exceeded safe limits, affecting soil quality and increasing freshwater, marine, and terrestrial ecotoxicity by more than 30%. (Kravchenko et al., 2025).

Human Health Hazards from Heavy Metal Contamination

In several developing nations, such as, India, Bangladesh, South Africa, Pakistan, Ethiopia, and Ghana, high levels of heavy metals have been documented, particularly in their cities. A few additional anthropogenic activities, wastewater irrigation, and fast industrialization are the primary reasons. Humans may become poisoned by heavy metals through direct skin contact, ingestion, or inhalation (Table 4). The majority of current instances of certain heavy metals have been linked to lead, arsenic, cadmium, and mercury poisoning in humans. Ingestion of leaded paint, coating in food packaging, and industrial exposure at work are their main human causes. According to the World Health Organization (WHO), heavy metals in food and drinking water must remain within safe limits to prevent chronic health risks (Table 2 and 3).

Table 2: Permissible limits for heavy metals in drinking water

Heavy metals	WHO guidelines values for drinking water
Arsenic (As)	0.01 mg/L
Cadmium (Cd)	0.003 mg/L
Chromium (Cr)	0.05 mg/L
Lead (Pb)	0.01 mg/L
Nickel (Ni)	0.02 mg/L
Mercury (Hg)	0.001 mg/L
Copper (Cu)	2.0 mg/L
Iron (Fe)	0.3 mg/L
Manganese (Mn)	0.4 mg/L
Zinc (Zn)	3.0 mg/L

Table 3: Permissible limits for heavy metals in Food crops

Heavy metals	WHO guidelines values for food crops
Arsenic (As)	0.015mg/kg ⁻¹
Cadmium (Cd)	0.007 mg/kg-1
Chromium (Cr)	1.4 mg/kg-1
Lead (Pb)	0.025 mg/kg-1
Nickel (Ni)	0.035 mg/kg-1
Mercury (Hg)	0.0016 mg/kg-1
Copper (Cu)	0.5 mg/kg-1
Iron (Fe)	126 mg/kg-1
Manganese (Mn)	35 mg/kg-1
Zinc (Zn)	105 mg/kg-1

Table 4: Heavy Metal Exposure Routes from Soil to People

Pathway	Description	Heavy Metal s	Health Impact
Ingestion	Eating contaminate d crops /soil particles	Cd, As and Pb	Gastrointestinal , renal damage
Inhalatio n	Breathing dust particles	Pb, Cr, Ni	Respiratory toxicity, lung cancer
Dermal Contact	Skin exposure to contaminate d soil	Cr, Ni	Allergies, dermatitis

Table 5. Heavy metals toxicological consequences on public health

Heavy metals	Toxicity
Arsenic	Cancer, Arsenicosis (Skin conditions such as skin pigmentation, and skin lesions), Cardiovascular diseases, Gastrointestinal disorders
Chromium	Lung cancer, injury to the skin, dermatitis, kidney and hepatic injury, cancer
Cadmium	Renal and hepatic disorder, respiratory disorders

Lead	Neurological, cardiovascular, renal, hematological and reproductive effects
Mercury	Impairment of intelligence and mood, low birth weight, behavioral dysfunction, delayed neurodevelopment in children
Nickel	Hair loss, eczema, oral and prostate cancer, Congenital abnormality, respiratory disorder and chronic bronchitis
Zinc	Vomiting and Nausea, paleness, renal and hepatic failure and prostatic carcinoma
Copper	Anemia, osteoporosis, skeletal problems, gastrointestinal distress, liver and kidney toxicity
Manganese	Neurological effects, causing tremors, difficulty walking, and cognitive issues
Iron	Nausea, vomiting, abdominal pain, and diarrhea

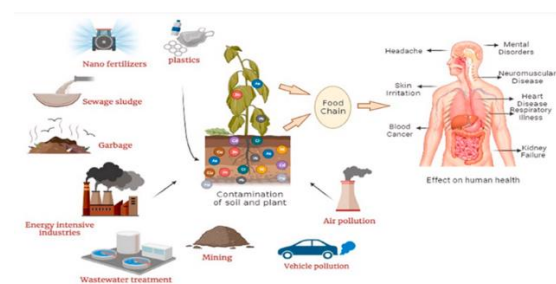


Figure 3: Health risks from heavy metal contamination

Arsenic, a toxic element often referred to as the 'king of poisons' presents a significant risk to public health because of its carcinogenic qualities. It is highly oncogenic and has been linked to cancers of the skin, lungs, prostate, and liver, high blood pressure, neurological disorders, diabetes mellitus (Herawati et al., 2000). Characteristic skin lesions, including pigmentation changes and melanoacanthoma,



keratosis are commonly observed signs of chronic arsenic exposure (Mazurek et al., 2017). Cadmium (Cd) is ranked as the sixth most dangerous toxin that affects human health by the Agency for Toxic Substances and Disease Registry. Calcium shortage and related issues including bone fractures and cartilage degradation are caused by Cd's interference with calcium absorption. Bone fractures and cartilage diseases can develop from a calcium shortage caused by cadmium's disruption of calcium metabolism (Singh and Kalamdhad, 2011). Cd poisoning has been shown to produce a number of harmful consequences on cellular molecules, primarily through imbalance of oxidants and antioxidants. Additionally, Cd has been implicated in the development of many cancers. Hypertension, diabetic nephropathy, peripheral artery disease, myocardial infarction, and itai-itai sickness (Ghosh and Indra, 2018). Furthermore, Pb is not a necessary element for human health, and too much of it can negatively affect the immunological, circulatory, skeletal, enzymatic, endocrine, neurological, and endocrine systems (Kankia and Abdulhamid, 2014). In China, survey conducted by researchers, it was observed that lead-contaminated soil dust in urban areas significantly impacted human health, particularly among children. The survey revealed that approximately 30% of Chinese children had blood lead levels exceeding the national safety limit of 100 µg/L, with the percentage rising to over 60% in urban regions. Additionally, according to Yabe et al. (2010), there was a significant exponential relationship between the amount of lead in urban soil and the lead concentration in children's blood, with $\text{blood Pb} = 18.5 + 7.2 \times \text{soil Pb} \pm 0.4$. It adversely affects various organs and systems, particularly the liver, kidneys, and reproductive system, as well as the neurological, urinary, and immune systems. Additionally, it disrupts essential cellular functions and gene regulation (Gerhardsson et al., 2002).

Mercury is among the most hazardous heavy elements for the environment, which is extremely poisonous. There are two common names for mercury poisoning: acrodynia and "pink disease." Numerous industries, including as the pharmaceutical, pulp and paper, agricultural, bleach, and sulfur-based soda manufacturing sectors, release mercury into the atmosphere (Morais et al., 2012). Human exposure to chromium (Cr) can cause skin ulcers, respiratory tract cancer, gastrointestinal hemorrhage, and allergic dermatitis. In addition, it may affect the kidneys, liver, and mucosal membranes (Arora et al., 2017).

Although copper (Cu), zinc (Zn), and nickel (Ni) are essential trace minerals for preserving human health, excessive exposure to these metals in the environment might have negative consequences. A significant public health concern is the potential for Ni and Cu to cause cancer, particularly their capacity to promote the growth of tumors. Research indicated that exposure to nickel powder increases the risk of lung cancer in workers, and elevated environmental nickel levels are directly associated with nasopharyngeal carcinoma. (Chen, 2011). Heavy metals classified as Group 1 carcinogens by the International Agency for Research on Cancer (IARC) include cadmium (Cd), hexavalent chromium [Cr (VI)], arsenic (As), and nickel (Ni), meaning that they are known to cause cancer in people. When these metals are present in the air, they constitute a serious risk to the environment and can significantly harm the health of individuals who are exposed. Numerous health problems, such as lung cancer, cardiovascular diseases, hypertension, renal damage, reproductive dysfunction, neurological disorders, asthma, and bronchitis, have been connected to exposure to such heavy metals. Furthermore, heavy metals can impair cognitive development in kids, leading to behavioral issues, learning difficulties, and a reduced IQ (Ghosh et al., 2023).

Conclusion

Soil contamination by heavy metals is a major environmental and public health issue worldwide. In addition to negatively impacting soil fertility, microbial diversity, and plant growth, the buildup of hazardous metals like lead, cadmium, arsenic, and mercury in agricultural and urban soils also directly exposes humans through the food chain, water, and air. Severe health effects, such as neurological, renal, cardiovascular, and developmental issues, can arise from long-term exposure to certain metals. Integrated strategies combining efficient pollution management, soil remediation technologies, sustainable farming methods, and stringent regulatory frameworks are needed to address this problem. To reduce human exposure, monitoring programs must be strengthened and public awareness must be increased. In the end, long-term food security and environmental health depend on sustainable management of soil ecosystems.

References

- [1] Acharya, S. (2024). Heavy metal contamination in food: Sources, impact, and remedy. In *Food safety and quality in the Global South* (pp. 233–261). Springer Nature Singapore.
- [2] Adelekan, B. A., & Abegunde, K. D. (2011). Heavy metals contamination of soil and groundwater at automobile mechanic villages in Ibadan, Nigeria. *International Journal of Physical Sciences*, 6, 1045–1058.
- [3] Adhikari, T., Gowda, R. C., Wanjari, R. H., & Singh, M. (2021). Impact of continuous fertilization on heavy metals content in soil and food grains under 25 years of long-term fertilizer experiment. *Communications in Soil Science and Plant Analysis*, 52, 389–405.
- [4] Adimalla, N., & Wang, H. (2018). Distribution, contamination, and health risk assessment of heavy metals in surface soils from northern Telangana, India. *Arabian Journal of Geosciences*, 11, 684.
- [5] Adimalla, N., Chen, J., & Qian, H. (2020). Spatial characteristics of heavy metal contamination and potential human health risk assessment of urban soils: A case study from an urban region of South India. *Ecotoxicology and Environmental Safety*, 194, 110406.
- [6] Adimalla, N., Qian, H., & Wang, H. (2019). Assessment of heavy metal contamination in agricultural soil lands in northern Telangana, India: An approach of spatial distribution and multivariate statistical analysis. *Environmental Monitoring and Assessment*, 191, 246.
- [7] Adnan, M., Xiao, B., Ali, M. U., Xiao, P., Zhao, P., Wang, H., & Bibi, S. (2024). Heavy metals pollution from smelting activities: A threat to soil and groundwater. *Ecotoxicology and Environmental Safety*, 274, 116189.
- [8] Afzal, M., Shabir, G., Iqbal, S., Mustafa, T., Khan, Q. M., & Khalid, Z. M. (2014). Assessment of heavy metal contamination in soil and groundwater at leather industrial area of Kasur, Pakistan. *CLEAN – Soil, Air, Water*, 42, 1133–1139.
- [9] Ahmad, N., Akbar, S., Zafar, R., Mirza, S. S., Fatima, A., Afzal, U., & Afzal, M. A. (2025). Assessment of soil contamination by heavy metals in the vicinity of the Sahiwal coal power plant, Pakistan, employing an innovative statistical analysis approach. *International Journal of Environmental Analytical Chemistry*, 105, 2160–2173.
- [10] Ahmed, J., Wong, L. P., Chua, Y. P., Channa, N., Memon, U. U. R., Garn, J. V., & VanDerslice, J. A. (2021). Heavy metals drinking water contamination and health risk assessment among primary school children of Pakistan. *Journal of Environmental Science and Health, Part A*, 56, 667–679.
- [11] Akpoveta, O. V., Osakwe, S. A., Okoh, B. E., & Otuya, B. O. (2010). Physicochemical characteristics and levels of some heavy metals in soils around metal scrap dumps in some parts of Delta State, Nigeria. *Journal of Applied Sciences and Environmental Management*, 14, 57–60.
- [12] Alam, R., Ahmed, Z., & Howladar, M. F. (2020). Evaluation of heavy metal contamination in water, soil and plant around the open landfill site Mogla Bazar in Sylhet, Bangladesh. *Groundwater for Sustainable Development*, 10, 100311.
- [13] AL-jibury, D. A., & Essa, S. K. (2016). Using pollution indexes to assessment of heavy metals pollution in highway-side soils around Baghdad City. *Journal of Environment and Earth Science*, 6, 161–175.
- [14] Angon, P. B., Islam, M. S., Das, A., Anjum, N., Poudel, A., & Suchi, S. A. (2024). Sources, effects and present perspectives of heavy metals contamination: Soil, plants and human food chain. *Heliyon*, 10, e28357.
- [15] Anyanwu, B. O., Ezejiyor, A. N., Igweze, Z. N., & Orisakwe, O. E. (2018). Heavy metal mixture exposure and effects in developing nations: An update. *Toxics*, 6, 65.
- [16] Arora, S., Jain, C. K., & Lokhande, R. S. (2017). Review of heavy metal contamination in soil. *International Journal of Environmental Sciences & Natural Resources*, 3, 139–144.
- [17] Ayoub, I. B., Ara, S., Lone, S. A., Bhat, B. J. I., Bangroo, Z. A., & Padder, S. A. (2025). Geochemical characterization of saffron growing Karewa soils of Kashmir Valley, Western Himalaya (WH), India. *Earth Systems and Environment*, 9, 881–900.
- [18] Bala, N., Pakade, Y. B., Mahurkar, K. M., Minakshi, R., & Katnoria, J. K. (2024). Spatial distribution and source



- identification of metal contaminants in soil and rice grain samples: A study on exploration of soil quality and risk assessment. *Environmental Monitoring and Assessment*, 196, 260.
- [19] Baltas, H., Sirin, M., Gökbayrak, E., & Ozelik, A. E. (2020). A case study on pollution and a human health risk assessment of heavy metals in agricultural soils around Sinop province, Turkey. *Chemosphere*, 241, 125015.
- [20] Begum, A., Ramaiah, M., Harikrishna, K. I., & Veena, K. (2009). Analysis of heavy metals concentration in soil and lichens from various localities of Hosur Road, Bangalore, India. *Journal of Chemistry*, 6, 13–22.
- [21] Bhatti, S. S., Kumar, V., Singh, N., Sambyal, V., Singh, J., Katnoria, J. K., & Nagpal, A. K. (2016). Physico-chemical properties and heavy metal contents of soils and kharif crops of Punjab, India. *Procedia Environmental Sciences*, 35, 801–808.
- [22] Bhuiyan, M. A., Parvez, L., Islam, M. A., Dampare, S. B., & Suzuki, S. (2010). Heavy metal pollution of coal mine-affected agricultural soils in the northern part of Bangladesh. *Journal of Hazardous Materials*, 173, 384–392.
- [23] Bi, X., Feng, X., Yang, Y., Qiu, G., Li, G., Li, F., & Jin, Z. (2006). Environmental contamination of heavy metals from zinc smelting areas in Hezhang County, western Guizhou, China. *Environment International*, 32, 883–890.
- [24] Borah, A., Lekshmy, J., Sajna, P., & Devipriya, S. P. (2024). Assessment of microplastic and heavy metal pollution in agricultural soils of Ernakulam District, Kerala, India. *Environmental Monitoring and Assessment*, 196, 1090.
- [25] Bueno, P. C., Bellido, E., Rubí, J. M., & Ballesta, R. J. (2009). Concentration and spatial variability of mercury and other heavy metals in surface soil samples of periurban waste mine tailing along a transect in the Almadén mining district (Spain). *Environmental Geology*, 56, 815–824.
- [26] Chabukdhara, M., & Nema, A. K. (2013). Heavy metals assessment in urban soil around industrial clusters in Ghaziabad, India: Probabilistic health risk approach. *Ecotoxicology and Environmental Safety*, 87, 57–64.
- [27] Chen, N., Zheng, Z., He, X., Li, X., & Zhang, X. (2017). Analysis of the report on the national general survey of soil contamination. *Journal of Agro-Environment Science*, 36, 1689–1692.
- [28] Chen, Y. F. (2011). Review of the research on heavy metal contamination of China's city soil and its treatment method. *Chinese Journal of Population, Resources and Environment*, 21, 536–539.
- [29] Dadwal, V., Shikha, D., Gupta, S., Mehta, V., & Acharya, R. (2024). Elemental profiling of agricultural soil in Hoshiarpur utilizing analytical techniques. *Environmental Geochemistry and Health*, 46, 352.
- [30] Dantu, S. (2009). Heavy metals concentration in soils of southeastern part of Ranga Reddy District, Andhra Pradesh, India. *Environmental Monitoring and Assessment*, 149, 213–222.
- [31] Das, M., Patel, D. K., Sarma, A. K., Baruah, B. K., Banu, S., & Kotoky, J. (2016). Assessment of polycyclic aromatic hydrocarbons and heavy metals pollution in soils of Guwahati city, Assam, India. *Current Science*, 110, 2285–2292.
- [32] de Souza, V. B., Hollas, C. E., Bortoli, M., Manosso, F. C., & de Souza, D. Z. (2023). Heavy metal contamination in soils of a decommissioned landfill southern Brazil: Ecological and health risk assessment. *Chemosphere*, 339, 139689.
- [33] Dehghani, S., Moore, F., & Keshavarzi, B. (2017). Health risk implications of potentially toxic metals in street dust and surface soil of Tehran, Iran. *Ecotoxicology and Environmental Safety*, 136, 92–103.
- [34] Delbari, A. S., Kulkarni, D. K., & Saptarshi, P. G. (2012). Heavy metal contamination in soils along highways near Pune-India. *International Journal of Pollution Abatement Technology*, 1, 35–39.
- [35] Dhaliwal, S. S., Setia, R., Kumar, V., Ghosh, T., Taneja, S., Singh, R., & Pateriya, B. (2021). Assessment of seasonal variations and human health risks due to heavy metals in water, soils and food crops using multi-indices approach. *Environmental Earth Sciences*, 80, 411.
- [36] Dheeba, B., & Sampathkumar, P. (2012). Evaluation of heavy metal contamination in surface soil around industrial area, Tamil Nadu, India. *International Journal of ChemTech Research*, 4, 1229–1240.
- [37] Dheri, G. S., Brar, M. S., & Malhi, S. S. (2007). Heavy-metal concentration of sewage-contaminated water and its impact on underground water, soil, and crop plants in alluvial soils of northwestern India. *Communications in Soil Science and Plant Analysis*, 38, 1353–1370.
- [38] Drall, J. K., Rautela, R., Jambhulkar, R., Kataria, A. K., & Kumar, S. (2025). Effect of heavy metals contamination due to leachate migration from uncontrolled dumpsites: A comprehensive analysis on soil and groundwater. *Journal of Environmental Management*, 373, 123473.
- [39] Dusengemungu, L., Mubemba, B., & Gwanama, C. (2022). Evaluation of heavy metal contamination in copper mine tailing soils of Kitwe and Mufulira, Zambia, for reclamation prospects. *Scientific Reports*, 12, 11283.
- [40] Elsheikh, M. A. A., Hesham, M., Mahmoud, H., & Momen, A. A. (2017). Determination of selected toxic trace elements in agricultural soil and wells water samples by ICP-OES. *Oriental Journal of Chemistry*, 33, 2263–2270.
- [41] Ennaji, W., Barakat, A., El Baghdadi, M., & Rais, J. (2020). Heavy metal contamination in agricultural soil and ecological risk assessment in the northeast area of Tadla plain, Morocco. *Journal of Sedimentary Environments*, 5, 307–320.



- [42] Fei, X., Christakos, G., Xiao, R., Ren, Z., Liu, Y., & Lv, X. (2019). Improved heavy metal mapping and pollution source apportionment in Shanghai City soils using auxiliary information. *Science of the Total Environment*, 661, 168–177.
- [43] Fonge, B. A., Nkoleka, E. N., Asong, F. Z., Ajonina, S. A., & Che, V. B. (2017). Heavy metal contamination in soils from a municipal landfill, surrounded by banana plantation in the eastern flank of Mount Cameroon. *African Journal of Biotechnology*, 16, 1391–1399.
- [44] Ganeshamurthy, A. N., Varalakshmi, L. R., & Sumangala, H. P. (2008). Environmental risks associated with heavy metal contamination in soil, water and plants in urban and periurban agriculture. *Journal of Horticultural Sciences*, 3, 1–29.
- [45] Gao, Z., Jiang, J., & Sun, G. (2024). Evaluation of heavy metal contamination in black soil at Sanjiang Plain: From source analysis to health risk assessment. *Processes*, 12, 2829.
- [46] George, A., Venugopal, A., & Vashisht, A. K. (2023). Heavy metal contamination in soil and groundwater around industrial areas of Kollam District, Kerala, India. *Environmental Monitoring and Assessment*, 195, 265.
- [47] Gerhardsson, L., Dahlin, L., Knebel, R., & Schütz, A. (2002). Blood lead concentration after a shotgun accident. *Environmental Health Perspectives*, 110, 115–117.
- [48] Ghosh, B., Padhy, P. K., Niyogi, S., Patra, P. K., & Hecker, M. (2023). A comparative study of heavy metal pollution in ambient air and the health risks assessment in industrial, urban and semi-urban areas of West Bengal, India: An evaluation of carcinogenic, non-carcinogenic, and additional lifetime cancer cases. *Environment*, 10, 190.
- [49] Ghosh, K., & Indra, N. (2018). Cadmium treatment induces echinocytosis, DNA damage, inflammation, and apoptosis in cardiac tissue of albino Wistar rats. *Environmental Toxicology and Pharmacology*, 59, 43–52.
- [50] Giri, S., & Singh, A. K. (2017). Ecological and human health risk assessment of agricultural soils based on heavy metals in mining areas of Singhbhum copper belt, India. *International Journal of Human and Ecological Risk Assessment*, 23, 1008–1027.
- [51] Gnandi, K., & Tobschall, H. (2002). Heavy metals distribution of soils around mining sites of cadmium-rich marine sedimentary phosphorites of Kpogame and Hahotoe (southern Togo). *Environmental Geology*, 41(5), 593–600.
- [52] Gowd, S. S., Reddy, M. R., & Govil, P. K. (2010). Assessment of heavy metal contamination in soils at Jajmau (Kanpur) and Unnao industrial areas of the Ganga Plain, Uttar Pradesh, India. *Journal of Hazardous Materials*, 174(1-3), 113–121.
- [53] Guan, Q., Zhao, R., Pan, N., Wang, F., Yang, Y., & Luo, H. (2019). Source apportionment of heavy metals in farmland soil of Wuwei, China: Comparison of three receptor models. *Journal of Cleaner Production*, 237, 117792.
- [54] Herawati, N., Suzuki, S., Hayashi, K., Rivai, I. F., & Koyama, H. (2000). Cadmium, copper, and zinc levels in rice and soil of Japan, Indonesia, and China by soil type. *Bulletin of Environmental Contamination and Toxicology*, 64(1), 33–39.
- [55] Horasan, B. Y., & Arık, F. (2019). Assessing heavy metal pollution in the surface soils of Central Anatolia Region of Turkey. *Carpathian Journal of Earth and Environmental Sciences*, 14(1), 107–118.
- [56] Hu, B., Jia, X., Hu, J., Xu, D., Xia, F., & Li, Y. (2017). Assessment of heavy metal pollution and health risks in the soil-plant-human system in the Yangtze River Delta, China. *International Journal of Environmental Research and Public Health*, 14(9), 1042.
- [57] Ihedioha, J. N., Ukoha, P. O., & Ekere, N. R. (2017). Ecological and human health risk assessment of heavy metal contamination in soil of a municipal solid waste dump in Uyo, Nigeria. *Environmental Geochemistry and Health*, 39(3), 497–515.
- [58] Järup, L. (2003). Hazards of heavy metal contamination. *British Medical Bulletin*, 68(1), 167–182.
- [59] Jiang, Y., Shi, L., Guang, A. L., Mu, Z., Zhan, H., & Wu, Y. (2018). Contamination levels and human health risk assessment of toxic heavy metals in street dust in an industrial city in Northwest China. *Environmental Geochemistry and Health*, 40(5), 2007–2020.
- [60] Kankia, H. I., & Abdulhamid, Y. (2014). Determination of accumulated heavy metals in benthic invertebrates found in Ajiwa Dam, Katsina State, Northern Nigeria. *Archives of Applied Science Research*, 6(5), 80–87.
- [61] Kanmani, S., & Gandhimathi, R. (2013). Assessment of heavy metal contamination in soil due to leachate migration from an open dumping site. *Applied Water Science*, 3(1), 193–205.
- [62] Kashem, M. A., Singh, B. R., & Kawai, S. (2007). Mobility and distribution of cadmium, nickel and zinc in contaminated soil profiles from Bangladesh. *Nutrient Cycling in Agroecosystems*, 77(2), 187–198.
- [63] Kaur, I., Dhillon, H. K., & Sharma, S. (2023). Human health risks in Ferozepur District, Punjab, India due to potentially toxic elements in agricultural soils. *Toxin Reviews*, 42(4), 640–654.
- [64] Kaur, I., Gupta, A., Singh, B. P., Sharma, S., & Kumar, A. (2019). Assessment of radon and potentially toxic metals in agricultural soils of Punjab, India. *Microchemical Journal*, 146, 444–454.
- [65] Kaur, J., Bhat, S. A., Singh, N., Bhatti, S. S., Kaur, V., & Katnoria, J. K. (2022). Assessment of the heavy metal contamination of roadside soils alongside Buddha Nullah, Ludhiana, (Punjab) India. *International Journal of Environmental Research and Public Health*, 19(3), 1596.
- [66] Kaur, M., Kaur, J., Sood, A., Katnoria, J. K., Nagpal, A. K., Bhatia, A., & Bhatti, S. S. (2025). Potentially toxic metal contamination in semi-arid agricultural soils:



- sources, risk analysis, and spatial distribution. *Environmental Monitoring and Assessment*, 197, 783.
- [67] Keshav Krishna, A., & Rama Mohan, K. (2016). Distribution, correlation, ecological and health risk assessment of heavy metal contamination in surface soils around an industrial area, Hyderabad, India. *Environmental Earth Sciences*, 75(5), 411.
- [68] Khalid, S., Shahid, M., Bibi, I., Natasha, M. B., Tariq, T. Z., & Niazi, N. K. (2022). Global arsenic contamination of groundwater, soil and food crops and health impacts. In *Global arsenic hazard: Ecotoxicology and remediation* (pp. 13–33). Springer International Publishing.
- [69] Khalaf, E. M., Taherian, M., Almalki, S. G., Asban, P., Kareem, A. K., Alhachami, F. R., & Mohammadi, M. J. (2024). Relationship between exposure to heavy metals on the increased health risk and carcinogenicity of urinary tract (kidney and bladder). *Reviews on Environmental Health*, 39(4), 539–549.
- [70] Kharazi, A., Leili, M., Khazaei, M., Alikhani, M. Y., Shokoohi, R., & Mahmoudi, H. (2021). Contamination of selective vegetables of Hamadan with heavy metals: non-carcinogenic risk assessment. *Avicenna Journal of Environmental Health Engineering*, 8(1), 43–51.
- [71] Kien, C. N., Noi, N. V., Son, L. T., Ngoc, H. M., Tanaka, S., Nishina, T., & Iwasaki, K. (2010). Heavy metal contamination of agricultural soils around a chromite mine in Vietnam. *Soil Science and Plant Nutrition*, 56(2), 344–356.
- [72] Kravchenko, E., Minkina, T., Mandzhieva, S., Bauer, T., Lacynnik, E., Wong, M. H., & Nazarenko, O. (2025). Ecological and health risk assessments of heavy metal contamination in soils surrounding a coal power plant. *Journal of Hazardous Materials*, 484, 136751.
- [73] Kumar, A., Sharma, S., Mehra, R., Kanwar, P., Mishra, R., & Kaur, I. (2018). Assessment of radon concentration and heavy metal contamination in groundwater of Udhampur district, Jammu & Kashmir, India. *Environmental Geochemistry and Health*, 40(2), 815–831.
- [74] Kumar, M. S., Sangwan, P. S., Chandra, M. S., Bhatt, R., Gaber, A., & Hossain, A. (2025). Assessing heavy metal contamination in roadside soils as a consequence of motor vehicle emissions. *International Journal of Environmental Science and Technology*, 22, 7119–7132.
- [75] Ramesh Kumar, K., & Anbazhagan, V. (2018). Analysis and assessment of heavy metals in soils around the industrial areas in Mettur, Tamilnadu, India. *Environmental Monitoring and Assessment*, 190(9), 519.
- [76] Laoye, B., Olagbemide, P., Ogunnusi, T., & Akpor, O. (2025). Heavy metal contamination: Sources, health impacts, and sustainable mitigation strategies with insights from nigerian case studies. *F1000Research*, 14, 134.
- [77] Leung, A. O., Duzgoren-Aydin, N. S., Cheung, K. C., & Wong, M. H. (2008). Heavy metals concentrations of surface dust from e-waste recycling and its human health implications in southeast China. *Environmental Science & Technology*, 42(7), 2674–2680.
- [78] Li, P., Lin, C., Cheng, H., Duan, X., & Lei, K. (2015). Contamination and health risks of soil heavy metals around a lead/zinc smelter in southwestern China. *Ecotoxicology and Environmental Safety*, 113, 391–399.
- [79] Li, R., Wang, J., Zhou, Y., Zhang, W., Feng, D., & Su, X. (2023). Heavy metal contamination in Shanghai agricultural soil. *Heliyon*, 9(12), e22824.
- [80] Li, X., Liu, L., Wang, Y., Luo, G., Chen, X., Yang, X., & He, X. (2013). Heavy metal contamination of urban soil in an old industrial city (Shenyang) in Northeast China. *Geoderma*, 192, 50–58.
- [81] Li, Y., Zhou, S., Jia, Z., Liu, K., & Wang, G. (2021). Temporal and spatial distributions and sources of heavy metals in atmospheric deposition in western Taihu Lake, China. *Environmental Pollution*, 284, 117465.
- [82] Liang, J., Chen, C., Song, X., Han, Y., & Liang, Z. (2011). Assessment of heavy metal pollution in soil and plants from Dunhua sewage irrigation area. *International Journal of Electrochemical Science*, 6, 5314–5324.
- [83] Maalouf, A., & Agamuthu, P. (2023). Waste management evolution in the last five decades in developing countries—A review. *Waste Management & Research*, 41(9), 1420–1434.
- [84] Mandal, S., Bhattacharya, S., & Paul, S. (2022). Assessing the level of contamination of metals in surface soils at thermal power area: Evidence from developing country (India). *Environmental Chemistry and Ecotoxicology*, 4, 37–49.
- [85] Mazurek, R., Kowalska, J., Gąsiorek, M., Zadrożny, P., Józefowska, A., Zaleski, T., & Orłowska, K. (2017). Assessment of heavy metals contamination in surface layers of Roztocze National Park forest soils (SE Poland) by indices of pollution. *Chemosphere*, 168, 839–850.
- [86] Morais, S., Costa, F. G., & Pereira, M. D. L. (2012). Heavy metals and human health. In *Environmental Health—Emerging Issues and Practice* (pp. 227–245). IntechOpen.
- [87] Neeraj, A., Hiranmai, R. Y., & Iqbal, K. (2023). Comprehensive assessment of pollution indices, sources apportionment and ecological risk mapping of heavy metals in agricultural soils of Raebareli District, Uttar Pradesh, India, employing a GIS approach. *Land Degradation & Development*, 34(1), 173–195.
- [88] Nhan, T. T. T., Hien, P. T., Hoang, T. D., Hai, N. T., Anh, B. T. K., Hang, N. T. A., & Ha, N. T. H. (2025). Accumulation of heavy metals (loids) in soils and crops at a decentralized metal recycling site: Health risk assessment and pollution management. *Environmental Monitoring and Assessment*, 197, 1–17.
- [89] Nnaji, J. C. (2015). Physico-chemical quality of reservoir sediments under long-term amendment with organic manure. *International Journal of Chemical and Biochemical Sciences*, 1, 218.



- [90] Nogueira, T. A. R., Franco, A., He, Z., Braga, V. S., Firme, L. P., & Abreu-Junior, C. H. (2013). Short-term usage of sewage sludge as organic fertilizer to sugarcane in a tropical soil bears little threat of heavy metal contamination. *Journal of Environmental Management*, 114, 168–177.
- [91] Ololade, I. A. (2014). An assessment of heavy-metal contamination in soils within auto-mechanic workshops using enrichment and contamination factors with geoaccumulation indexes. *Journal of Environmental Protection*, 5(11), 970–982.
- [92] Olumayowa Oluwasola, H., Oluoye, O., Mohammad Bashir, S., Odewole, O. A., Onyeka Abugu, H., Akpomie, K. G., & Aishatu Umar, M. (2023). Geochemical and health risk assessment of heavy metals concentration in soils around Oke-Ere mining area in Kogi State, Nigeria. *International Journal of Environmental Analytical Chemistry*, 103(4), 685–700.
- [93] Onat, B., & Stakeeva, B. (2013). Personal exposure of commuters in public transport to PM_{2.5} and fine particle counts. *Atmospheric Pollution Research*, 4(3), 329–335.
- [94] Özkul, C. (2016). Heavy metal contamination in soils around the Tuncbilek thermal power plant (Kütahya, Turkey). *Environmental Monitoring and Assessment*, 188(5), 284.
- [95] Palit, S., & Hussain, C. M. (2022). Green sustainability and arsenic groundwater remediation in developing countries—a far-reaching review. In *Biobased Materials: Recent Developments and Industrial Applications* (pp. 171–193). Springer Nature Singapore.
- [96] Pandey, B., Agrawal, M., & Singh, S. (2016). Ecological risk assessment of soil contamination by trace elements around coal mining area. *Journal of Soils and Sediments*, 16(1), 159–168.
- [97] Parvez, M. S., Nawshin, S., Sultana, S., Hossain, M. S., Rashid Khan, M. H., Habib, M. A., & Khan, R. (2023). Evaluation of heavy metal contamination in soil samples around Rampal, Bangladesh. *ACS Omega*, 8(17), 15990–15999.
- [98] Podgórska, M., & Jóźwiak, M. (2024). Heavy metals contamination of post-mining mounds of former iron-ore mining activity. *International Journal of Environmental Science and Technology*, 21, 4645–4652.
- [99] Pradhan, J. K., & Kumar, S. (2014). Informal e-waste recycling: environmental risk assessment of heavy metal contamination in Mandoli industrial area, Delhi, India. *Environmental Science and Pollution Research*, 21(13), 7913–7928.
- [100] Rahman, S. H., Khanam, D., Adyel, T. M., Islam, M. S., Ahsan, M. A., & Akbor, M. A. (2012). Assessment of heavy metal contamination of agricultural soil around Dhaka Export Processing Zone (DEPZ), Bangladesh: implication of seasonal variation and indices. *Applied Sciences*, 2(3), 584–601.
- [101] Rajkumar, H., Naik, P. K., & Rishi, M. S. (2019). Evaluation of heavy metal contamination in soil using geochemical indexing approaches and chemometric techniques. *International Journal of Environmental Science and Technology*, 16(11), 7467–7486.
- [102] Rani, J., Chaudhary, S., & Agarwal, T. (2023). Impact of industrialization on heavy metals contamination in agricultural soils of Sonapat, a satellite township of New Delhi, India. *Sustainable Agriculture and Food Environmental Research*, 12.
- [103] Rattan, R. K., Datta, S. P., Chhonkar, P. K., Suribabu, K., & Singh, A. K. (2005). Long-term impact of irrigation with sewage effluents on heavy metal content in soils, crops and groundwater—a case study. *Agriculture, Ecosystems & Environment*, 109(3–4), 310–322.
- [104] Ravindra, K., Vig, N., Agarwal, N., Malik, V. S., Arumugam, E., Rajkumar, P., & Mor, S. (2024). Metal contamination of different water categories and surface soil near thermal power plants at varied geographic sites of India and their health risk assessment. *Water, Air, & Soil Pollution*, 235(3), 152.
- [105] Sable, H., Singh, V., Khosla, A., & Chaudhary, V. (2025). Detection and Analysis of Cadmium Prevalence in Soil-Water Matrices of Industrial Settings of Delhi: Bioavailability and Geochemical Study. *Journal of The Electrochemical Society*, 172(2), 027514.
- [106] Sahen, M. S., Naim, M. A. H. K., Hosen, M. S., Pranta, M. A., Hasan, M., Rahman, M. M., & Don, A. W. (2025). Multi-compartmental risk assessment of heavy metal contamination in soil, plants, and wastewater: A model from Industrial Gazipur, Bangladesh. *Environmental Monitoring and Assessment*, 197(4), 397.
- [107] Salem, M. A., Bedade, D. K., Al-Ethawi, L., & Al-Waleed, S. M. (2020). Assessment of physiochemical properties and concentration of heavy metals in agricultural soils fertilized with chemical fertilizers. *Heliyon*, 6(10), e05224.
- [108] Sankalp, M., Gondwal, A., Agnihotri, A. K., Mir, A. A., Patel, M., & Singh, R. (2023). Hydrogeological study of contamination of soil and water in the vicinity of municipal dumping ground: A case study. In *International Conference on Environmental Geotechnology, Recycled Waste Materials and Sustainable Engineering* (pp. 219–235). Springer Nature Singapore.
- [109] Sarwar, N., Imran, M., Shaheen, M. R., Ishaque, W., Kamran, M. A., Matloob, A., & Hussain, S. (2017). Phytoremediation strategies for soils contaminated with heavy metals: modifications and future perspectives. *Chemosphere*, 171, 710–721.
- [110] Setia, R., Dhaliwal, S. S., Singh, R., Kumar, V., Taneja, S., Kukal, S. S., & Pateriya, B. (2021). Phytoavailability and human risk assessment of heavy metals in soils and food crops around Sutlej river, India. *Chemosphere*, 263, 128321.
- [111] 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.
- [112] Sezgin, N., Balkaya, N., Sahnurova, A., & Aysal, N. (2019). Assessment of heavy metal contamination in



- urban soil (Tuzla District, Istanbul, Turkey). *Desalination and Water Treatment*, 172, 167–176.
- [113] Shakil, S., Nawaz, K., & Sadeq, Y. (2023). Evaluation and environmental risk assessment of heavy metals in the soil released from e-waste management activities in Lahore, Pakistan. *Environmental Monitoring and Assessment*, 195(1), 89.
- [114] Sharma, M. R., & Raju, N. S. (2013). Correlation of heavy metal contamination with soil properties of industrial areas of Mysore, Karnataka, India by cluster analysis. *International Research Journal of Environment Sciences*, 2(10), 22–27.
- [115] Sharma, P., Kaur, J., & Katnoria, J. K. (2023). Assessment of spatial variations in pollution load of agricultural soil samples of Ludhiana district, Punjab. *Environmental Monitoring and Assessment*, 195(1), 222.
- [116] Sharma, R., Yadav, A., Ramteke, S., Patel, K. S., Lata, L., Milosh, H., & Martín-Ramos, P. (2019). Heavy metal pollution in surface soil of Korba Basin, India. *Journal of Hazardous, Toxic, and Radioactive Waste*, 23(4), 05019004.
- [117] Singare, P. U., Lokhande, R. S., & Pathak, P. P. (2010). Study on physico-chemical properties and heavy metal content of the soil samples from Thane Creek of Maharashtra, India. *Interdisciplinary Environmental Review*, 11(1), 38–56.
- [118] Singh, A., Dwivedi, S. P., & Tripathi, A. (2018). Study of the toxicity of metal contamination in soil samples collected from abandoned e-waste burning sites in Moradabad, India. *Nature Environment and Pollution Technology*, 17(3), 973–979.
- [119] Singh, G., Patel, N., Jindal, T., & Ranjan, M. R. (2021). Heavy metal contamination in soils and crops irrigated by Kali River in Uttar Pradesh, India. *Bulletin of Environmental Contamination and Toxicology*, 107(5), 931–937.
- [120] Singh, J., & Kalamdhad, A. S. (2011). Effects of heavy metals on soil, plants, human health and aquatic life. *International Journal of Research in Chemistry and Environment*, 1(2), 15–21.
- [121] Singh, M., Thind, P. S., & John, S. (2018). Health risk assessment of the workers exposed to the heavy metals in e-waste recycling sites of Chandigarh and Ludhiana, Punjab, India. *Chemosphere*, 203, 426–433.
- [122] Singh, P. K., Shikha, D., & Saw, S. (2023). Evaluation of potential toxic heavy metal contamination in soil, fly ash, vegetables and grain crops along with associated ecological and health risk assessment of nearby inhabitants of a thermal power station in Jharkhand (India). *Environmental Science and Pollution Research*, 30(3), 7752–7769.
- [123] Singh, S., Raju, N. J., & Nazneen, S. (2015). Environmental risk of heavy metal pollution and contamination sources using multivariate analysis in the soils of Varanasi environs, India. *Environmental Monitoring and Assessment*, 187(6), 345.
- [124] Sonkar, V., Jaswal, V., Chenlak, S., & Nandabalan, Y. K. (2024). Pollution status and health risk assessment of heavy metals in the soil of Sahibzada Ajit Singh (SAS) Nagar district of Punjab, India and its source apportionment. *Journal of Geochemical Exploration*, 261, 107453.
- [125] Sutkowska, K., Teper, L., Czech, T., Hulok, T., Olszak, M., & Zogala, J. (2020). Quality of peri-urban soil developed from ore-bearing carbonates: Heavy metal levels and source apportionment assessed using pollution indices. *Minerals*, 10(12), 1140.
- [126] Su, W., Li, Z., Gong, T., Wang, F., Jin, M., Wang, Y., & Lu, Z. (2023). An alternative ZnO with large specific surface area: Preparation, physicochemical characterization and effects on growth performance, diarrhea, zinc metabolism and gut barrier function of weaning piglets. *Science of The Total Environment*, 882, 163558.
- [127] Teschke, R. (2024). Copper, iron, cadmium, and arsenic, all generated in the universe: Elucidating their environmental impact risk on human health including clinical liver injury. *International Journal of Molecular Sciences*, 25(12), 6662.
- [128] Tiwari, M. K., Bajpai, S., & Dewangan, U. K. (2015). An analytical study of heavy metal concentration in soil of an industrial region of Chhattisgarh, central India. *International Journal of Science and Research*, 5, 1–8.
- [129] Tiwari, M., Rathod, T., Bhangare, R., Sahu, S. K., & Pulhani, V. (2025). Comprehensive elemental and carbon profiling of Punjab's soils: distribution patterns, pollution assessment, and source attribution. *Environmental Geochemistry and Health*, 47(1), 1–19.
- [130] Tóth, G., Hermann, T., Da Silva, M. R., & Montanarella, L. (2016). Heavy metals in agricultural soils of the European Union with implications for food safety. *Environment International*, 88, 299–309.
- [131] Tuakuila, J., Lison, D., Lantin, A. C., Mbuyi, F., Deumer, G., Haufroid, V., & Hoet, P. (2012). Worrying exposure to trace elements in the population of Kinshasa, Democratic Republic of Congo (DRC). *International Archives of Occupational and Environmental Health*, 85(8), 927–939.
- [132] Tun, A. Z., Wongsasuluk, P., & Siri Wong, W. (2020). Heavy metals in the soils of placer small-scale gold mining sites in Myanmar. *Journal of Health and Pollution*, 10(26), 200911.
- [133] Upadhyay, V., Kumari, A., & Kumar, S. (2024). From soil to health hazards: Heavy metals contamination in northern India and health risk assessment. *Chemosphere*, 354, 141697.
- [134] Venkanna, R. M., & Karthikeyan, J. S. K. (2017). Soil quality and heavy metal contamination of soils in Mindi industrial area, Visakhapatnam, Andhra Pradesh, India. *Indian Journal of Ecology*, 44(4), 774–777.
- [135] Wang, X., Fu, R., Li, H., Zhang, Y., Lu, M., Xiao, K., & Xiong, Y. (2020). Heavy metal contamination in surface sediments: A comprehensive, large-scale evaluation for



- the Bohai Sea, China. *Environmental Pollution*, 260, 113986.
- [136] Wu, H., Yang, F., Li, H., Li, Q., Zhang, F., Ba, Y., & Zhu, J. (2020). Heavy metal pollution and health risk assessment of agricultural soil near a smelter in an industrial city in China. *International Journal of Environmental Health Research*, 30(2), 174–186.
- [137] Xing, W., Liu, H., Banet, T., Wang, H., Ippolito, J. A., & Li, L. (2020). Cadmium, copper, lead and zinc accumulation in wild plant species near a lead smelter. *Ecotoxicology and Environmental Safety*, 198, 110683.
- [138] Xu, S., Li, C., Wang, Y., Wu, A., Gao, G., & Zang, F. (2024). Characteristics and evaluation of heavy metal pollution in a soil–wheat system of an arid oasis city in northwest China. *Ecotoxicology and Environmental Safety*, 271, 115958.
- [139] Yabe, J., Ishizuka, M., & Umemura, T. (2010). Current levels of heavy metal pollution in Africa. *Journal of Veterinary Medical Science*, 72(10), 1257–1263.
- [140] Yabe, J., Nakayama, S. M., Ikenaka, Y., Muzandu, K., Ishizuka, M., & Umemura, T. (2011). Uptake of lead, cadmium, and other metals in the liver and kidneys of cattle near a lead-zinc mine in Kabwe, Zambia. *Environmental Toxicology and Chemistry*, 30(8), 1892–1897.
- [141] Yaylalı-Abanuz, G. (2011). Heavy metal contamination of surface soil around Gebze industrial area, Turkey. *Microchemical Journal*, 99(1), 82–92.
- [142] Yildiz, U., & Ozkul, C. (2024). Heavy metals contamination and ecological risks in agricultural soils of Uşak, western Türkiye: a geostatistical and multivariate analysis. *Environmental Geochemistry and Health*, 46(2), 58.
- [143] Younas, T., & Younas, W. (2025). Assessment of toxic metals contamination, co-occurrence, and health hazards in rice grains and soils irrigated with wastewater. *International Journal of Environmental Science and Technology*, 22, 8869–8882.
- [144] Yuan, X., Xue, N., & Han, Z. (2021). A meta-analysis of heavy metals pollution in farmland and urban soils in China over the past 20 years. *Journal of Environmental Sciences*, 101, 217–226.
- [145] Zhuang, P., McBride, M. B., Xia, H., Li, N., & Li, Z. (2009). Health risk from heavy metals via consumption of food crops in the vicinity of Dabaoshan mine, South China. *Science of The Total Environment*, 407(4), 1551–1561.