Al-Muthanna J. For Agric Sci Print ISSN: 2226-4086 Online ISSN:2572-5149
Vol. 11 , Issue 2. 2024

https://muthjas.mu.edu.iq/ http://doi.org/10.52113/mjas04/11.2/5

Fate and effects of heavy metals in the environment- A Review

Alaa Mahmoud*, Ibtehal Al-Taee

Department of Biology, College of Science, Al-Muthanna University, Samawa, Iraq

alaa.jabar@mu.edu.iq

Received on 01/5/2024 Accepted on 15/5/2024 Published on 15/12/2024

Abstract

Heavy metals represent a significant environmental concern due to their persistence, toxicity, and potential for bioaccumulation in ecosystems. The sources of heavy metals are diverse, including natural geological processes, industrial activities, agricultural practices, and urbanization. Once released into the environment, heavy metals can undergo various pathways such as atmospheric deposition, surface runoff, leaching into groundwater, and bioaccumulation through food chains. The environmental impacts of heavy metals extend beyond individual organisms to ecosystem structure and function. They can alter nutrient cycling, microbial communities, species composition, and biodiversity, ultimately affecting ecosystem stability and resilience.

A multimodal strategy that incorporates source reduction, pollution prevention, remediation techniques, and regulatory measures is needed to mitigate the dangers related to heavy metals. Sustainable management techniques include membrane bioreactors, microbial systems, electrochemical processes, supercritical fluid extraction, adsorption, filtration, electrodialysis, precipitation, and ion exchange.

Key words: Heavy metals, Environment, Treatment technologies

Introduction

The environment is the surroundings where humans, plants, animals and micro-organisms live or work. It is composed of the land, the Earth's atmosphere and the water. The Earth system is defined by four spheres: biosphere, atmosphere, lithosphere, and hydrosphere, all of which work together harmoniously. Environmental pollutants and contaminants are chemical substances present in the environment. Higher levels than in any section of the environment [1]

Industrialization has grown rapidly over the past hundred years. This has increased the need for ruthless exploitation of the earth's natural resources, thereby exacerbating the global environmental pollution problem. The environment is severely polluted by various pollutants such as inorganic ions, organic pollutants, organometallic compounds, radioactive isotopes, gaseous pollutants, and nanoparticles [2].

In ecosystem environments, most heavy metal elements are transferred through anthropogenic inputs e.g., mining, fisheries, aquaculture, fossil fuel combustion, pesticides, ecotourism, and shipping activities as well as natural continuous inputs and sudden events [3].

In all environments, such as freshwater or marine ecosystems, most heavy metals naturally occurring in the earth's crust or from dust storms have low concentrations, in addition to heavy metals from various pollution sources in the area. Sediments act as sinks for heavy metals and become potential sources of water pollution when environmental conditions change [4].

Now, the importance of water to the environment is considered a basic need all over the world. Water is a basic need for human survival. Environmental pollution increases due to water contamination and water shortages, while limited availability is increasing due to the destruction of natural water resources [5]. This leads to the degradation of economic development, human livelihoods, and the environment. In recent years, environmental protocols have changed to reduce water pollution. About 40% of the population are affected by water scarcity due to rapid growth in the urbanization, climate change, natural resource use, and food demand [6].

The increasing use of freshwater for agricultural and industrial purposes has led to an increase in water demand. According to a new water supply agency, this problem can be solved by using treated wastewater [7]. However, the mandate is based on updated wastewater regulations. Although treated water plays an important role in reducing the above problems, it may have certain health effects due to the presence of pathogenic microorganisms, endocrine disrupting chemicals (EDCs), pharmaceuticals, personal care products (PCPs), and organic compounds in it [8].

There has been a debate on the definition of the term "heavy metals". They are defined as heavy metals either because of their high atomic weight or because of their high density [7;9]. Today, the term "heavy metals" is used to describe metallic chemical elements and metalloids that are toxic to the environment and humans. Some metalloids as well as lighter metals such as selenium, arsenic, and aluminum are toxic. They have been termed heavy metals while some heavy metals are typically not toxic such as the element gold [9].

The rapid pace of industrialization, rapidly growing energy demands and reckless

exploitation of natural resources are the main reasons for the aggravation of environmental pollution problems, which currently pose a serious threat to biodiversity and ecosystem processes. Heavy metals are one of the most dangerous pollutants affecting the environment [10]. Metals are the main category of globally distributed pollutants, natural elements extracted from the earth and used in human industry and products for thousands of years. In recent decades, the use of heavy metal ions has increased significantly, which inevitably leads to an increase in the flux of metallic substances into aquatic and terrestrial environments. [2].

Heavy metals are of particular concern because they are non-biodegradable and therefore persistent. Metals have long been abundant on Earth, with approximately 75% of the elements classified as metals in the periodic table. Most of the contaminants listed by USEPA as trace inorganic contaminants are heavy metals [7]. In recent years, public awareness has increased due to the long-term toxic effects of water containing dissolved metal ions. Unlike most organic pollutants, heavy metals are generally not eliminated from aquatic ecosystems through natural processes. Therefore, heavy metal concentrations increase and cause biological and physiological problems. They have the unique property of long-term accumulation along the food chain and may cause acute or chronic toxicity to aquatic organisms and humans [11].

Types of heavy metals and their effects

Heavy metals occur in the environment either in water, land, suspended load, or deposited sediments in aquatic environments. However, measuring their concentrations in water over short periods of time does not provide accurate results about the extent of pollution, since water runoff is non-uniform and the release of these pollutants is irregular. Therefore, the focus is on sediments [12], as they are the sinks of various types of pollutants and organic matter that settle from the water bodies above, and because they represent a more stable indicator of the level of heavy element pollution in the aquatic environment [13].

Elements with atomic weights between 63.5 and 200.6 and specific gravity above 5.0 are heavy metals [14]. They exist as natural elements in the environment. The term heavy metals refer to elements that have a high density and are toxic even in low concentrations. In recent years, heavy metals in wastewater have become a major environmental concern as they pose a high risk to ecosystems and human health even in very low concentrations. Heavy metal pollution is a major environmental burden due to its flexibility, accumulation, non-degradability, and longevity [15]. Some heavy metals form small amounts of essential components required for metabolic activities of organisms. At the same time, the use of these metals in large quantities can cause irreparable toxicity to human health [16].

Heavy metals in open waters lead to the end of aquatic life, oxygen insufficiency and algal blooms. When they discharge into the rivers, the heavy metals get converted into hydrated ions which are highly toxic than the metal atoms. These hydrated ions disrupt the enzymatic process as well as the absorption is faster in it. Hence the removal of heavy metals is compulsory to lower the public risks. To limit the water pollution level, World Health Organization (WHO) and Environmental Protection Agency (EPA) have set the most admissible discharge

level of heavy metal into the environment. Yet, the discharged effluent contains a high concentration of heavy metals than the permissible limits which causes the human health problems and environmental problems [17].

Heavy metals: Though these heavy metals have been present in nature for several years, their toxicity has increased due to anthropogenic activities like mining and urbanization. The health of humans and plants depends on the surroundings they live, so it is very important to study the direct and indirect effects on the environment due to heavy metals. Heavy metals are a group of metals or metalloids. Examples are copper, lead, nickel, cadmium, mercury, arsenic, zinc, and chromium [18].

The proportion of heavy metals must be balanced or else it will be harmful. As these metals are toxic, they dissolve in water and affect living organisms. Some of the effects of heavy metals on human organs like kidneys, liver, lungs, hairs, and skin may cause severe damage and also affect high blood pressure, cancer, and many severe diseases [19].

Although there are harmful effects of heavy metals, there are some positive effects of heavy metals on the environment, like plants requiring macro-nutrients (C, H, N, O2, P, S, etc.) as well as micronutrients (B, Cl, Cu, Fe, Mn, Mo, Ni and Zn) [20]. Below are the most important heavy metals that have an impact on the environment.

1. Arsenic (As): is an easily available heavy metal everywhere in the form of oxides, sulfides, and other compounds in polluted water and soil from the weathering of rocks and also by human activities. It is used in the manufacturing of agricultural insecticides and fungicides and is also used as a drug to cure diseases. Arsenic is mainly transported by polluted water or air by industries like smelting and refining metals and chemicals into the environment [17]. Both the natural and human sources of the creation of arsenic and its other compounds accumulate in the marine biota of the estuaries. Accumulation of arsenic at a certain level is not very harmful for the species in the estuaries but the excess concentration of arsenic could be toxic for all the organisms in the estuary and also for humans that consume fish and other products from the same estuary [20]. Higher concentrations of arsenic in drinking water can cause lung, liver, kidney, and skin diseases. Study also reveals that arsenic affects the growth of children and is sometimes responsible for infant mortality [21].

2. Cadmium (Cd): is the most toxic non-essential heavy metal added into the river by disposal of cadmium-containing materials, cadmium is used in paints, cosmetics, welding, electroplating, batteries, pesticides, and fertilizers which people widely use. Cigarette smoking is also one of the sources of cadmium exposure in humans [22]. Dust containing cadmium and contaminated water plays the role of conductor of cadmium from the environment to the living. Cadmium accumulates in sediments, particulate matter, and water in the estuarine ecosystems. Bioaccumulation of cadmium into marine organisms depends upon the cadmium compound structures, salinity, and temperature of the aquatic systems [23]. Higher accumulation of cadmium can harm vitamin D metabolism in kidneys and harm the bones, heart, and blood vessels, kidney damage, the central nervous system, and other organs [24].

3. Chromium (Cr): Various industries use chromium for different activities but 90% of chromium production is used in metallurgical industries. The untreated

wastewater increases the contamination of chromium in the environment. Though it is an essential micronutrient for humans, a higher intake of chromium is toxic to the human body. According to previous research [25], chromium is generally not collected in the fish's body still if the amount of chromium increases, there are very harmful effects on fish gills at the discharge point. The oxidation state of chromium affects the uptake of chromium in plants, excessive amount of chromium harms the respiratory system and could cause lung cancer. Skin sensitization, liver, and heart disorders are other effects of high chromium in the human body [26].

4. Copper (Cu): is often used for the manufacturing of water pipes or the alloys of brass and bronze which contain copper, electroplating, pesticides, mining, fiber productions, use of fertilizers, and fungicidal spray activities are the source of copper contamination in the environment. Industrial waste as well as domestic waste added into the rivers leads to an increase in the concentration of heavy metals in the estuarine ecosystems and produces a threat to the marine plants and animal species [27]. The balance of heavy metals present naturally gets disturbed and provides high exposure of copper to the plant, species, and sediments created. Copper used as a packaging material can also contaminate food and water [28]. Harmful effects of copper contamination are failures of the brain and kidney, liver damage, and demolition of red blood cells, and could be transferred into severe anemia, and intestinal irritation [29].

5. Lead (Pb): Humans generally get exposed to lead near mining activities due to inhalation. In the case of fish and other marine organisms, lead is collected indirectly from the food chain and directly from contaminated water. Lead is a more toxic heavy metal and needs to have control measures on its use. Drinking water and seafood are some of the major exposures to lead to humans [23]. Lead is found to be tolerable in aquatic systems because it is slightly soluble in saline water and shows adaptability. This helps some kind of protection from lead to accumulate in the marine organisms [25]. Lead is harmful to all organs, but specifically, the lung is the most common organ attacked by the higher concentration of lead which possibly results in lung cancer15. It is harmful to adults and children but children are affected at an even lower level by an accumulation of lead, Nervous system is also damaged by the high amount of lead in the body. Infertility in men, premature delivery in women, and miscarriage are also the effects of higher levels of lead [25].

6. Zinc (Zn): is used in fertilizers and pesticides on a large scale as it is essential for plant growth. It is also useful for humans, but the overdose of zinc may cause fatigue or weakness. Zinc is used for different activities such as galvanization of metals, paints, weapons, cosmetics, batteries, plastic, pharmaceuticals purpose [30]. Zinc gets added into the estuaries by natural as well as anthropogenic sources. The zinc percentage in the estuarine ecosystem could be raised by the use of lubricating oil containing zinc in it, and this contamination of Zn can increase the health risk to aquatic plants and animals. The harmful effects of over-accumulation of zinc can cause nausea, anemia, and cholesterol and also may affect the immune system of humans [9].

Sources of Heavy metals in environment

Metals are classified into the following categories: alkali metals, alkaline earth metals, transition metals, precious metals, platinum metals, rare metals, rare earth metals, actinides, and light metals. The main sources are industrial wastes from

manufacturing or metal refining. The second major source of heavy metal pollution is the use of metal-containing compounds in agriculture as fertilizers, pesticides, etc. These metals are transported to surface water and groundwater through leaching, diffusion, and infiltration [31].

Metals differ from other toxic substances in that they are neither created nor destroyed by humans. Environmental pollution from hazardous metals and minerals can arise from natural as well as anthropogenic sources [31]. These minerals arrive from the natural source, which is rocks and sediments, to the aquatic environment, and these released minerals which are dissolved or suspended in rainwater drifting on the surface ground or suspended in the air to be moved by the wind from one place to another one. Also, volcanic activities are among the most important natural sources that lead to pollution of the aquatic environment [32]. Anthropogenic sources Manufacturing activity is a major source of pollution with heavy metals in the environment, including the petroleum industries, oil refineries, iron and steel factories, copper, glass, aluminum, tanning factories, fertilizers, pesticides, gasoline, etc [4]. Heavy metal pollution mainly arises from the effluents of industrial units. Irrigation by effluents released from paper mills and fertilizer factories are adding various alkalies, ammonia, cyanides, and heavy metals into the water resources [33]. The wastewater from the dyes and pigment industries, metal cleaning, electroplating, leather, and mining industries contains considerable amounts of heavy metal ions. Burning of fossil fuel and transport sectors redistribute toxic heavy metals into the environment. The distribution of contaminants released to soils by human activities is related to how and where they are added [34].

Generally, metals enter the aquatic environment through atmospheric deposition, erosion of the geological milieu, or due to anthropogenic activities caused by industrial effluents, domestic sewage and mining waste, urban storms, water runoff, landfills, and mining of coal and ore. But naturally, metals get into water by chemical weathering of minerals and soil leaching [35]. Heavy metals are always present at background levels of non-anthropic origin where their source in soils could be related to weathering of parent rocks and pedogenesis. The metals dissolve and move downstream to lower reaches of the water bodies while others settle into the sediments Also, Historical Contamination of past industrial activities, such as historical mining and manufacturing operations, can leave behind legacy contamination of heavy metals in soil, groundwater, and sediments, which can persist for many years [36].

The fate of heavy metals in the ecosystem

A. Bioaccumulation and Biomagnification: Heavy metals can accumulate in living organisms through various pathways, including absorption of soil, water, and food. In aquatic environments, for example, plankton and other organisms at the base of the food chain may accumulate metals from water, which then bioaccumulate in larger predators through consumption. This process can lead to bio-magnification, where the concentration of heavy metals increases at higher trophic levels [37].

B. Soil Sorption and Mobility: In soils, heavy metals may undergo sorption onto mineral surfaces or organic matter, reducing their mobility and availability for plant uptake or leaching into groundwater. However,

certain factors such as soil pH, organic matter content, and soil type can influence the mobility and bioavailability of heavy metals [38].

C. Leaching and Groundwater Contamination: Heavy metals can leach from soils into groundwater, especially in high rainfall or irrigation areas. Once in groundwater, metals may persist for long periods and pose risks to drinking water quality and aquatic ecosystems [39].

D. Plant Uptake and Translocation: Plants can take up heavy metals from the soil or water through their roots and accumulate them in various tissues. Some plants, known as hyperaccumulators, can accumulate high concentrations of metals in their tissues without experiencing toxicity. Once absorbed, metals may be translocated within the plant and transferred to higher trophic levels through consumption by herbivores or omnivores [9].

E. Volatilization and Atmospheric Transport: Certain heavy metals, such as mercury, can undergo volatilization from soil or water surfaces and be transported over long distances through the atmosphere. Atmospheric deposition of metals can then occur through precipitation or dry deposition, contributing to contamination of terrestrial and aquatic ecosystems [9].

F. Detoxification and Bioremediation: Some microorganisms can metabolize or transform heavy metals into less toxic forms through processes such as bioreduction, biosorption, or bioaccumulation. Bioremediation strategies harness the potential of microorganisms, plants, or enzymes to remediate contaminated environments by enhancing the natural degradation or sequestration of heavy metals [40].

Treatment technologies

There are several treatment technologies for removing heavy metals from water and wastewater. These methods can be categorized into physical, chemical, and biological processes depending on the nature of heavy metals which have grown into an important research area [41]. Ion exchange, supercritical fluid extraction, adsorption, filtration, electrodialysis, precipitation, microbial system, the electrochemical process, an advanced oxidation process, and membrane bioreactors are better challenging and assuring techniques available for the disposal of heavy metals [42]. Each technology has certain advantages and

disadvantages which are described in Table 1 [43]. The selection of a particular treatment technology depends on factors such as the concentration and type of heavy metals present, the volume of water to be treated, cost considerations, and regulatory requirements. Often, a combination of different treatment methods may be employed to effectively remove heavy metals from water and wastewater [44], are better challenging and assuring techniques available for the disposal of heavy metals. The above-mentioned methods are broadly classified into three sections: physical, chemical and biological. But depending upon the nature of heavy metals the treatment techniques are applied [48].

Table 1. Advantages and disadvantages of various treatment techniques accessible for the removal of heavy metals from wastewater.

NO	Techniques	Advantages	Disadvantages	References
1	Coagulation	Cost effective, Dewatering qualities	Generation of sludge, Utilization of chemicals is high	[42]
2	Membrane filtration	High removal of heavy metals, lower space requirement	Very expensive, membrane fouling, complex process.	[42]
3	Adsorption	Easy operation, less sludge production, utilization of low cost adsorbents	Desorption	[45]
4	Electrochemical treatment	Efficient for the removal of important metal ions, low chemical usage	Initial investment is high, need high electrical supply	[42]
5	Electrodialysis	High segregation of metals	Clogging and energy loss	[45]
6	Ion exchange	High transformation of components	Removes only limited metal ions, operational cost is high	[46]
7	Photo catalysis	Eliminates both the metal ions and organic pollutants concurrently	It takes prolonged time to remove the metals	[43]
8	Biological treatment	This technology is beneficial in removing heavy metals	Need to be developed	[47]
9	Oxidation	No need of electricity	Rusting occurs in the system due to the usage of oxidation	[44]

Conclusion

Many of the estuaries in the world already showed an alert of high contamination of heavy metals in the sediments, and other organisms in their ecosystems. This contamination of heavy metals in the sediments and marine ecosystem has potential of health risk to the humans and therefore strong remediation techniques and research should be promoted. Hazardous heavy metals must be trapped at the outlets of waste water discharged from the factories and industries.

The health of many people is being affected by the pollution of the world with heavy metals, primarily caused by human contamination. The extent of negative health effects differs depending on the specific heavy metal and its chemical composition, as well as the duration and amount of exposure. It has been found that the severity of these effects is influenced by the dose and length of exposure. Prolonged, low-level exposure to various heavy metals poses a significant public health risk in areas affected by metal contamination.

References

1.Masindi, V., & Muedi, K. L. (2018). Environmental contamination by heavy metals. Heavy metals, 10(4), 115-133.

2.Gautam, P. K., Gautam, R. K., Banerjee, S., Chattopadhyaya, M. C., & Pandey, J. D. (2016). Heavy metals in the environment: fate, transport, toxicity and remediation technologies. Nova Sci Publishers, 60, 101-130.

3.Kong, M., Zhu, Y., Han, T., Zhang, S., Li, J., Xu, X., ... & Gao, Y. (2021). Interactions of heavy metal elements across sediment-water interface in Lake Jiaogang. Environmental Pollution, 286, 117578.

4. Al-Sarraj, E. S., Eskandera, M. Z., & Al-Taee, S. K. (2022). Heavy metal pollution in Iraqi rivers and impact on human and fish health: A Review. Biol App Environ Res, 6(2), 95-112.

5. Ota, Y., Suzuki, A., Yamaoka, K., Nagao, M., Tanaka, Y., Irizuki, T., et al., 2021.Geochemical distribution of heavy metal elements and potential ecological risk assessment of Matsushima Bay sediments during 2012-2016. Sci. Total Environ. 751, 141825-141825.

6.Elgallal, M., Fletcher, L., & Evans, B. (2016). Assessment of potential risks associated with chemicals in wastewater used for irrigation in arid and semiarid

zones: A review. Agricultural Water Management, 177, 419-431.

7.Ahmed, M. B., Zhou, J. L., Ngo, H. H., Guo, W., Thomaidis, N. S., & Xu, J. (2017). Progress in the biological and chemical treatment technologies for emerging contaminant removal from wastewater: a critical review. Journal of hazardous materials, 323, 274-298.

8.Carolin, C. F., Kumar, P. S., Saravanan, A., Joshiba, G. J., & Naushad, M. (2017). Efficient techniques for the removal of toxic heavy metals from aquatic environment: A review. Journal of environmental chemical engineering, 5(3), 2782-2799.

9.Briffa, J., Sinagra, E., & Blundell, R. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. Heliyon, 6(9).

10.Wu, X., Cobbina, S. J., Mao, G., Xu, H., Zhang, Z., & Yang, L. (2016). A review of toxicity and mechanisms of individual and mixtures of heavy metals in the environment. Environmental Science and Pollution Research, 23, 8244-8259.

11.Zaynab, M., Al-Yahyai, R., Ameen, A., Sharif, Y., Ali, L., Fatima, M., ... & Li, S. (2022). Health and environmental effects of heavy metals. Journal of King Saud University-Science, 34(1), 101653.

12.AI-Shawi, S. R., Kadhim, H. A., & Al-Saad, H. T. (2022). Assessment of heavy metals in exchangeable sediments samples from Tigris: Euphrates and Shatt al-Arab rivers. Technology audit and production reserves, 6(3/68), 6-14.

13.Issa, M. J., Al-Obaidi, B. S., & Muslim, R. I. (2020). Evaluation of some trace elements pollution in sediments of the Tigris river in Wasit governorate, Iraq. Baghdad Science Journal, 17(1), 9-22.

14.Srivastava, N. K., & Majumder, C. B. (2008). Novel biofiltration methods for the treatment of heavy metals from industrial wastewater. Journal of hazardous materials, 151(1), 1-8.

15.Raval, N. P., Shah, P. U., & Shah, N. K. (2016). Adsorptive removal of nickel (II) ions from aqueous environment: A review. Journal of environmental management, 179, 1-20.

16.Koedrith, P., Kim, H., Weon, J. I., & Seo, Y. R. (2013). Toxicogenomic approaches for understanding molecular mechanisms of heavy metal mutagenicity and carcinogenicity. International journal of hygiene and environmental health, 216(5), 587-598.

17.Jassim, H. H., Salman, I. M., & Al-Khafaji, R. M. N. (2021). Sedimentological and Heavy metals characteristics of streets dust in some areas east of Baghdad for 2020. The Iraqi Geological Journal, 117-125.

18.Li ChangFeng, L. C., Zhou KeHai, Z. K., Qin WenQiang, Q. W., Tian ChangJiu, T. C., Qi Miao, Q. M., Yan XiaoMing, Y. X., & Han WenBing, H. W. (2019). A review on heavy metals contamination in soil: effects, sources, and remediation techniques.

19.Szyczewski, P., Siepak, J., Niedzielski, P., & Sobczyński, T. (2009). Research on heavy metals in Poland. Pol. J. Environ. Stud, 18(5), 755.

20.Gavhane, S. K., Sapkale, J. B., Susware, N. K., & Sapkale, S. J. (2021). Impact of heavy metals in riverine and estuarine environment: A review. Res. J. Chem. Environ, 25(5), 226-233.

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.

22.Zhuang, W., & Zhou, F. (2021). Distribution, source and pollution assessment of heavy metals in the surface sediments of the Yangtze River Estuary and its adjacent East China Sea. Marine Pollution Bulletin, 164, 112002.

23.Tamele, I. J., & Vazquez Loureiro, P. (2020). Lead, mercury and cadmium in fish and shellfish from the Indian Ocean and Red Sea (African Countries): public health challenges. Journal of Marine Science and Engineering, 8(5), 344.

24.Bernhoft, R. A. (2013). Cadmium toxicity and treatment. The Scientific World Journal, 2013.

25.Sall, M. L., Diaw, A. K. D., Gningue-Sall, D., Efremova Aaron, S., & Aaron, J. J. (2020). Toxic heavy metals: impact on the environment and human health, and treatment with conducting organic polymers, a review. Environmental Science and Pollution Research, 27, 29927-29942.

26.Rahman, Z., & Singh, V. P. (2019). The relative impact of toxic heavy metals (THMs)(arsenic (As), cadmium (Cd), chromium (Cr)(VI), mercury (Hg), and lead (Pb)) on the total environment: an overview. Environmental monitoring and assessment, 191, 1-21.

27.Awual, M. R., Yaita, T., El-Safty, S. A., Shiwaku, H., Suzuki, S., & Okamoto, Y. (2013). Copper (II) ions capturing from water using ligand modified a new type mesoporous adsorbent. Chemical Engineering Journal, 221, 322-330.

28.Bat, L., Bilgin, S., & Öztekin, A. (2017). Toxicity of copper on marine organisms from the Black Sea. J. Coastal Life Med., 5, 422-426.

29.Mahurpawar, M. (2015). Effects of heavy metals on human health. Int J Res Granthaalayah, 530(516), 1-7.

30.Ramessur, R. T., Boodhoo, K., Balgobin, J., & Aurellio, A. (2010). Statistical comparison between consecutive winter and summer concentrations in zinc and lead from sediments in a tropical urban estuary in Mauritius. Environmental monitoring and assessment, 168, 345-351.

31.Jin, M., Yuan, H., Liu, B., Peng, J., Xu, L., & Yang, D. (2020). Review of the distribution and detection methods of heavy metals in the environment. Analytical methods, 12(48), 5747-5766.

32.Butu, A. W., & Iguisi, E. O. (2013). Concentration of heavy metals in sediment of river Kubanni, Zaria, Nigeria. Compr J Environ Earth Sci, 2(1), 10-17.

33.Nethaji, S., Kalaivanan, R., Viswam, A., & Jayaprakash, M. (2017). Geochemical assessment of heavy metals pollution in surface sediments of Vellar and Coleroon estuaries, southeast coast of India. Marine Pollution Bulletin, 115(1-2), 469-479.

34.Sun, B., Zhao, F. J., Lombi, E., & McGrath, S. P. (2001). Leaching of heavy metals from contaminated soils using EDTA. Environmental pollution, 113(2), 111-120.

35.Kołodyńska, D. (2011). Chelating agents of a new generation as an alternative to conventional chelators for heavy metal ions removal from different waste waters. Expanding issues in desalination, 339-370.

36.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.

37.Beasley, V., & Levengood, J. (2012). Principles of ecotoxicology. In Veterinary Toxicology (pp. 831-855). Elsevier Inc.

38.Gupta, N., Khan, D. K., & Santra, S. C. (2012). Heavy metal accumulation in vegetables grown in a long-term wastewater-irrigated agricultural land of tropical India. Environmental Monitoring and Assessment, 184, 6673-6682.

39.Chibuike, G. U., & Obiora, S. C. (2014). Heavy metal polluted soils: effect on plants and bioremediation methods. Applied and environmental soil science, 2014.

40.Blewett, T. A., & Leonard, E. M. (2017). Mechanisms of nickel toxicity to fish and invertebrates in marine and estuarine wastewaters. Journal of Environmental Chemical Engineering, 4(1), 468-487.

44.Yu, L., Han, M., & He, F. (2017). A review of treating oily wastewater. Arabian journal of chemistry, 10, S1913-S1922.

45.Ruihua, L., Lin, Z., Tao, T., & Bo, L. (2011). Phosphorus removal performance of acid mine drainage from wastewater. Journal of hazardous materials, 190(1-3), 669-676.

46.Nguyen, T. A. H., Ngo, H. H., Guo, W. S., Zhang, J., Liang, S., Yue, Q. Y., ... & Nguyen, T. V. (2013). Applicability of agricultural waste and by-products for adsorptive removal of heavy metals from wastewater. Bioresource technology, 148, 574-585.

47.Ghernaout, D., Al-Ghonamy, A. I., Boucherit, A., Ghernaout, B., Naceur, M. W., Messaoudene, N. A., ... & Elboughdiri, N. A. (2015). Brownian motion and

waters. Environmental Pollution, 223, 311-322.

41.Boamah, P. O., Huang, Y., Hua, M., Zhang, Q., Wu, J., Onumah, J., ... & Boamah, P. O. (2015). Sorption of heavy metal ions onto carboxylate chitosan derivatives—a mini-review. Ecotoxicology and Environmental Safety, 116, 113-120.

42.Ahmed, M. J. K., & Ahmaruzzaman, M. J. J. O. W. P. E. (2016). A review on potential usage of industrial waste materials for binding heavy metal ions from aqueous solutions. Journal of Water Process Engineering, 10, 39-47.

43.Patil, D. S., Chavan, S. M., & Oubagaranadin, J. U. K. (2016). A review of technologies for manganese removal from

coagulation process. American Journal of Environmental Protection, 4(5-1), 1-15.

48.Nagajyoti, P. C., Lee, K. D., & Sreekanth, T. V. M. (2010). Heavy metals, occurrence and toxicity for plants: a review. Environmental chemistry letters, 8, 199-216.