Science World Journal Vol. 20(No 2) 2025
www.scienceworldjournal.org
ISSN: 1597-6343 (Online), ISSN: 2756-391X (Print)
Published by Faculty of Science, Kaduna State University
https://dx.doi.org/10.4314/swj.v20i2.5

EFFECTS OF CONTAMINANTS ON THE GROWTH OF VEGETABLES IN AN ABANDONED MINING SITE

Amina Kabir, Ibrahim Muhammad, Adamu Abdulhameed,*Abbas Ibrahim, Ahmad A. Abubakar, Muhammad Kabir Umar

Department of Chemistry, Sa'adu Zungur University, Bauchi State, Nigeria

*Corresponding Author Email Address: abasibrahim@basug.edu.ng

ABSTRACT

The growing concern over the contamination of agricultural soils, particularly in mining regions, has prompted significant research into the uptake of contaminants by crops. Heavy metals are known to accumulate in soils due to industrial and mining activities, and translocation within plants can present potential risks to food safety. Using advanced analytical techniques such Atomic Absorption Spectroscopy (AAS) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS) helps to evaluate the concentrations of contaminants in the roots, stems, leaves and vegetables. The vegetables grown in contaminated soils accumulate harmful levels of these metals, with uptake influenced by soil characteristics and environmental conditions. This review article highlights the effect of absorption of heavy metals, such as lead (Pb), cadmium (Cd), and arsenic (As) by vegetables at the abandoned mining site and the need for effective soil remediation and preventive measures to ensure agricultural sustainability and the safety of food products in mining-impacted areas.

Keywords: Contaminants. Heavy Metals, Vegetables, Mining Site, pollutants

INTRODUCTION

Abandoned Mining Sites and its Impact to the Environment.

Abandoned mining sites became a primary major global environmental concern due to their legacy of contamination. Mining activities often leave behind a cocktail of pollutants, including heavy metals (e.g., lead, cadmium, arsenic, and mercury), metalloids, and acidic drainage, which persist in the environment long after operations cease. These contaminants can infiltrate soil and water systems, posing risks to ecosystems and human health. Vegetables grown in such contaminated soils are particularly vulnerable, as they can accumulate toxic elements, leading to reduced growth, yield, and nutritional quality. Soil contamination caused by various pollutants, including heavy metals, organic contaminants, and radioactive materials, is a growing environmental concern, particularly in areas affected by mining activities (Tao *et al.,*2020). In mining and abandoned mine regions, mining activities have significantly impacted soil quality, leaving behind toxic contaminants that threaten both the environment and agriculture (Yin *et al.,* 2020). Vegetables are widely cultivated crops that are sensitive to environmental pollutants and serve as useful bioindicators for assessing soil contamination (Zhang, & Zhao, 2021). This review synthesizes recent research on the uptake of contaminants, such as heavy metals, organic pollutants, and radioactive materials by vegetables grown in soils impacted by mining activities.

Heavy metals like arsenic (As), cadmium (Cd), and lead (Pb) are non-biodegradable and tend to accumulate in soils, posing long-term risks to the ecosystem and human health (Basu*et al.*, 2021). These metals can be absorbed by plants, contaminating the food chain. Organic pollutants, such as pesticides (e.g., DDT), polycyclic aromatic hydrocarbons (PAHs), and volatile organic compounds (VOCs), are chemicals that persist in the environment and can be absorbed by plants, leading to contamination of food crops (Chakraborty*et al.,* 2020). Additionally, radioactive materials, such as radon (Rn), uranium (U), and thorium (Th), may be present in mining areas due to natural radioactive minerals in the soil, and they can also be taken up by plants, contributing to radiation exposure (Liu *et al.,*2019).

Vegetables, like many other crops, are known to accumulate pollutants from their surrounding environment. Previous studies have highlighted the ability of tomatoes to absorb heavy metals and organic pollutants in their roots, stems, and fruits, depending on the contamination level in the soil (Adebayo, 2022). However, further research is needed on the levels of uptake of these contaminants, particularly radioactive materials and organic pollutants, in vegetables grown in mining-affected regions(Basu*et al.*, 2021).

CONTAMINANTS IN ABANDONED MINING SITES

Abandoned mining sites are often significant sources of environmental contamination, and the pollutants found in these areas can pose severe risks to both ecosystems and human health (Hachimi*et al.*, 2014; Seo-Jin *et al.*, 2014; Xun*et al.*, 2017). Mining operations leave behind various pollutants including heavy metals, radioactive materials, and organic pollutants. These contaminants can persist in the environment for extended periods, affecting soil, water, and biota. The following subsections will discuss the major types of contaminants typically found in abandoned mining sites, their sources, and impact on the surrounding environment.

Heavy Metals

Heavy metals, such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg), are commonly found in the waste products of mining operations(Kazemi*et al.*, 2021; Younji*et al.*, 2022).. These metals often leach into the surrounding environment, contaminating soil and water. Heavy metals can be toxic to plants, animals, and humans, even at low concentrations. In mining sites, these metals accumulate in the soil and water, and they can enter the food chain through bioaccumulation in plants and animals (; Krachler*et al.,* 2020; Santos *et al.,* 2019). The presence of these metals in the environment poses significant challenges for agriculture and human health, especially when crops such as tomatoes absorb them from contaminated soils (Wang *et al.,* 2020).

Radioactive Materials

Certain mining activities, particularly those related to uranium and thorium extraction, can release radioactive materials into the environment. These materials can accumulate in soil, water, and plant , posing long-term health risks through radiation exposure.

Radioactive contamination is often difficult to detect and measure without specialized equipment like Gamma Spectrometry, which allows for the detection of gamma-emitting radionuclides such as Cesium-137 (Cs-137) and Uranium isotopes (Uranium-238 and Uranium-235) (Van der Westhuizen*et al.,* 2020). Radioactive contamination in abandoned mining sites can persist for decades, creating a significant hazard for agriculture and local communities.

Organic Pollutants

Organic pollutants, such as pesticides, solvents, and petroleum products, are often found at mining sites due to improper disposal or spills during mining operations. These organic contaminants can persist in the environment and affect plant and animal life. In particular, organic compounds like polycyclic aromatic hydrocarbons (PAHs) and petroleum hydrocarbons can accumulate in the soil, water, and plants. These pollutants are toxic, and their presence in the food chain can pose significant risks to both human health and the broader ecosystem. The use of advanced analytical techniques like AAS and ICP-MS can help quantify the levels of organic pollutants in mining-affected areas (Santos *et al.,* 2019).

IMPACTS OF CONTAMINANTS ON AGRICULTURE AND FOOD SAFETY

The presence of these contaminants in abandoned mining sites has direct implications for agricultural productivity and food safety. Crops grown in contaminated soils may absorb toxic metals, radioactive materials, and organic pollutants, leading to potential risks for consumers. The bioaccumulation of these contaminants in edible crops such as tomatoes can pose significant risks to food safety, affecting both local communities and agricultural practices. Understanding the levels of uptake of these contaminants by plants and the resulting impact on crop quality is essential for assessing the risks to public health and establishing guidelines for land reclamation and agricultural use in contaminated areas.

MECHANISMS OF CONTAMINANT EFFECTS ON VEGETABLE GROWTH

Soil-Plant Interactions

Contaminants in soil can directly affect vegetable growth by altering soil properties, such as pH, nutrient availability, and microbial activity. For example, heavy metals can displace essential nutrients like zinc and iron, leading to deficiencies in plants (Ali *et al.,* 2020). Additionally, the presence of heavy metals can disrupt soil microbial communities, reducing the availability of nutrients essential for plant growth (Sharma *et al.,* 2022).

Bioaccumulation and Phytotoxicity

Vegetables can absorb contaminants through their roots, leading to bioaccumulation in edible parts. This not only reduces crop yield but also poses health risks to consumers. For instance, cadmium accumulation in leafy greens like spinach has been linked to reduced chlorophyll content and growth inhibition (Khan *et al.,* 2021). Similarly, lead contamination in root vegetables such as carrots has been shown to reduce their size and nutritional quality (Liu *et al.,* 2020).

Oxidative Stress

Heavy metals induce the production of reactive oxygen species (ROS), causing oxidative damage to plant cells. This results in symptoms such as leaf necrosis, reduced photosynthesis, and premature aging (Sharma *et al.,* 2022). The oxidative stress caused by heavy metals can also lead to DNA damage and cell death, further impairing plant growth (Gopalakrishnan*et al.,* 2022).

CASE STUDIES: EFFECTS ON SPECIFIC VEGETABLES

Leafy Greens (Spinach, Lettuce)

Leafy greens are particularly susceptible to heavy metal contamination due to their high transpiration rates. Studies have shown that spinach grown in arsenic-contaminated soil exhibits reduced biomass and increased arsenic accumulation in leaves (Rahman*et al.,* 2021). Similarly, lettuce grown in lead-contaminated soil has been found to accumulate high levels of lead, leading to reduced growth and yield (Wang *et al.,* 2021).

Root Vegetables (Carrots, Potatoes)

Root vegetables are prone to contamination due to their direct contact with soil. Cadmium contamination has been shown to reduce the size and nutritional quality of carrots (Liu *et al.,* 2020). Potatoes grown in mercury-contaminated soil have also been found to accumulate high levels of mercury, leading to reduced tuber size and yield (Yan *et al.,* 2023).

Fruit-Bearing Vegetables (Tomatoes, Peppers)

Fruit-bearing vegetables can accumulate heavy metals in their fruits, affecting both yield and safety. For example, lead contamination has been linked to reduced fruit size and increased metal content in tomatoes (Gopalakrishnan*et al.,* 2022). Similarly, peppers grown in cadmium-contaminated soil have been found to accumulate high levels of cadmium, leading to reduced fruit quality and yield (Zhang *et al.,* 2022).

PHYSICAL AND CHEMICAL PARAMETERS IN SOIL AND WATER

The physical and chemical characteristics of both soil and water play a fundamental role in the behavior, mobility, and bioavailability of contaminants. These parameters help determine how pollutants, such as heavy metals, organic contaminants, and radioactive materials, interact with the environment and how they are taken up by plants, including tomatoes. Understanding these parameters is essential for assessing the degree of contamination in mining-affected areas and predicting the potential risks to agricultural productivity and food safety.

Physical Parameters in Soil and Water

Soil Texture and Structure: Soil texture (the proportion of sand, silt, and clay) influences the retention and mobility of contaminants. Fine-textured soils (clay) tend to hold contaminants more strongly than coarse-textured soils (sand), affecting the extent of pollutant uptake by plants (Kabata-Pendias, 2020). Soil structure, including porosity and compaction, also affects water retention, nutrient availability, and contaminant leaching (Tao *et al.,* 2020).
Water pH and Soil pH*:* Soil and water pH directly influence the solubility and mobility of contaminants. In acidic environments (low pH), heavy metals like lead, cadmium, and arsenic are more mobile and bioavailable, leading to increased uptake by plants (Adelekan & Abegunde, 2021). Similarly, in water, pH regulates the dissolution of pollutants such as ammonia, phosphate, and organic compounds (De *et al.,* 2021).
Electrical Conductivity (EC) in Water: EC measures the salinity or ion concentration in water, which can indicate the presence of pollutants like dissolved metals or organic compounds. High EC

values in water bodies near mining sites often suggest contamination from heavy metals or acidic drainage (Chakraborty*et al.,* 2020). EC is also an important indicator of soil fertility and the availability of nutrients for plant growth (Yin *et al.,* 2020).

Chemical Parameters in Soil and Water

Heavy Metals in Soil and Water*:* The concentration of heavy metals in both soil and water is a critical parameter in determining the extent of contamination. Common metals of concern in mining areas include lead, cadmium, arsenic, and mercury. These metals are often present in both water and soil because of mining activities and can enter the food chain through plant uptake (Tibbo*et al.,* 2020). For example, high levels of arsenic in soil can lead to significant bioaccumulation in crops like tomatoes, affecting food safety and quality (Zhao *et al.,* 2020).

Organic Pollutants in Water and Soil*:* Organic pollutants such as pesticides, petroleum hydrocarbons, and polycyclic aromatic hydrocarbons (PAHs) are common in mining-impacted environments. These contaminants can be detected in water and soil through chemical analysis, and their bioavailability is influenced by factors like organic matter content and soil pH. Organic pollutants, especially PAHs, can accumulate in plant tissues and pose risks to human health when contaminated crops are consumed (Liu *et al.,* 2020).

Radioactive Materials in Soil and Water: The presence of radioactive materials, particularly in uranium mining areas, is another significant concern. Radioactive contaminants like uranium and thorium are often present in both soil and water near mining sites. These contaminants can be absorbed by plants, leading to the potential transfer of radiation into the food chain. Gamma spectrometry is commonly used to monitor radioactive contamination in soil and water (Van der Westhuizen*et al.,* 2020). Understanding the concentration of radioactive isotopes in environmental matrices is essential for assessing their potential risk to crops and public health.

The measurement of physical and chemical parameters in soil and water provides essential insights into the extent of contamination in mining areas and the potential for contaminants to be absorbed by plants. Parameters like pH, EC, and metal concentration directly influence the mobility and bioavailability of pollutants. Monitoring these parameters alongside contaminant analysis using advanced techniques like AAS, ICP-MS, and Gamma Spectrometry can help assess the environmental risks posed by mining contamination and guide remediation efforts (Kabata-Pendias, 2020; Zhao *et al.,* 2020).

ANALYTICAL TECHNIQUES FOR CONTAMINANTS DETECTION

The detection and quantification of contaminants in soil, water, and plant samples from mining-impacted areas require advanced analytical methods. These techniques allow for the precise measurement of trace elements, heavy metals, radioactive materials, and organic pollutants, which are essential for environmental monitoring and assessing the extent of contamination. The following methods are commonly employed in environmental chemistry to analyze pollutants from mining sites.

Atomic Absorption Spectroscopy (AAS)

Atomic Absorption Spectroscopy (AAS) is a highly sensitive technique used to detect and quantify metals in environmental samples. The technique relies on the absorption of light by free atoms in the gas phase, which occurs at characteristic wavelengths for each element. AAS is particularly effective for detecting heavy metals such as lead, cadmium, arsenic, and mercury, which are commonly found in mining-affected areas (Santos *et al.,* 2019). It is widely used to analyze soil and water samples to assess the levels of metal contamination.

AAS is typically used in conjunction with sample preparation techniques like digestion and filtration, ensuring that the samples are free from particulate matter that could interfere with measurements. The sensitivity of AAS allows for the detection of metal concentrations in the parts per billion (ppb) range, which is crucial when monitoring trace metals in contaminated environments (Arnot*et al.,* 2019).Applications of AAS in mining research include measurement of heavy metals such as lead, cadmium, arsenic, mercury, and zinc in soil and water samples (Wang *et al.,* 2020).

Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is a versatile technique used to measure trace elements and isotopes in environmental samples. ICP-MS offers high sensitivity and precision, allowing for the analysis of a wide range of metals and non-metals, including rare earth elements and radionuclides. It is particularly useful for detecting low concentrations of contaminants in complex matrices such as mining waste, soil, and water (Krachler*et al.,* 2020).

ICP-MS operates by ionizing the sample using an argon plasma and then separating and detecting the ions based on their mass-to-charge ratio. This method can provide multi-element analysis in a single run, making it ideal for detecting multiple contaminants such as heavy metals, trace elements, and even radioactive isotopes (Santos *et al.,* 2019). The ability to measure a broad spectrum of contaminants at very low detection limits makes ICP-MS a powerful tool for environmental research, particularly in areas with complex contamination from mining operations (Krachler*et al.,* 2020).Applications in mining research include detection of metals like arsenic, copper, and zinc, and radioactive isotopes in environmental samples (Van der Westhuizen*et al.,* 2020).

Gamma Spectrometry

Gamma Spectrometry is a non-destructive technique used to detect and quantify gamma-emitting radionuclides, making it highly effective for monitoring radioactive contamination in mining sites. The method involves measuring the gamma radiation emitted by radioactive isotopes in the sample and identifying the radionuclides based on their characteristic gamma-ray energies (Liu *et al.,* 2019). Gamma Spectrometry is often used in environmental monitoring because it allows for real-time measurement of radioactivity without the need for extensive sample preparation. It is particularly valuable for detecting radioactive materials such as Cesium-137 (Cs-137) and Uranium isotopes (Uranium-238 and Uranium-235), which are commonly associated with uranium mining operations. The technique has applications in both field and laboratory settings, making it an important tool for monitoring environmental contamination at mining sites (Van der Westhuizen*et al.,* 2020).Applications in mining research include monitoring radioactive materials in mining areas, including uranium and thorium contamination (Liu *et al.,* 2019).

APPLICATIONS OF ANALYTICAL TECHNIQUES IN PLANT CONTAMINATION STUDIES

In addition to monitoring environmental contaminants in soil and water, these analytical methods are also applied to plant samples, particularly tomatoes, to assess the uptake of pollutants from contaminated environments. Vegetables are widely used in agricultural studies due to their ability to absorb heavy metals, radioactive materials, and organic pollutants from soil and water (Wang *et al.,* 2020). By analyzing the concentrations of contaminants in plant tissues, researchers can assess the extent of bioaccumulation in crops grown in polluted environments.

A combination of AAS, ICP-MS, and Gamma Spectrometry can provide comprehensive data on the levels of various contaminants in tomatoes, enabling a detailed analysis of the plant's uptake of metals, radionuclides, and organic pollutants (Wang *et al.,* 2020; Krachler*et al.,* 2020). These methods also allow for the detection of trace levels of contaminants in plant tissues, which is crucial for assessing the potential risks to food safety and human health.

CONTAMINANTS ANALYSIS

Heavy metals, organic pollutants, and radioactive materials are analyzed using AAS, ICP-MS, and Gamma Spectrometry. AAS is employed for the quantification of metals such as lead, cadmium, and mercury (Santos *et al.,* 2019). ICP-MS is used to detect trace elements like arsenic, copper, and zinc, providing high sensitivity and accuracy in complex environmental matrices (Krachler*et al.,* 2020). Gamma Spectrometry is applied to detect radioactive isotopes, such as Cesium-137 and Uranium, in the soil and water samples (Van der Westhuizen*et al.,* 2020).

Vegetable Planting and Uptake Analysis

Vegetables such as tomatoes (Solanumlycopersicum) are grown in the contaminated soil and watered with the contaminated water. After a sufficient growth period, the tomatoes are harvested, and their tissues are analyzed for contaminant uptake. The harvested tomatoes, along with re-analyzed soil and water samples, are subjected to AAS, ICP-MS, and Gamma Spectrometry to measure the levels of bioaccumulated contaminants in the plant tissues (Wang *et al.,* 2020; Arnot*et al.,* 2019).

Contaminant Levels in Soil and Water

The analysis of soil and water samples revealed the concentrations of contaminants at various depths in the soil and across different water bodies affected by mining runoff. Heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) are expected to be present in varying concentrations, depending on the proximity to mining activities(Zhao *et al.,* 2020). Organic pollutants, such as polycyclic aromatic hydrocarbons (PAHs), may also be detected in the soil and water samples, which are typical contaminants found in mining areas. Furthermore, radioactive materials, including uranium (U) and thorium (Th), are assessed using Gamma Spectrometry to quantify their levels in the environment (Santos *et al.,* 2019; Krachler*et al.,* 2020).

Contaminant Uptake by Vegetables

To assess the level of uptake of contaminants by vegetables tomatoes (*Solanumlycopersicum)* grown in the contaminated soils, the tomatoes are analyzed for the presence of heavy metals, organic pollutants, and radioactive materials, with particular attention given to the bioaccumulation of these contaminants in the edible parts of the plant(Bui *et al.,* 2020). AAS, ICP-MS, and Gamma Spectrometry will be used to detect and quantify these contaminants in the tomato tissues (Wang *et al.,* 2020; Arnot*et al.,* 2019). The comparison of contaminant levels in the soil, water, and plant samples before and after the growing period will provide insights into the extent of contaminant uptake and the potential risks posed by consuming crops from contaminated sites.

Conclusion

This review highlights the importance of investigating contamination levels in abandoned mining sites and the potential risks associated with the uptake of these contaminants by vegetables, such as tomatoes. Mining activities often lead to the accumulation of heavy metals, organic pollutants, and radioactive materials in the surrounding environment, including soil and water resources. These contaminants can potentially affect agricultural productivity and human health through bioaccumulation in crops grown on contaminated land.

Through advanced analytical techniques such as Atomic Absorption Spectroscopy (AAS), Inductively Coupled Plasma Mass Spectrometry (ICP-MS), and Gamma Spectrometry, this study aims to assess the levels of these contaminants in the soil, water, and tomato plants. By evaluating the bioaccumulation of heavy metals, organic pollutants, and radioactive materials in tomatoes, this research will provide valuable data on the extent to which such contaminants are taken up by crops and the potential risks posed to food safety.

The findings from this review will contribute to the growing body of knowledge on environmental contamination from mining sites and provide a basis for developing effective remediation strategies to mitigate the risks associated with these contaminants. Furthermore, the study will inform agricultural practices and policy-making related to food safety in areas affected by mining activities, ultimately helping to safeguard public health and promote sustainable agricultural practices in contaminated regions.

In conclusion, this review underscores the need for continued monitoring of contamination levels in mining-affected areas and the development of strategies to protect both the environment and human health. By focusing on the uptake of contaminants by crops, particularly tomatoes, this research will contribute to understanding the long-term environmental and agricultural consequences of mining and offer solutions for improving food safety in contaminated regions.

Future Research Directions

While this review highlights the potential risks associated with the uptake of contaminants by tomatoes grown in mining-affected environments, several gaps remain that warrant further exploration. Future research in this area should focus on the following key areas:

Expanded Analysis of Other Crops:

While tomatoes have been the focus of this study, other commonly cultivated crops should also be evaluated for their potential to uptake heavy metals, organic pollutants, and radioactive materials from contaminated soils. Crops such as maize, rice, and leafy vegetables, which are staples in many regions, could exhibit different uptake patterns and serve as better indicators of contamination in the local food chain. Comparative studies across various crops will provide more comprehensive data on the bioaccumulation of contaminants and food safety risks in agricultural systems affected by mining (Bui *et al.,* 2020).

Long-term Monitoring of Contaminants:
The current study focuses on the initial uptake of contaminants by crops, but the long-term effects of persistent contamination on soil health, plant growth, and the food chain need to be further investigated. Long-term studies could assess the effectiveness of remediation strategies, such as phytoremediation, and determine the sustainability of agricultural practices in contaminated environments (Wong *et al.,* 2021). This would contribute to the development of more sustainable agricultural practices in mining-impacted regions.

The Role of Soil Microorganisms:
Soil microorganisms play a crucial role in the bioavailability of contaminants and can influence the uptake of metals and pollutants by plants. Future research should examine the role of soil microbiomes in the transformation of contaminants (e.g., the conversion of arsenate to arsenite) and their interaction with plant roots. Understanding these interactions can help develop bioremediation strategies to reduce the bioavailability of harmful contaminants and promote safer agricultural practices (Xie*et al.,* 2020).

Development of Rapid Screening Tools:
There is a need for the development of rapid and cost-effective methods for screening soil, water, and crops for contaminant levels in affected regions. While ICP-MS, AAS, and Gamma Spectrometry are highly effective, they require specialized equipment and expertise. Future research could focus on developing field-based techniques or portable devices that can quickly assess contamination in remote or resource-limited areas, making contamination monitoring more accessible to farmers and policymakers (Ouyang*et al.,* 2020).

Influence of Climate Change on Contaminant Uptake:
Climate change can exacerbate the spread and mobility of contaminants in the environment, particularly in mining-impacted areas. Future research should explore how changing weather patterns, such as increased rainfall or drought, affect the movement of contaminants in the soil and their uptake by plants. Understanding these dynamics is essential for predicting future food safety risks in areas already facing environmental challenges due to mining (Liu *et al.,* 2021).

Human Health Risk Assessment:
Although this study focuses on contaminant uptake in plants, future research should integrate human health risk assessments to quantify the actual exposure to heavy metals and pollutants through the consumption of contaminated crops. This could involve a more detailed analysis of the bioavailability of contaminants in the digestive system and the potential toxicological effects of consuming crops grown in mining-impacted soils (Margarit*et al.,* 2020).

Integrated Remediation Strategies:
Finally, future research should explore integrated remediation strategies that combine physical, chemical, and biological methods to restore contaminated soils and reduce the levels of harmful substances. Phytoremediation, bioremediation, and the use of soil amendments can be studied in combination to assess their effectiveness in mitigating contamination and promoting sustainable agricultural practices in mining-impacted regions (Marschner*et al.,* 2020).

REFERENCES

Adebayo, O. (2022). Contaminant uptake in vegetables: A review of the impact of mining activities. Science of the Total Environment, 607, 238-246. https://doi.org/10.1016/j.scitotenv.2022.09.045

Adelekan, B. A., &Abegunde, A. S. (2021). Heavy metal contamination in soils and water of mining areas: A review of analytical techniques and remediation approaches. Science of the Total Environment, 692, 465-478.

Adewumi, J., &Ogunleye, S. (2023). Heavy metal contamination in Nigerian soils and its effects on agricultural production. International Journal of Environmental Science and Technology, 22(5), 667-678. https://doi.org/10.1007/s10510-023-01980-6

Ali, H., Khan, E., &Sajad, M. A. (2020).Phytoremediation of heavy metals—Concepts and applications. *Chemosphere*, 91, 869-881.

Arnot, J. A., et al. (2019). A review of the environmental impact of mining activities and remediation techniques for contaminated soil and water. Environmental Pollution, 252, 1202-1212.

Basu, N., et al. (2021). Radioactive contamination in mining sites: Mechanisms of plant uptake and risks to food safety. Environmental Toxicology and Chemistry, 40(2), 568-577.

Bui, L. T., et al. (2020). Heavy metal uptake by various crops grown on contaminated soils: A comparative study. Environmental Toxicology and Chemistry, 39(1), 57-70.

Chakraborty, S., et al. (2020). Organic pollutants in mining-affected regions: Identification, challenges, and plant uptake. Environmental Pollution, 267, 115-126.

De, A., et al. (2021).pH regulation and nutrient availability in contaminated water bodies: Implications for aquatic ecosystems. Environmental Science & Technology, 55(4), 345-357.

Gopalakrishnan, S., Srinivas, V., & Kumar, P. (2022). Lead contamination in tomatoes: Effects on growth and fruit quality. *Journal of Hazardous Materials,* 415, 125634.

Hachimi, M., Fekhaoui, M., Abidi, A. E., Ali, R. (2014) "Contamination des sols par les mtauxlourdspartir de minesabandonnes : le cas des minesAouli-Mibladen-Zeda au Maroc." None (2014). 10.1684/AGR.2014.0702.

Hossain, M. B., et al. (2020). Long-term monitoring of heavy metal uptake in contaminated soils: A review of field studies. Science of the Total Environment, 705, 135838.

Jesmin, A., Jang, J., Jan, T., Kim, J. G., Hosik, L. (2020) "Contamination assessment of pollutants and sediments of abandoned mines using integrated pollution index (IPI)." None . 10.5004/dwt.2020.26119.

Kabata-Pendias, A. (2020). Trace Elements in Soils and Plants (5th ed.). CRC Press.

Kazemi, M. (2021) "Screening of native plant species for phytoremediation potential in Pb-Zn mines in Iran." None. 10.22069/IJERR.2021.5545.

Khan, Z. I., Ugulu, I., & Ahmad, K. (2021).Cadmium accumulation in spinach grown in contaminated soils and its health implications.*Environmental Science and Pollution Research,* 28(12), 14567-14576.

Krachler, M., et al. (2020). Trace element analysis using AAS and ICP-MS in environmental science. Journal of

Environmental Chemistry, 23(4), 324-335.

Lee, S. Y., et al. (2021). Portable devices for real-time detection of environmental contaminants. Environmental Chemistry Letters, 19(5), 345-357.

Liu, X., et al. (2019).Gamma spectrometry applications for the monitoring of radioactive contamination in mining areas. Environmental Radiation Monitoring, 45(1), 68-74.

Liu, X., et al. (2020).Effectiveness of soil amendments in reducing the bioavailability of contaminants in mining-impacted soils.Environmental Pollution, 262, 114317.

Liu, X., et al. (2020).Organic pollutants in soil and water and their uptake by plants in mining-impacted environments. Environmental Science and Pollution Research, 27, 11956-11967.

Liu, X., et al. (2021). Environmental monitoring in contaminated sites: A review of sample preparation methods for soil and water analyses. Environmental Monitoring and Assessment, 193(2), 10-24.

Liu, X., et al. (2021). Influence of climate change on the spread of soil contaminants: A review. Science of the Total Environment, 789, 148030.

Liu, X., Zhang, S., & Shan, X. (2020).Effects of cadmium on the growth and nutritional quality of carrots.*Journal of Agricultural and Food Chemistry,* 68(15), 4567-4574.

Margarit, M. D., et al. (2020). Health risks from consuming contaminated crops: A review of bioaccumulation of toxic metals. Environmental Research, 183, 109234.

Marschner, H., et al. (2020). Integrated approaches to soil remediation in contaminated mining areas.Ecological Engineering, 155, 105971.

Ouyang, Y., et al. (2020). Portable sensors for rapid detection of heavy metals in soils: A review. Environmental Monitoring and Assessment, 192(9), 594.

Rahman, Z., & Singh, V. P. (2021). Arsenic toxicity in spinach: Growth, biochemical, and physiological responses. *Ecotoxicology and Environmental Safety,* 208, 111630.

Santos, R., et al. (2019). Heavy metal contamination in soils and water of mining areas: A review of analytical techniques and remediation approaches. Science of the Total Environment, 692, 465-478.

Seo-Jin, Y., Lin, H. K., Gang, C., Hwang, G., "The investigation of arsenic and heavy metal concentrations in soil, water and crops around abandoned metal mines." None (2014). 10.1504/IJMME.2014.060203.

Sharma, P., Jha, A. B., &Dubey, R. S. (2022). Oxidative stress and antioxidative defense systems in plants under heavy metal stress. *Plant Physiology and Biochemistry,* 170, 56-72.

Tao, X., et al. (2020). Soil structure and its role in the mobility of contaminants: A review. Soil Science Society of America Journal, 84(5), 1342-1353.

Tibbo, M., et al. (2020). The influence of mining activities on soil contamination and plant uptake of heavy metals: A review of current research. Journal of Environmental Quality, 49(1), 10-21.

Van der Meer, T. R., et al. (2020). Climate change and the mobility of contaminants in mining areas: A review. Global Change Biology, 26(6), 3140-3153.

Van der Westhuizen, M., et al. (2020). Environmental contamination from uranium mining: Detection and characterization using Gamma Spectrometry. Radiation Protection Dosimetry, 184(2), 124-132.

Wang, L., et al. (2020). Bioaccumulation of heavy metals in tomatoes from contaminated soils: An analysis using AAS and ICP-MS. Environmental Science and Pollution Research, 27, 11956-11967.

Wang, Y., Li, Y., & Liu, F. (2021). Biochar amendment reduces cadmium and lead uptake in vegetables grown in contaminated soils. *Science of the Total Environment*, 750, 141638.

Wong, M. H., et al. (2021). Long-term monitoring of phytoremediation strategies for contaminated soils.Environmental Monitoring and Assessment, 194(3), 745.

Xu, Z., Wang, Z., Deng, Z., & Zhu, G. (2021). Recent advances in the synthesis, stability, and activation of platinum(IV) anticancer prodrugs. *Coordination Chemistry Reviews*, *442*, 213991.

Yan, A., Wang, Y., & Tan, S. N. (2023). Phytoremediation of heavy metals using *Brassica juncea*: Recent advances and future prospects. *Environmental Research, 216*, 114641.

Yin, C., et al. (2020).Electrical conductivity and its relationship with soil quality and fertility in mining regions.Environmental Monitoring and Assessment, 192(10), 620.

Younji, L., Minseok, P., Seunghun, H. (2022). "Leaching Behavior of Metallic Elements from Abandoned Mine Sites in Varying Environmental Factors."*Institute of Life Science and Natural Resources* (2022). 10.33147/lsnrr.2022.30.1.87.

Zhang, X., Li, H., & Chen, Y. (2022).Role of arbuscularmycorrhizal fungi in enhancing plant tolerance to heavy metals.*Frontiers in Microbiology,* 13, 789234.

Zhang, Y., & Zhao, S. (2021). Bioaccumulation of heavy metals in crops grown in mining regions.Environmental Pollution, 279, 116884. https://doi.org/10.1016/j.envpol.2021.116884.

Zhou, D., et al. (2021). Integrated risk assessment models for environmental contamination from mining activities. Environmental Science and