Review

The Synopsis of Environmental Heavy Metal Pollution

[1,2]Anyiam N. Donald, [3,4]Pene B. Raphael, [2]Oluwole J. Olumide and [5]Okoro F. Amarachukwu

[1]*Department of Environmental Sciences, COMSATS University Islamabad, Abbottabad Campus, 22060, KPK, Pakistan*
[2]*Department of Industrial Chemistry, University of Ilorin, P.M.B. 1515, Ilorin, Kwara State, Nigeria*
[3]*Department of Environmental and Agricultural Engineering, Rivers State University, Port Harcourt, Rivers State, Nigeria*
[4]*Operations Unit, Hydrocarbon Pollution Remediation Project (HYPREP), Port Harcourt, Rivers State, Nigeria*
[5]*Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University Awka, Anambra State, Nigeria*

Article history
Received: 02-08-2022
Revised: 22-09-2022
Accepted: 25-10-2022

Corresponding Author:
Anyiam N. Donald
Department of Environmental Sciences, COMSATS University Islamabad, Abbottabad Campus, 22060, KPK, Pakistan
Email: macdonust@yahoo.com

Abstract: Heavy metal pollution continues to be a serious problem in the environment due to uncontrolled pesticide use, mining, foundry operations, smelting, fossil fuel burning and sewage sludge dumping. Mercury, lead, chromium, cadmium, copper and other heavy metals are non-biodegradable and remain in the environment in regions where human activity is prevalent. Heavy metal contamination is a serious hazard to all biota in the ecosystem because of its devastating consequences and their accumulation in soil and water has significant implications for food safety and security, the growth of plants and the survival of soil microorganisms that play significant roles in sustaining agricultural crop production. Even at low doses, these metals are toxic and can affect the food chain, posing serious public health risks. Hence, the purpose of this study is to present a concise but detailed potential source and impacts of heavy metals on the biotic segment of the ecosystems with a view to understanding and building long-term strategies for reducing their pollution and protecting public health.

Keywords: Heavy Metal, Environmental Pollution, Sources, Public Health, Ecosystem

Introduction

The term "heavy metal" refers to a class of metals and metalloids with atomic densities more than or equal to 4000 kg/m^3 (Hawkes, 1997; Edelstein and Ben-Hur, 2018). Metal levels in soil can range from a few milligrams per kilogram to 100,000 milligrams per kilogram (Singh *et al*., 2011). Heavy metals are the most prevalent inorganic contaminants that have contaminated a vast region as a result of the usage of agrochemicals, municipal waste and sludge, pesticides, emissions from municipal waste incineration, mining residues, smelting industries, and other elements have contaminated a large area of the environment (Halima *et al*., 2003). Great amounts of various heavy metals, regardless of where they come from, can cause soil deterioration and reduction in crop yield leading to poor quality agricultural produce, all of which pose major health hazards. Gilbert and Weiss (2006) reported that "heavy metals have a strong tendency to accumulate in all media, including soil and water because they are non-biodegradable and resistant to natural biodegradation". Bio-concentration explains the absorption of heavy metals from the environment into organisms, and it is the most essential phase in food chain contamination. When bio-concentration and bio-magnification levels exceed what is considered tolerable, they constitute a significant source of health concerns (Khan *et al*., 2008). Heavy metals build up in the food web owing to both natural and human activities (Zhang *et al*., 2017). Hence, the goal of this review is to present a concise but informative account of environmental heavy metal pollution in the environment and evaluate their impacts on various life forms. The findings of this study will probably serve as a reference tool for environmental scientists and health experts who work in ensuring environmental sustainability and improvement in public health.

Sources of Heavy Metal Pollution

The many sources of heavy metals around the world have been grouped into two categories: Natural and man-made sources (i.e., anthropogenic sources). Large swaths of human environment have been impaired by mining and smelting operations. To better understand the pressing issues of heavy metal pollution, the two main sources are illustrated in Fig. 1 and described in detail in subsequent sections.

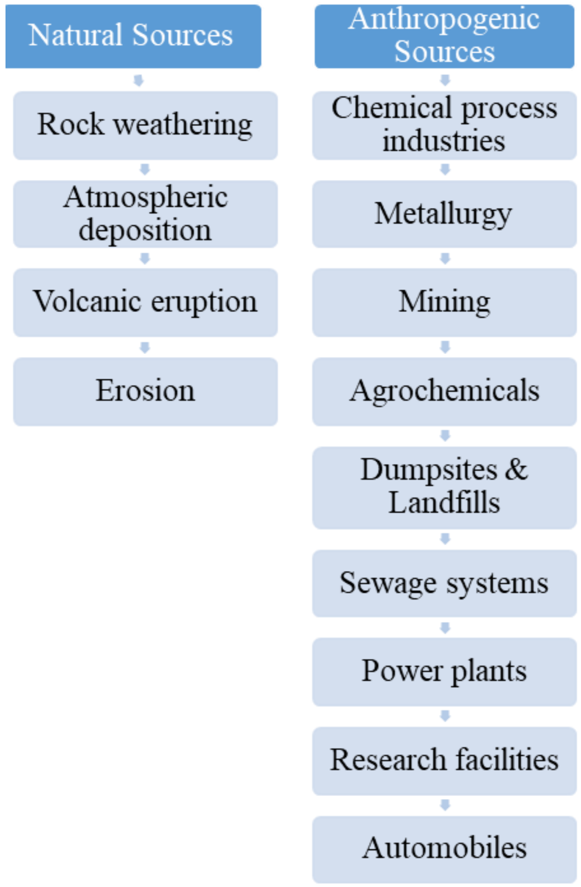

Fig 1: Natural and anthropogenic sources of heavy metals, adapted from Kanwar *et al.* (2020)

Sources of Heavy Metals

Natural Sources

Natural sources are those processes in nature that release heavy metals to the environment (without human intervention). Erosion, volcanic eruptions, and mineral weathering are examples of natural processes (Ayangbenro and Babalola, 2017). The primary and natural sources of heavy metals are weathering and pedogenesis from geologic parent material or rock outcroppings. Mineral ores such as arsenopyrite, galena, cerussite, and cassiterite are prone to dissolution by chemical weathering during which heavy metals bound within their structures are released (Abdu, 2010; Abdu *et al.*, 2011a). The kind of rock and the surrounding environment determines the nature and the amount of heavy metals in an environment. Mercury (Hg), lead (Pb), nickel (Ni), manganese (Mn), cadmium (Cd), tin (Sn), zinc (Zn), Cobalt (Co), chromium (Cr), and copper (Cu) are typically found in high concentrations in geologic plant materials (Nagajyoti *et al.*, 2010). As pointed by Rodríguez-Rodríguez *et al.* (2013) "many erosion characteristics, such as rainfall intensity, volume and frequency, vegetation and soil physical properties, influence the release and dispersion of heavy metals from rocks to varied environmental media,". Furthermore, volcanoes generate enormous levels of Al, Zn, Mn, Pb, Ni, Cu, and Hg, in addition to dangerous and hazardous gases (Nagajyoti *et al.*, 2010). According to a study, "wind dust (i.e., atmospheric deposition) from desert regions contains high amounts of Fe but low levels of Pb, Zn, Mn, Ni and Cr, and the marine aerosols, as well as forest fires, play a role in the migration of some heavy metals in various ecosystems (Nagajyoti *et al.*, 2010). In precise terms, (Zhang *et al.* 2017) are of the opinion that "natural sources of heavy metals include volcanic eruptions and continental weathering, which, when combined with anthropogenic sources, produce heavy metal accumulation in the food chain".

Anthropogenic Sources

Although heavy metals are discharged into the environment via natural phenomena, the most common and dangerous type of environmental pollution is caused by human activity. This is most likely due to their instability and solubility, as well as their bioavailability (Abdu *et al.*, 2011b). Among the anthropogenic sources of heavy metals are alloy (steel) production, discharge from automobile exhaust, battery manufacturing, biosolids and sewage sludge, coating, cement and explosive manufacturing, processing of electronic waste, fossil-fuel burning, mining, improper stacking of industrial solid wastes, leather tanning, use of agrochemicals (fertilizers and pesticides), textiles and dyes, farmland irrigation, photographic materials, steel printing pigments, electroplating and smelting (Bi *et al.*, 2006; Walter *et al.*, 2006; Navarro *et al.*, 2008; Fulekar *et al.*, 2009; Atafar *et al.*, 2010; Luo *et al.*, 2011; Zhang *et al.*, 2012; Ogunkunle and Fatoba, 2013; Boussen *et al.*, 2013; Armah, 2014; Dixit *et al.*, 2015; Balkhair *et al.*, 2016; Noli and Tsamos, 2016; Chaoua *et al.*, 2019).

Impacts of Heavy Metals on the Ecosystem

Large amounts of toxic wastes, heavy metals, metalloids (elements possessing the properties of non-metals and typical metal, e.g., arsenic and antimony), and organic contaminants are consistently released as a result of industrialization and technological advancement, all of which have caused problems in the natural environment. Ayangbenro and Babalola (2017) are of the firm believe that "heavy metals and metalloids continue to build up in soils and rivers, creating serious global health hazards owing to their inability to be converted into harmless forms and hence persist in the environment". This is validated by the report that "the amount of heavy metal contamination in the environment has reached an unacceptably high level, posing a hazard to all living things (Tak *et al.*, 2013; Gaur *et al.*, 2014; Dixit *et al.*, 2015)". The permissible limits of several heavy metals in

DOI: 10.3844/ajessp.2022.125.134

water, according to the United States Comprehensive Environmental Response Compensation and Liability Act (CERCLA), are 0.05, 0.002, 0.015, 0.01, 0.05, 0.015, 0.002 and 0.05 mg/L for Ag, Hg, Pb, Cr, Cd, and As., respectively (Chaturvedi *et al*., 2015). For Zn, Pb, Ni, Cu, and Cd, the standards for soil are 300-600, 250-500, 75-150, 135-270, and 3-6 mg/kg, respectively, based on the Indian heavy metals standards (Nagajyoti *et al*., 2010). These metals are substantial pollutants in the environment and their effects are becoming more worrisome. Humans and plants are usually exposed and are susceptible to heavy metal toxicity. Being naturally phytotoxic, heavy metals have an adverse effect on plant growth even at low concentrations. This means that when heavy metal concentrations are high, plant development is significantly impeded (Donald *et al*., 2022). Because of the health implications associated with these metals, regulatory agencies such as the Food and Agriculture Organisation (FAO), World Health Organization (WHO), and the United Nations Environmental Agency (USEPA) have set the acceptable heavy metal limits in drinking water, soil as well as plants. For drinking water, the maximum permissible and desirable limits have been presented in Table, 1a, while the maximum permissible limits for soil and plants are shown in Table 1b. In addition, the summary of the sources and impacts of heavy metals on different life forms is presented in Table 2

Table 1a: Maximum permissible and desirable limits of some heavy metals in drinking water (USEPA, 2009; Abdullahi *et al*., 2016; WHO, 2017; Kumar *et al*., 2019; Joseph *et al*., 2019)

Heavy metals (mg/L)	WHO MPL	WHO MDL	USEPA max. perm. limits
Chromium, Cr	0.005	0.003	0.100
Manganese, Mn	1.000	2.00	0.050
Iron, Fe	1.000	0.10	3.000
Cobalt, Co	0.100	0.04	0.110
Nickel, Ni	0.070	NA	0.015
Lead, Pb	0.010	NA	0.015
Copper, Cu	3.000	0.05	1.300
Cadmium, Cd	0.100	0.50	0.005
Zinc, Zn	5.000	3.00	5.000
Arsenic, As	0.050	0.01	0.010
Mercury, Hg	0.001	NA	0.002

NA= Not available. MPL= Maximum Permissible Limit. MDL= Maximum Desirable Limit. USEPA= United States Environmental Protection Agency

Table 1b: Maximum Permissible Limits of Heavy Metals in Soil and Plants/Vegetables (WHO/FAO, 2007; WHO, 2011; Mensah *et al*., 2009; Taber, 2009; FAO/WHO, 2001; Chiroma *et al*., 2014; Adagunodo *et al*., 2018; Fosu-Mensah *et al*., 2018; Iyama *et al*., 2021; Alkhatib *et al*., 2022)

Heavy metals (mg/kg)	MPL in Soil	MPL in Plants/Vegetables
Cadmium, Cd	3	0.20
Iron, Fe	300	425.50
Zinc, Zn	300	99.40
Chromium, Cr	300	1.30
Lead, Pb	50	0.43
Copper, Cu	100	40.00
Arsenic, As	20	0.15
Mercury, Hg	2	NA.00
Manganese, Mn	2000	500.00
Cobalt, Co	100	50.00
Nickel, Ni	50	67.90
Selenium, Se	10	NA.00

Table 2: Summary of heavy metal sources and impacts on living things

Heavy metals	Sources	Humans	Plants	Microbes	References
Cd	Chemical process industries, Plastic, Pigments, Ni batteries, agrochemical application, coal combustion, mining, coating of metal, weathering of ingenious rocks, welding/metallurgy smelting, refining, combustion of fossil fuel, sewage/sludge, electroplating, nuclear plants	Bronchitis, renal malfunction, bone disease, cancer, hypertension, emphysema, lung disease, prostate cancer, itai-itai, testicular atrophy, gastrointestinal disorder, microcytic hypochromic anemia, kidney diseases, headache, lymphocytosis, vomiting, and high blood pressure and cough.	Chlorosis, seed germination retardation, decrease in nutrient uptake, root and shoot growth inhibition	Protein denature, cell division inhibition, decrease in carbon and nitrogen release, nucleic acid defects.	Jiang *et al.* (2001; Wang *et al*., 2007; Nagajyoti *et al*., 2010; Barakat, 2011; Ahmad *et al*., 2012; Yourtchi and Bayat, 2013; Chibuike and Obiora, 2014; Sebogodi and Babalola *et al*., 2011; Hallaji *et al*., 2015; Fashola *et al*., 2016; Ayangbenro and Babalola, 2017; Atari *et al*., 2018; Rajendran *et al*., 2022)

Table 2: Continue

Pb	Paints, pigments, soldering, coal combustion, plumbing fixtures, municipal sewage, electroplating, Pb-battery, ceramic, oil, glass, lead mining, combustion of leaded gasoline, x-ray shields, Pb-enriched industrial wastes, metal ores, and smelting, ammunition, smoking and automobile, electronic waste, glass manufacture and coal combustion, crude oil exploration, cable coverings	Insomnia and brain damage, learning deficits, neuron damage, liver, and kidney failure, coma, anorexia, high blood pressure, hyperactivity, infertility, arthralgia, chronic nephropathy, renal system damage, central nervous system gastrointestinal tract disorder, shortened attention span, reproductive system disorder, anemia, and behavior changes in children, Alzheimer's disease risk factor, fatigue causing, irritability risk factors.	Growth and photosynthesis inhibition, seed germination suppression, chlorosis, decrease in height, biomass, number of leaves and leaf area, oxidative stress, protein deficiency, inhibit enzyme activities and enzyme activity inhibition negatively impacting CO_2 fixation.	Nucleic acid and protein denaturing, and enzyme activity inhibition and transcription	Moustakas *et al.* (1994; Malik, 2004; Kabir *et al.*, 2009; Nagajyoti *et al.*, 2010; Wuana and Okieimen, 2011; Hussain *et al*., 2013; Chibuike and Obiora, 2014; Fashola *et al.*, 2016; Ayangbenro and Babalola, 2017; Atari *et al*., 2018; Kapahi and Sachdeva, 2018; Hoang *et al*., 2019; Yogeshwaran and Priya, 2021; Rathi *et al*., 2021; Sangeetha *et al*., 2021)
As	Ceramics and electrical production, pesticides, fungicides, herbicides usage, petroleum refining, wood preservatives, animal supplements, veterinary drugs, against parasitic diseases, coal combustion in power plants, mining and smelting, semiconductors, fireworks, volcanoes, atmospheric deposition and rock sedimentation	Vascular complications, brain damage, muscle weakness, keratosis, cardiovascular and respiratory (disease) disorder, cancer, cramping and diabetes, skin disease, immuno-toxicity and genotoxicity issues, melanosis and skin cancer, dermatitis, diarrhea, vomiting, conjunctivitis, neurobehavioral disorder, and human hyper-pigmentation	Reduction in seed germination, inhibits of roots extension and proliferation, reduced leaf area, weight and dry matter production, oxidative stress, cell membrane damage, growth inhibition, critical metabolic processes interference, reduced fruit yield, wilting, fertility loss, physiological disorders and chlorosis.	Deactivation of enzymes	Abedin *et al*. (2002; Bissen and Frimmel, 2003; Singh *et al*., 2007; Wuana and Okieimen, 2011; Abdul-Wahab and Marikar, 2012; Finnegan and Chen, 2012; Chibuike and Obiora, 2014; Hallaji *et al*., 2015; Choong *et al*., 2007; Ferguson and Gavis, 1972; Iervolino, 2020; Rajendran *et al*., 2022)
Cr	Metal processing, electroplating, dyeing, leather tanning and textile, paints and pigment production; wood preservation; metallurgy (ferroalloys generation), welding, boilers and cooking systems as anti-corrosives, sludge/solid waste	Carcinogenic, dermatitis, bronchopneumonia, headache, migraine, skin ulceration, asthma, lung/respiratory tract cancer, itching of the respiratory tract, diarrhea, renal failure, nausea, cardiovascular and neurological disorders, severe gastrointestinal disorder, ulcers of the nose, kidney damage, emphysema, central nervous system disorder, liver diseases, reproductive toxicity	Reduced plant shoot and root growth, stunted growth, decrease in plant biomass, chlorosis, reduced biosynthesis germination, wilting, biochemical lesions and and decrease in plant nutrients acquisition, germination inhibition, oxidative stress, and senescence.	Inhibition of oxygen uptake, lag phase elongation and growth inhibition.	Sharma and Sharma, (1993; Moral *et al*., 1995; Moral *et al*., 1996; Panda and Patra, 2000; Rogival *et al*., 2007; Gadd, 2010; Barakat, 2011; Nematshahi *et al*., 2012; Mohanty *et al.*, 2012; Ayangbenro and Babalola, 2017; Chen and Hao, 1998; García *et al*., 2019)
Cu	Ingenious rocks, electroplating and copper polishing industry, chemical/pharmaceutical instruments, alloys, water pipelines, printing operations, roofing, mining, paint, production, biosolids, smelting and refining	Kidney complications, abdominal pain, diarrhea, sleeping disorder, anemia, nausea, liver, metabolic disorders, headache	Chlorosis, biomass reduction, root and malformation resulting in root growth reduction, retard growth, oxidative stress, death, seed and production	Cellular function disruption, enzyme activity inhibition	Kjær and Elmegaard, (1996; Cook *et al*., 1998; Salem *et al*., 2000; Sheldon and Menzies, 2005; Montagne *et al.*, 2007; Nagajyoti *et al*., 2010; Dixit *et al.*, 2015; Fashola *et al.*, 2016; Ahamed and Lichtfouse, 2020; Leong and Chang, 2020; Rajendran *et al*., 2022)
Ni	Geologic/rock weathering, bubble bursting, porcelain enameling, molds of glass (ceramics), surgical instruments, paints, catalyst, kitchen appliances, computer constituents, electroplating, Ni-Cd batteries, landfill, industrial effluents, forest fires, non-ferrous metal and steel alloys, gas exchange in the ocean, volcanic eruptions	Cancer-causing, cardiovascular diseases, dermatitis and skin diseases, dry cough, and breathing disorder, headache, kidney diseases, nausea, dizziness and chest pain	Chlorophyll content reduction, reduction in stomata conductance, inhibition of root growth enzyme activities, and growth inhibition, inhibition of Calvin cycle and CO_2 fixation, decrease in shoot yield, reduced nutrient uptake and chlorosis	Disruption of the cell membrane, oxidative stress, inhibition of activities	Khalid and Tinsley, (1980; Sheoran *et al.*, 1990; Pandolfini *et al.*, 1992; Barsukova and Gamzikova, 1999; Malik, 2004; Lin and Kao, 2005; Rogival *et al.*, 2007; Fashola *et al.*, 2016; Atari *et al*., 2018)
Hg	Rock weathering, volcano eruptions, forest fire, thermometers, metal extraction process, coal combustion, paint and paper industries, Mercury vapor lamps, wood burning, mining, emissions from caustic soda producing industries, peat, dentistry, incinerators, batteries, switches	Dysphasia, ataxia, reduced immunity, attention deficit, gastrointestinal toxicity, blindness, deafness, dizziness, loss of memory, decrease the rate of fertility and abortions, dementia, mutagenic effects, gingivitis, kidney, and renal problems, nervous system problem and neurotoxicity, pulmonary edema, sclerosis, circulation problems tremor	Decrease in germination percentage, defects in antioxidative system, reduction in plant height, overall growth, nutrient uptake, and yield reduction, decrease in the tiller and panicle formation, fruit development flowering suppression, loss of weight, photosynthesis activity reduction, chlorosis, bioaccumulation in roots and shoots of seedlings genotoxic effect inducement, homeostasis inhibition, oxidative stress, lipid peroxidation enhancement	Cell membrane disruption, reduction in population size, protein denature, enzyme function inhibition	Du *et al.* (2005; Kibra, 2008; Shekar *et al*., 2011; Wuana and Okieimen, 2011; Wang *et al*., 2012; Ali *et al.* 2015; Chibuike and Obiora, 2014; Hallaji *et al*., 2015; Fashola *et al*., 2016; Leong and Chang, 2020; Rajendran *et al*., 2022)
Zn	Brass manufacturing, polyvinyl chloride stabilizer, zinc alloy, mining, rubber and paint industry, biosolids, oil refinery, plumbing, electroplating, smelting and refining	Lethargy, macular degeneration, ataxia, vomiting, depression, anxiety, gastrointestinal irritation, metal fume fever, hematuria, seizures, icterus, impotence, prostate cancer, liver and kidney failure	Reduction in photosynthetic activity, plant growth reduction, decrease in chlorophyll content, decrease in germination percentage, and plant biomass, reduction in amino acid, sugar, carotenoid, and starch contents, the structure of chloroplast the alteration, decrease in plant nutrient content	Growth inhibition, reduction biomass, and death	Bonnet *et al*., (2000; Doncheva, *et al*., 2001; Manivasagaperumal and Balamurugan, 2011; Chibuike and Obiora, 2014; Gumpu *et al.*, 2015; Ayangbenro and Babalola, 2017)

Conclusion

Globally, the contamination of the environment by heavy metals has become a major concern to public health owing to man's reliance on industry. Agricultural practices, mining, fossil fuel combustion, wastewater irrigation, sewage sludge dumping, smelting, corrosion, weathering, volcanic eruption, and atmospheric deposition, among other anthropogenic activities and natural phenomena, have all contributed to heavy metal pollution of land and water bodies. Anthropogenic activities such as automobile use and mixed industrial activity also contribute to heavy metal contamination. These metals enter the human system via ingestion of contaminated foods and water and are nephrotoxic, carcinogenic, immunotoxic, genotoxic, and reproductive organ disruptors, according to experts and scholars in many research and review publications. Heavy metals are regarded as persistent pollutants, because they continue to be detected in different life forms, in addition to being present in every segment of the environment, including foods owing to their chemical stability, bio-magnification tendency, large production and high intake. And heavy metal hazardous effects on plants, animals, and microorganisms start to manifest beyond a specific threshold. Analysis of the effects of heavy metal pollution on many living things has been presented in this review. However, the lack of integrated analysis globally limits research on the risk assessment of micropollutants, especially heavy metals in all environmental systems. Sometimes, residue analysis simply examines a single compound and excludes related matrices, like the constituents of aquatic ecosystem. Another issue is the restriction on undertaking a quick analysis of a single substance under controlled circumstances. Hence, the following data gaps should be considered so as to carry out a thorough risk assessment of heavy metals: (i) The human accumulation parameters for heavy metals, especially in groups with high exposure rates, like young women of reproductive age, inhabitants of coastal cities, who consume crops that may have accumulated these metals and people who live close to chemical process industries, (ii) heavy metal contamination screening for edible goods and environmental components and (iii) hazard characterization based on the permissible limits set by USEPA, WHO and other environmental protection agencies. Therefore, to keep the ecological balance of the earth, it is imperative to strengthen scientific studies to look into the effects of heavy metal toxicity on different life forms. In addition, it is crucial to concentrate on risk assessment and research on the concentrations and distribution of these persistent environmental toxins in the environment.

Acknowledgment

The authors are grateful for the immeasurable support from the faculty members of their respective universities. In addition, Anyiam N. Donald, uses this medium to express his gratitude to the Association of Commonwealth Universities (ACU) for sponsoring his Master's programme through the Queen Elizabeth Commonwealth Scholarship scheme.

Funding Information

The authors declare that no funding was received for the preparation of this scientific article.

Authors' Contributions

Anyiam N. Donald: Study conception and design, critical review of relevant literature, writing of the first and final draft.

Pene B. Raphael: Data collection, critical review of relevant literature and writing of the first draft.

Oluwole J. Olumide: Critical review of relevant literature, revision of the final draft for scientific errors.

Okoro F. Amarachukwu: Data collection, checking/revision of the final draft for grammatical errors.

Ethics

This scientific article is original and has neither been published nor being considered for publication in any other journal. The corresponding author attests that all other authors have read and approved the manuscript and that no ethical principles were violated.

References

Abdu, N., Agbenin, J. O., & Buerkert, A. (2011a). Geochemical assessment, distribution and dynamics of trace metals in urban agricultural soils under long-term wastewater irrigation in Kano, northern Nigeria. *J Plant Nutr Soil Sci* 173(3), 447-458. https://doi.org/10.1002/jpln.201000333

Abdu, N., Abdulkadir, A., Agbenin, J. O., Buerkert, A. (2011b). Vertical distribution of heavy metals in wastewater-irrigated vegetable garden soils of three West African cities. *Nutr Cycl Agroecosyst* 89, 387-397. https://doi.org/10.1007/s10705-010-9403-3

Abdu, N. (2010). *Availability, transfer, and balances of heavy metals in urban agriculture of West Africa*. Kassel university press GmbH. ISBN-10: 9783899589573

Abdullahi, S., Ndikilar, C. E., Suleiman, A. B., & Hafeez, H. Y. (2016). Evaluation of Heavy Metal Concentration in Drinking Water Collected from Local Wells and Boreholes of Dutse Town, North West, Nigeria. *Advances in Physics Theories and Applications*, *51*(1). https://doi.org/10.11648/j.ijema.20160401.12

Abdul-Wahab, S., & Marikar, F. (2012). The environmental impact of gold mines: Pollution by heavy metals. *Open Engineering*, *2*(2), 304-313. https://doi.org/10.2478/s13531-011-0052-3

Abedin, M. J., Feldmann, J., & Meharg, A. A. (2002). Uptake kinetics of arsenic species in rice plants. *Plant Physiology*, *128*(3), 1120-1128. https://doi.org/10.1104/pp.010733

Adagunodo, T. A., Sunmonu, L. A., & Emetere, M. E. (2018). Heavy metals' data in soils for agricultural activities. *Data in brief*, *18*, 1847-1855.

Ahamed, M. I., & Lichtfouse, E. (Eds.). (2020). Water pollution and remediation: Heavy metals. *Berlin/Heidelberg*, Germany: Springer.

Ahmad, I., Akhtar, M. J., Zahir, Z. A., & Jamil, A. (2012). Effect of cadmium on seed germination and seedling growth of four wheat (*Triticum aestivum* L.) cultivars. *Pak. J. Bot*, *44*(5), 1569-1574.

Ali, S. W., Mirza, M. L., & Bhatti, T. M. (2015). Removal of Cr (VI) using iron nanoparticles supported on porous cation-exchange resin. *Hydrometallurgy*, *157*, 82-89. https://doi.org/10.1016/j.hydromet.2015.07.013

Alkhatib, M., Qutob, A., Kattan, E., Malassa, H., & Qutob, M. (2022). Heavy Metals Concentrations in Leafy Vegetables in Palestine, Case Study: Jenin and Bethlehem Districts. *Journal of Environmental Protection*, *13*(1), 97-111.Armah, F. A., Quansah, R., & Luginaah, I. (2014). A systematic review of heavy metals of anthropogenic origin in environmental media and biota in the context of gold mining in Ghana. *International Scholarly Research Notices*, 1-38. *2014*. https://doi.org/10.1155/2014/252148

Atafar, Z., Mesdaghinia, A., Nouri, J., Homaee, M., Yunesian, M., Ahmadimoghaddam, M., & Mahvi, A. H. (2010). Effect of fertilizer application on soil heavy metal concentration. *Environmental Monitoring and Assessment*, *160*(1), 83-89. https://doi.org/10.1007/s10661-008-0659-x

Atari, L., Esmaeili, S., Zahedi, A., Mohammadi, M. J., Zahedi, A., & Babaei, A. A. (2018). Removal of heavy metals by conventional water treatment plants using poly aluminum chloride. *Toxin Reviews*. *38*, 127-134. https://doi.org/10.1080/15569543.2018.1431676

Ayangbenro, A. S., & Babalola, O. O. (2017). A new strategy for heavy metal polluted environments: A review of microbial biosorbents. *International Journal of Environmental Research and Public Health*, *14*(1), 94. https://doi.org/10.3390/ijerph14010094

Balkhair, K. S., & Ashraf, M. A. (2016). Field accumulation risks of heavy metals in soil and vegetable crops irrigated with sewage water in the western region of Saudi Arabia. *Saudi Journal of Biological Sciences*, *23*(1), S32-S44. https://doi.org/10.1016/j.sjbs.2015.09.023

Barakat, M. A. (2011). New trends in removing heavy metals from industrial wastewater. *Arabian Journal of Chemistry*, *4*(4), 361-377. https://doi.org/10.1016/j.arabjc.2010.07.019

Barsukova, V. S., & Gamzikova, O. I. (1999). Effects of nickel surplus on the element content in wheat varieties contrasting in Ni resistance. *Agrokhimiya*, *1*(1999), 80-85.

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*(7), 883-890. https://doi.org/10.1016/j.envint.2006.05.010

Bissen, M., & Frimmel, F. H. (2003). Arsenic-a review. Part I: occurrence, toxicity, speciation, mobility. *Acta Hydrochimica et. Hydrobiologica*, *31*(1), 9-18. https://doi.org/10.1002/aheh.200390025

Bonnet, M., Camares, O., & Veisseire, P. (2000). Effects of zinc and influence of Acremonium lolii on growth parameters, chlorophyll a fluorescence and antioxidant enzyme activities of ryegrass (*Lolium perenne L.* cv Apollo). *Journal of Experimental Botany*, *51*(346), 945-953. https://doi.org/10.1093/jxb/51.346.945

Boussen, S., Soubrand, M., Bril, H., Ouerfelli, K., & Abdeljaouad, S. (2013). Transfer of lead, zinc and cadmium from mine tailings to wheat (Triticum aestivum) in carbonated Mediterranean (Northern Tunisia) soils. *Geoderma*, *192*, 227-236. https://doi.org/10.1016/j.geoderma.2012.08.029

Chaoua, S., Boussaa, S., El Gharmali, A., & Boumezzough, A. (2019). Impact of irrigation with wastewater on accumulation of heavy metals in soil and crops in the region of Marrakech in Morocco. *Journal of the Saudi Society of Agricultural Sciences*, *18*(4), 429-436. https://doi.org/10.1016/j.jssas.2018.02.003

Chaturvedi, A. D., Pal, D., Penta, S., & Kumar, A. (2015). Ecotoxic heavy metals transformation by bacteria and fungi in aquatic ecosystem. *World Journal of Microbiology and Biotechnology*, *31*(10), 1595-1603. https://doi.org/10.1007/s11274-015-1911-5

Chen, J. M., & Hao, O. J. (1998). Microbial chromium (VI) reduction. *Critical Reviews in Environmental Science and Technology*, *28*(3), 219-251. https://doi.org/10.1080/10643389891254214

Chibuike, G.U., & Obiora (2014). Heavy Metal Polluted Soils: Effect on Plants and Bioremediation Methods". *Applied and Environmental Soil Science*. 12 Article ID 752708. https://doi.org/10.1155/2014/752708

Chiroma, T. M., Ebewele, R. O., & Hymore, F. K. (2014). Comparative assessment of heavy metal levels in soil, vegetables and urban grey waste water used for irrigation in Yola and Kano. *International refereed Journal of Engineering and Science*, *3*(2), 01-09.

Choong, T. S., Chuah, T. G., Robiah, Y., Koay, F. G., & Azni, I. (2007). Arsenic toxicity, health hazards and removal techniques from water: An overview. *Desalination*, *217*(1-3), 139-166. https://doi.org/10.1016/j.desal.2007.01.015

Cook, C. M., Kostidou, A., Vardaka, E., & Lanaras, T. (1998). Effects of copper on the growth, photosynthesis and nutrient concentrations of Phaseolus plants. *Photosynthetica*, *34*(2), 179-193. https://doi.org/10.1023/A:1006832321946

Dixit, R., Malaviya, D., Pandiyan, K., Singh, U. B., Sahu, A., Shukla, R., & Paul, D. (2015). Bioremediation of heavy metals from soil and aquatic environment: An overview of principles and criteria of fundamental processes. *Sustainability*, *7*(2), 2189-2212. https://doi.org/10.3390/su7022189

Doncheva, S., Stoynova, Z., & Velikova, V. (2001). Influence of succinate on zinc toxicity of pea plants. *Journal of Plant Nutrition*, *24*(6), 789-804. https://doi.org/10.1081/PLN-100103774

Donald, A. N., Raphael, P. B., Olumide, O. J. & Amarachukwu, O. F. (2022). Environmental Heavy Metal Pollution: Physicochemical Remediation Strategies to the Rescue. *Journal of Environment Pollution and Human Health*. 10 (2), 31-45. https://doi.org/10.12691/jephh-10-2-1

Du, X., Zhu, Y. G., Liu, W. J., & Zhao, X. S. (2005). Uptake of mercury (Hg) by seedlings of rice (Oryza sativa L.) grown in solution culture and interactions with arsenate uptake. *Environmental and Experimental Botany*, *54*(1), 1-7. https://doi.org/10.1016/j.envexpbot.2004.05.001

Edelstein, M., & Ben-Hur, M. (2018). Heavy metals and metalloids: Sources, risks and strategies to reduce their accumulation in horticultural crops. *Scientia Horticulturae*, *234*, 431-444. https://doi.org/10.1016/j.scienta.2017.12.039

Fashola, M. O., Ngole-Jeme, V. M., & Babalola, O. O. (2016). Heavy metal pollution from gold mines: Environmental effects and bacterial strategies for resistance. *International Journal of Environmental Research and Public Health*, *13*(11), 1047. https://doi.org/10.3390/ijerph13111047

FAO/WHO. (2001). Food additives and contaminants. In Joint FAO/WHO Food Standards Program; ALI-NORM 01/12A; Codex Alimentarius Commission: Geneva, Switzerland, 2–7 July 2001; pp. 1-289.

Ferguson, J. F., & Gavis, J. (1972). A review of the arsenic cycle in natural waters. *Water Research*, *6*(11), 1259-1274. https://doi.org/10.1016/0043-1354(72)90052-8

Finnegan, P. M., & Chen, W. (2012). Arsenic toxicity: The effects on plant metabolism. *Frontiers in Physiology*, *3*, 182. https://doi.org/10.3389/fphys.2012.00182

Fosu-Mensah, B. Y., Ofori, A., Ofosuhene, M., Ofori-Attah, E., Nunoo, F. E., Darko, G., & Appiah-Opong, R. (2018). Assessment of heavy metal contamination and distribution in surface soils and plants along the west coast of Ghana. *West African Journal of Applied Ecology*, *26*, 167-178.

Fulekar, M. H., Singh, A., & Bhaduri, A. M. (2009). Genetic engineering strategies for enhancing phytoremediation of heavy metals. *African Journal of Biotechnology*, *8*(4).

Gadd, G. M. (2010). Metals, minerals and microbes: Geomicrobiology and bioremediation. *Microbiology*, *156*(3), 609-643. https://doi.org/10.1099/mic.0.037143-0

García, F. E., Senn, A. M., Meichtry, J. M., Scott, T. B., Pullin, H., Leyva, A. G., & Litter, M. I. (2019). Iron-based nanoparticles prepared from yerba mate extract. Synthesis, characterization and use on chromium removal. *Journal of Environmental Management*, *235*, 1-8. https://doi.org/10.1016/j.jenvman.2019.01.002

Gaur, N., Flora, G., Yadav, M., & Tiwari, A. (2014). A review with recent advancements on bioremediation-based abolition of heavy metals. *Environmental Science: Processes & Impacts*, *16*(2), 180-193. https://doi.org/10.1039/C3EM00491K

Gilbert, S. G., & Weiss, B. (2006). A rationale for lowering the blood lead action level from 10 to 2 μg/dL. *Neurotoxicology*, *27*(5), 693-701. https://doi.org/10.1016/j.neuro.2006.06.008

Gumpu, M. B., Sethuraman, S., Krishnan, U. M., & Rayappan, J. B. B. (2015). A review on detection of heavy metal ions in water–an electrochemical approach. *Sensors and Actuators B: Chemical*, *213*, 515-533. https://doi.org/10.1016/j.snb.2015.02.122

Halima, M., Conte, P., & Piccolo, A. (2003). Potential availability of heavy metals to phytoextraction from contaminated soils induced by exogenous humic substances. *Chemosphere*, *52*(1), 265-275. https://doi.org/10.1016/S0045-6535(03)00185-1

Hallaji, H., Keshtkar, A. R., & Moosavian, M. A. (2015). A novel electrospun PVA/ZnO nanofiber adsorbent for U (VI), Cu (II) and Ni (II) removal from aqueous solution. *Journal of the Taiwan Institute of Chemical Engineers*, *46*, 109-118. https://doi.org/10.1016/j.jtice.2014.09.007

Hawkes, S. J. (1997). What is a" heavy metal" *Journal of Chemical Education*, *74*(11), 1374. https://doi.org/10.1021/ed074p1374

Hoang, M. T., Pham, T. D., Nguyen, V. T., Nguyen, M. K., Pham, T. T., & Van der Bruggen, B. (2019). Removal and recovery of lead from wastewater using an integrated system of adsorption and crystallization. *Journal of Cleaner Production*, *213*, 1204-1216. https://doi.org/10.1016/j.jclepro.2018.12.275

Hussain, A., Abbas, N., Arshad, F., Akram, M., Khan, Z. I., Ahmad, K., & Mirzaei, F. (2013). Effects of diverse doses of Lead (Pb) on different growth attributes of Zea-Mays L. *Agricultural Sciences*, vol. 4, no. 5, pp. 262–265. https://doi.org/10.4236/as.2013.45037

Iervolino, G. (2020). Visible light active photocatalysts for the removal of inorganic emerging contaminants. In *Visible Light Active Structured Photocatalysts for the Removal of Emerging Contaminants*, 141-162. https://doi.org/10.1016/B978-0-12-818334-2.00006-7

Iyama, W. A., Okpara, K., & Techato, K. (2021). Assessment of Heavy Metals in Agricultural Soils and Plant (Vernonia amygdalina Delile) in Port Harcourt Metropolis, Nigeria. *Agriculture*, *12*(1), 27.

Jiang, W., Liu, D., & Hou, W. (2001). Hyperaccumulation of cadmium by roots, bulbs and shoots of garlic (*Allium sativum* L.). *Bioresource Technology*, *76*(1), 9-13. https://doi.org/10.1016/S0960-8524(00)00086-9

Joseph, A., Majesty, D., & Friday, U. (2019). Water quality assessment of Nwangele River in Imo State, Nigeria. *Journal of Ecobiotechnology*, *11*, 1-5.

Kabir, M., Iqbal, M. Z., & Shafiq, M. (2009). Effects of lead on seedling growth of Thespesia populnea L. *Advances in Environmental Biology*, 184-191.

Kanwar, V. S., Sharma, A., Srivastav, A. L., & Rani, L. (2020). Phytoremediation of toxic metals present in soil and water environment: A critical review. *Environmental Science and Pollution Research*, *27*(36), 44835-44860. https://doi.org/10.1007/s11356-020-11461-0

Kapahi, M., & Sachdeva, S. (2019). Bioremediation options for heavy metal pollution. *Journal of Health and Pollution*, *9*(24). https://doi.org/10.5696/2156-9614-9.24.191203

Khalid, B. Y., & Tinsley, J. (1980). Some effects of nickel toxicity on rye grass. *Plant and Soil*, *55*(1), 139-144. https://doi.org/10.1007/BF02149717

Khan, S., Cao, Q., Zheng, Y. M., Huang, Y. Z., & Zhu, Y. G. (2008). Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. *Environmental Pollution*, *152*(3), 686-692. https://doi.org/10.1016/j.envpol.2007.06.056

Kibra, M. G. (2008). Effects of mercury on some growth parameters of rice (*Oryza sativa* L.). *Soil Environ*, *27*(1), 23-28.

Kjær, C., & Elmegaard, N. (1996). Effects of Copper Sulfate on Black Bindweed (Polygonum convolvulus L.). *Ecotoxicology and Environmental Safety*, *33*(2), 110-117. https://doi.org/10.1006/eesa.1996.0014

Kumar, V., Parihar, R. D., Sharma, A., Bakshi, P., Sidhu, G. P. S., Bali, A. S., & Rodrigo-Comino, J. (2019). Global evaluation of heavy metal content in surface water bodies: A meta-analysis using heavy metal pollution indices and multivariate statistical analyses. *Chemosphere*, *236*, 124364. https://doi.org/10.1016/j.chemosphere.2019.124364

Leong, Y. K., & Chang, J. S. (2020). Bioremediation of heavy metals using microalgae: Recent advances and mechanisms. *Bioresource Technology*, *303*, 122886. https://doi.org/10.1016/j.biortech.2020.122886

Lin, Y-C., & Kao, C-H. (2005). Nickel toxicity of rice seedlings: Cell wall peroxidase, lignin and $NiSO_4^-$ inhibited root growth, Crop, *Environment Bioinformatics*, 2, 131–136.

Luo, C., Liu, C., Wang, Y., Liu, X., Li, F., & Zhang, G., Li, X. (2011). Heavy metal contamination in soils and vegetables near an e-waste processing site, south China. *Journal of Hazardous Materials*, *186*(1), 481-490. https://doi.org/10.1016/j.jhazmat.2010.11.024

Malik, A. (2004). Metal bioremediation through growing cells. *Environment International*, *30*(2), 261-278. https://doi.org/10.1016/j.envint.2003.08.001

Manivasagaperumal, R., Balamurugan, S., Thiyagarajan, G., & Sekar, J. (2011). Effect of zinc on germination, seedling growth and biochemical content of cluster bean (*Cyamopsis tetragonoloba* (L.) Taub). *Current Botany*, *2*(5), 11-15.

Mensah, E., Kyei-Baffour, N., Ofori, E., & Obeng, G. (2009). Influence of human activities and land use on heavy metal concentrations in irrigated vegetables in Ghana and their health implications. In *Appropriate Technologies for Environmental Protection in the Developing World* (pp. 9-14). Springer, Dordrecht.

Mohanty, M., Pattnaik, M. M., Mishra, A. K., & Patra, H. K. (2012). Bio-concentration of chromium-an in situ phytoremediation study at South Kaliapani chromite mining area of Orissa, India. *Environmental Monitoring and Assessment*, *184*(2), 1015-1024. https://doi.org/10.1007/s10661-011-2017-7

Montagne, D., Cornu, S., Bourennane, H., Baize, D., Ratié, C., & King, D. (2007). Effect of agricultural practices on trace-element distribution in soil. *Communications in Soil Science and Plant Analysis*, *38*(3-4), 473-491. https://doi.org/10.1080/00103620601174411

Moral, R., Gomez, I., Pedreno, J. N., & Mataix, J. (1996). Absorption of Cr and effects on micronutrient content in tomato plant (*Lycopersicum esculentum* M). *Agrochimica*, *40*(2-3), 132-138.

Moral, R., Pedreno, J. N., Gomez, I., & Mataix, J. (1995). Effects of chromium on the nutrient element content and morphology of tomato. *Journal of Plant Nutrition*, *18*(4), 815-822. https://doi.org/10.1080/01904169509364940

Moustakas, M., Lanaras, T., Symeonidis, L., & Karataglis, S. (1994). Growth and some photosynthetic characteristics of field grown Avena sativa under copper and lead stress. *Photosynthetica (Czech Republic)*. *30* (3), 389-396.

Nagajyoti, P. C., Lee, K. D., & Sreekanth, T. V. M. (2010). Heavy metals, occurrence and toxicity for plants: A review. *Environmental Chemistry Letters*, *8*(3), 199-216. https://doi.org/10.1007/s10311-010-0297-8

Navarro, M. C., Pérez-Sirvent, C., Martínez-Sánchez, M. J., Vidal, J., Tovar, P. J., & Bech, J. (2008). Abandoned mine sites as a source of contamination by heavy metals: A case study in a semi-arid zone. *Journal of Geochemical Exploration*, *96*(2-3), 183-193. https://doi.org/10.1016/j.gexplo.2007.04.011

Nematshahi, N., Lahouti, M., & Ganjeali, A. (2012). Accumulation of chromium and its effect on growth of (*Allium cepa* cv. Hybrid). *European Journal of Experimental Biology*, *2*(4), 969-974.

Noli, F., & Tsamos, P. (2016). Concentration of heavy metals and trace elements in soils, waters and vegetables and assessment of health risk in the vicinity of a lignite-fired power plant. *Science of the Total Environment*, *563*, 377-385. https://doi.org/10.1016/j.scitotenv.2016.04.098

Ogunkunle, C. O., & Fatoba, P. O. (2013). Pollution Loads and the Ecological Risk Assessment of Soil Heavy Metals around a Mega Cement Factory in Southwest Nigeria. *Polish Journal of Environmental Studies*, *22*(2).

Panda, S. K., & Patra, H. K. (2000). Nitrate and ammonium ions effect on the chromium toxicity in developing wheat seedlings. *Proceedings of the National Academy of Sciences India. Section B, Biological Sciences*, *70*(1), 75-80.

Pandolfini, T., Gabbrielli, R., & Comparini, C. (1992). Nickel toxicity and peroxidase activity in seedlings of Triticum aestivum L. *Plant, Cell & Environment*, *15*(6), 719-725. https://doi.org/10.1111/j.1365-3040.1992.tb01014.x

Rajendran, S., Priya, T. A. K., Khoo, K. S., Hoang, T. K., Ng, H. S., Munawaroh, H. S. H., & Show, P. L. (2022). A critical review on various remediation approaches for heavy metal contaminants removal from contaminated soils. *Chemosphere*, *287*, 132369. https://doi.org/10.1016/j.chemosphere.2021.132369

Rathi, B. S., Kumar, P. S., & Show, P. L. (2021). A review on effective removal of emerging contaminants from aquatic systems: Current trends and scope for further research. *Journal of Hazardous Materials*, *409*, 124413. https://doi.org/10.1016/j.jhazmat.2020.124413

Rodríguez-Rodríguez, M. F., Sánchez-García, A., Salas, J. J., Garcés, R., & Martínez-Force, E. (2013). Characterization of the morphological changes and fatty acid profile of developing Camelina sativa seeds. *Industrial Crops and Products*, *50*, 673-679. https://doi.org/10.1016/j.indcrop.2013.07.042

Rogival, D., Scheirs, J., & Blust, R. (2007). Transfer and accumulation of metals in a soil–diet–wood mouse food chain along a metal pollution gradient. *Environmental Pollution*, *145*(2), 516-528. https://doi.org/10.1016/j.envpol.2006.04.019

Salem, H. M., Eweida, E. A., & Farag, A. (2000). Heavy metals in drinking water and their environmental impact on human health. In *Int. Conference on the Environ Hazards Mitigation, Cairo Univ. Egypt*. 542-56.

Sangeetha, V., Thenmozhi, A., & Devasena, M. (2021). Enhanced removal of lead from soil using biosurfactant derived from edible oils. *Soil Sediment Contam. Int. J*, *30*, 135-147. https://doi.org/10.1080/15320383.2020.1811204

a Identification of soil bacteria from mining environments in Rustenburg, South Africa. *Life Sci. J*, *8*, 25-32.

Sharma, D. C., & Sharma, C. P. (1993). Chromium uptake and its effects on growth and biological yield of wheat. *Cereal Research Communications*, 317-322.

Shekar, C. C., Sammaiah, D., Shasthree, T., & Reddy, K. J. (2011). Effect of mercury on tomato growth and yield attributes. *International Journal of Pharma and Bio Sciences*, *2*(2).

Sheldon, A. R., & Menzies, N. W. (2005). The effect of copper toxicity on the growth and root morphology of Rhodes grass (*Chloris gayana Knuth*.) in resin buffered solution culture. *Plant and Soil*, *278*(1), 341-349. https://doi.org/10.1007/s11104-005-8815-3

Sheoran, I. S., Singal, H. R., & Singh, R. (1990). Effect of cadmium and nickel on photosynthesis and the enzymes of the photosynthetic carbon reduction cycle in pigeonpea (*Cajanus cajan* L.). *Photosynthesis Research*, *23*(3), 345-351. https://doi.org/10.1007/BF00034865

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.

Singh, N., Kumar, D., & Sahu, A. P. (2007). Arsenic in the environment: Effects on human health and possible prevention. *Journal of Environmental Biology*, *28*(2), 359.

Taber, H. G. (2009). Plant Analysis Sampling Procedures and Micronutrient Characteristics with emphasis on vegetable crops. *Commercial Vegetables, Horticulture. Iowa State University of Science and Technology*.

Tak, H.I.; Ahmad, F., & Babalola, O.O. (2013). Advances in the application of plant growth-promoting Rhizobacteria in phytoremediation of heavy metals. In Reviews of Environmental Contamination and Toxicology; Springer: New York, NY, USA, pp. 33-52. https://doi.org/10.1007/978-1-4614-5577-6_2

USEPA, (2009). Drinking Water Standards and Health Advisories. Office of Water, Washington, DC, USA. EPA 822-R-09-011.

Walter, I., Martinez, F., & Cala, V. (2006). Heavy metal speciation and phytotoxic effects of three representative sewage sludges for agricultural uses. *Environmental Pollution*, *139*(3), 507-514. https://doi.org/10.1016/j.envpol.2005.05.020

Wang, J., Feng, X. anderson, C. W., Xing, Y., & Shang, L. (2012). Remediation of mercury contaminated sites–a review. *Journal of Hazardous Materials*, *221*, 1-18. https://doi.org/10.1016/j.jhazmat.2012.04.035

Wang, M., Zou, J., Duan, X., Jiang, W., & Liu, D. (2007). Cadmium accumulation and its effects on metal uptake in maize (*Zea mays* L.). *Bioresource Technology*, *98*(1), 82-88. https://doi.org/10.1016/j.biortech.2005.11.028

WHO, (2017). Guidelines for Drinking-Water Quality, fourth ed. incorporating the first addendum, Geneva.

WHO. (2011). Joint FAO/WHO Food Standards Programme Codex Committee on Contaminants in Foods. 21-25.

WHO/FAO. (2007). Joint FAO/WHO Food Standard Programme Codex Alimentarius Commission 13th Session. Report of the Thirty-Eight Session of the Codex Committee on Food Hygiene. Houston, United States of America, ALINORM. Accessed 30/07/2022.

Wuana, R. A., & Okieimen, F. E. (2011). Heavy metals in contaminated soils: A review of sources, chemistry, risks and best available strategies for remediation. *International Scholarly Research Notices*. 1–20. https://doi.org/10.5402/2011/402647

Yogeshwaran, V., & Priya, A. K. (2021). Adsorption of lead ion concentration from the aqueous solution using tobacco leaves. *Materials Today: Proceedings*, *37*, 489-496. https://doi.org/10.1016/j.matpr.2020.05.467

Yourtchi, M. S., & Bayat, H. R. (2013). Effect of cadmium toxicity on growth, cadmium accumulation and macronutrient content of durum wheat (Dena CV.). *International Journal of Agriculture and Crop Sciences (IJACS)*, *6*(15), 1099-1103.

Zhang, F., Yan, X., Zeng, C., Zhang, M., Shrestha, S., Devkota, L. P., & Yao, T. (2012). Influence of traffic activity on heavy metal concentrations of roadside farmland soil in mountainous areas. *International Journal of Environmental Research and Public Health*, *9*(5), 1715-1731. https://doi.org/10.3390/ijerph9051715.

Zhang, H., Huang, B., Dong, L., Hu, W., Akhtar, M. S., & Qu, M. (2017). Accumulation, sources and health risks of trace metals in elevated geochemical background soils used for greenhouse vegetable production in southwestern China. *Ecotoxicology and Environmental Safety*, *137*, 233-239. https://doi.org/10.1016/j.ecoenv.2016.12.010.