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Mini review

Carcinogenic Nature of Heavy Metals and Their Sequestration by Batch Adsorption Technique: A Review

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Abstract

The risk of heavy metals accumulating up in wastewater is growing because of their potential to harm human health, particularly in the last ten years. Environmental organizations throughout the world are working to enact several laws that would enable the management and control of random heavy metal disposal. Finding appropriate materials and methods for wastewater purification has been the focus of scientific research, but most solutions have been rejected because of financial concerns. To find the best material for the purification process, a few possible materials have been identified and compared. Recent work on wastewater treatment shows that adsorption is the most facile and economical method for the treatment of wastewater to sequestrate metals form aqueous system. This review will focus on the carcinogenic nature of metals and their removal by adsorption from aqueous system.

Introduction

Due to the existence of dangerous and non-degradable heavy metals, water pollution is a significant issue for all living things on Earth. Water must be available in sufficient quantities for human survival, industrial processes, and agricultural requirements, but this water is constantly being contaminated by different human activities. Many harmful substances are released into underground water by industries, polluting it and leading to a variety of health issues. Human activities, industrial waste, and rapid urbanisation are the primary causes of water contamination. Heavy metal contamination in water poses an alarming danger to modern human life because they do not degrade [1]. In general, there are two primary natural sources of water: ground water and surface water. Only 1% of the water on the surface of the earth, as measured by international norms, is suitable for human consumption. Freshwater makes up 3% of the planet's overall water supply, but only 0.01% of it can be used by humans. Worldwide fresh water supplies are in danger due to anthropogenic activities, rapid urbanization, and industrialization [2]. Chemicals, particularly heavy metals like chromium, arsenic, etc., and dyes released into the water system pollute the water. They have been shown to be carcinogenic and to create a variety of health issues. In general, there are four distinct categories of contaminants that can affect water quality: organic, inorganic, radiological, and biological contaminants. Most organic and inorganic contaminants have detrimental effects on health.

Heavy metals are an example of inorganic pollutants. Elements between 63.5 and 200 in atomic weight are considered heavy metals.6. Chromium, cadmium, arsenic, silver, gold, zinc, lead, mercury, nickel, and uranium are some of the heavy elements found in wastewater [3]. Due to their minuscule concentration in the atmosphere, heavy metals are also referred to as trace elements. These heavy metals are classified as human toxins by the International Agency on Cancer and the US EPA (Environmental Protection Agency). The main factor contributing to heavy metals' increased distribution in the environment and the serious health issues it causes are their exponential domestic, medical, agricultural, industrial, and technological uses [4]. The primary sources of heavy metals in the atmosphere are household effluent, geogenic effluent, pharmaceutical effluent, and agricultural effluent. These metals can lead to several health issues, including harm to the cardiovascular, nervous, and gastrointestinal systems as well as cancer. Dementia, Alzheimer's disease, Parkinson's disease, senility, problems with the liver and muscles, diabetes, neuropathy, pancreatic and hepatic dysfunction are some of the illnesses that are brought on by heavy metals [5].

For the elimination of heavy metal from aqueous solution, various techniques are used. Precipitation, coagulation, ion exchange, filtering, and adsorption are a few techniques used to clean up aqueous solutions. All these techniques are used to remove heavy metals from water solutions, but they have some drawbacks because they are impractical and expensive. The most practical technique for decontaminating water is adsorption because it is inexpensive and widely accessible. Adsorption is a type of mass movement. This method involves transferring a liquid or gas to a firm surface. Adsorbents have a very porous surface and a large surface area, so they draw or adsorb many organic and inorganic molecules as well as metal ions [6]. Adsorption is an advanced surface event that keeps organic ligands and metal ions in the soil environment. A solute from a solution builds up on a firm surface in this process. In general, the process is viewed as a balance between the adsorbate and the surface that results in the formation of a complex through adsorption or precipitation: Surface plus adsorbate equals SM. (complex). The build-up of one species when there is another sorbing species is known as competitive adsorption. Due to the coexistence of different sorbate species in nature, this is extremely pertinent. When another species is present, their individual adsorption properties frequently undergo substantial change. Adsorption is impacted by several variables, including pH, contact time, adsorbate dose, temperature, and adsorbent concentration, which also have an impact on the process of heavy metals' adsorptive capacity. The amount of adsorption can also be controlled by changing these variables. For this reason, various types of adsorbents are employed, which are derived from various sources, including industrial waste, fruit and vegetable residues, commercially available activated carbon, and bio adsorbents [7].

Due to its high porosity and flexible solid nature, activated carbon is frequently used as an adsorbent and is typically produced as powder. Many toxic heavy metals can be removed using activated carbon. Clay, biomaterials, used industrial materials, and zeolites are a few of the frequently used adsorbents for the removal of metals. One of the sources of inexpensive adsorbents is natural adsorbents or adsorbents made from industrial or farming waste because they are widely accessible [8]. Chitosan is used extensively for the adsorption of heavy metals because it has a high capacity for binding metals and is less expensive than activated carbon that is readily accessible in the market. In the cleaning of wastewater, chitosan is used extensively. Because of their ion exchange capabilities, natural zeolites are also inexpensive adsorbents for the absorption of heavy metals. One of the likely substitutes for activated carbon is clay. Because of their large surface area, they have a high adsorption capability. Clay's mineral structure has a strong ability to draw heavy metal ions due to its negative charge. Industrial refuse is another low-cost adsorbent that is used. Industrial wastes are produced as a by-product, so they are readily accessible and inexpensive, but they must be processed to increase their adsorptive capacity [9]. This review will open new channels for the new researchers to work on the removal of metals employing this facile technique of wastewater treatment.

Carcinogenic Nature of Heavy Metals

Although some heavy metals are necessary for certain biological processes in humans, ingesting them can have harmful effects on a person's health and physiological systems based on the dosage. Even though heavy metals have a lot of positive impacts, they also act in a way that is cancer-causing to humans. Metals that have been dissolved into other substances such as soil, air, or water penetrate the body of a person, harming the cellular structure and increasing the risk of cancer. Non-essential metals like chromium, arsenic, and cadmium are significant cancer-causing agents, according to reports from the international organisation for research on cancer [10].

Chromium is the common human cancer-causing heavy metal. Cr exists in different oxidation states from -2- +6 but most of these states are unstable to exist in any substantial amount, but Cr III and Cr VI are the common oxidation states. The toxicity of Cr III and Cr IV depends on their ability to pass cell membranes. As Cr IV mostly exists as chromate anions that are isostructural to sulphate and phosphate and sulphate anions, $CrO4^{-2}$ release from the hexavalent chromium and by anion transport process easily move across the biological membrane. But only a small fraction of trivalent chromium is taken up by phagocytosis by the cells due to its octahedral structure and bigger size [11]. Traditionally cancer was a genetic disease but now from research non genetic events can also contribute towards carcinogenesis. Hexavalent induced lesions play an important role to the start of lungs cancer. Chromium exposure also causes many diseases including tubular necrosis, transient renal failure, skin sensitization and renal failure [12].

Arsenic (As), a metalloid, forms a complex with pyrite and under specific conditions it dissociates from its soil bound types and enter the water systems that is why the major source of arsenic exposure is contaminated water from underground wells. International agency for research on cancer in 2004 claimed that roughly 100 million people are exposed to as at levels higher than 10 μg/L.

Human exposure to As produces various health diseases like heart disease, diabetes, neuropathy, liver disease, arteriosclerosis and cancer. But the carcinogenic potential of arsenic by drinking water is of considerable concern [13].

Lead is a pervasive element identified in many organic or inorganic forms. The exposure of Pb mainly occurs through ingestion of contaminated food or polluted water and by inhalation. Exposure to lead may lead to many haematological, renal, hypertension, cardiovascular and neurological toxic effects. Approximately 800 million people aged between 0-19 years have an alarming concentration of blood lead level nearly 5 μg/dL whereas in 2021 the tolerance limit of Pb was updated to 3.5 μg/dL which is earlier 5 ug/dl [14]. Lead at high concentrations bind to DNA and alter its conformation and break nucleic acids. However, the straight genotoxicity of Pb appears only at cytotoxic doses [15].

Cadmium is a rarely occurring natural element and is of great industrial importance because of its specific properties like low melting temperature, high thermal conductivity, specific chemical properties, corrosion resistance and high electrical conductivity. Cadmium Cd is used in nickel cadmium batteries, coatings, paints, pigments and stabilizers for plastics. Cadmium exposure occurs through contaminated food, inhalation and due to the accumulation of Cd in tobacco plants, smoking also promotes to Cd exposure [16]. Cadmium exposure induces diversity of health problems like bone lesions, hypertension, kidney dysfunction, anaemia and cancer. Cadmium is also considered as an carcinogen [17].

Conventional Methods for Heavy Metal Removal

Different methods are used for the removal of heavy metal from aqueous solution. Some of methods that are used for the decontamination of aqueous solution are given below [18]:

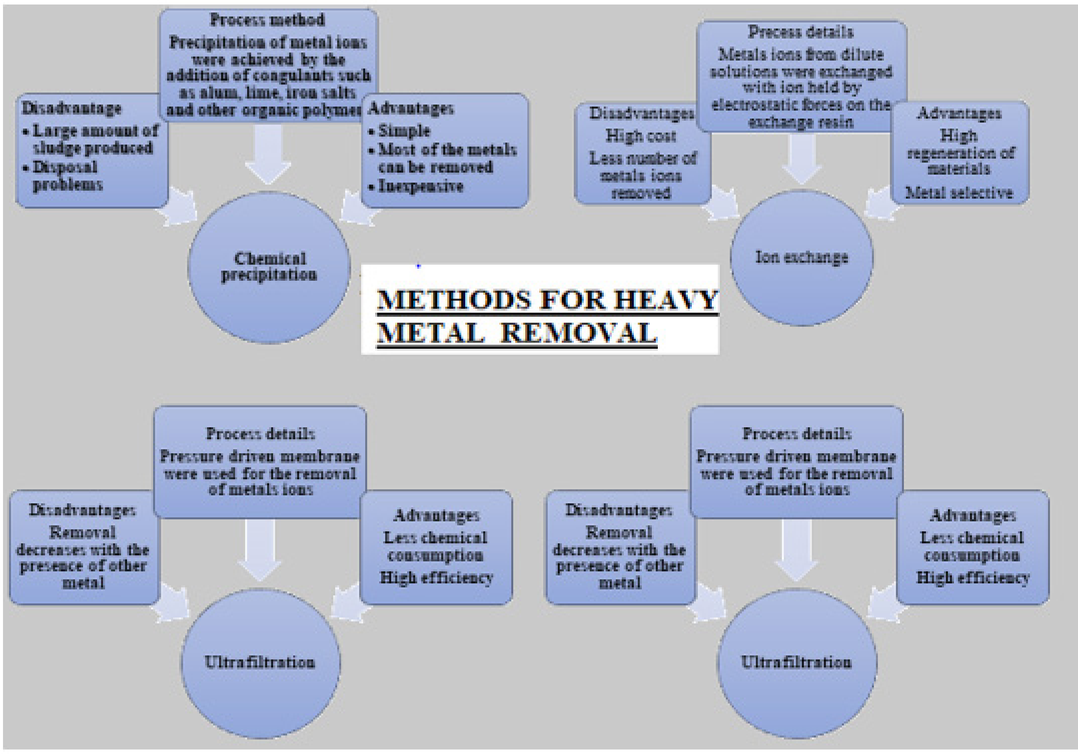

Figure 1: Different methods for the decontamination of water from heavy metals.

Adsorption

All the above methods are used for the removal of heavy metals from aqueous solution, but these methods have some limitations as they are not feasible and of high cost. Adsorption is defined as a process that occurs when a liquid or a gas accumulates on the surface of solid to form an atomic or molecular film. The phenomena of accumulation of the molecules of a liquid or a gas on a solid surface is known as adsorption. Adsorption is the most feasible method for water decontamination as it is low cost and easily available method. Different type of adsorbents is used for this purpose that are obtained from different sources like industrial waste, fruits and vegetables residues, commercially available activated carbon as well as bio adsorbents [19]. Activated carbon is widely used as adsorbent as it is highly porous and amorphous solid usually made in powder form. Activated carbon can remove many harmful heavy metals [20]. Some commonly used adsorbents for removal of metals are clay, biomaterials, industrial waste material and zeolites. Natural adsorbents or adsorbents from agricultural or industrial wastes are one of the sources of low-cost adsorbents as they are easily available. chitosan is widely used for the adsorption of heavy metals as it has high metal binding capacity, and less cost as compared to commercially available activated carbon. Chitosan has wide applications in wastewater treatment. Natural zeolites are also low-cost adsorbents for the adsorption of heavy metals because of their ability of ion exchange capability [21]. Clay is one of the probable alternatives to activated carbon. The adsorption capacity is high due to their high surface area. The negative charge on clay mineral structure gives it a high capacity to attract heavy metal ions. Industrial waste is also used as low-cost adsorbent. industrial wastes are made as by product that is why it is easily available and is low cost, but this needs some processing to make its adsorptive capacity high [22].

Principle of Adsorption

Adsorption is a mass transfer phenomenon. In this technique the transfer of liquid or gas onto a solid surface takes place. Adsorbents have extremely porous surface and have large surface area therefore it attracts or adsorbs metal ions as well as many organic and inorganic molecules on its surface due to its porous nature [23]. Generally, there are two types of adsorption.

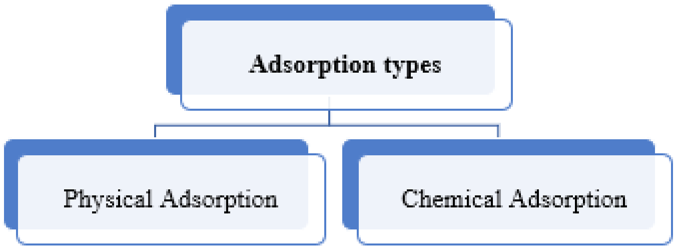

Figure 2:

Factors effecting the rate of adsorption

There are some factors that affect the rate of adsorption that are as follow:

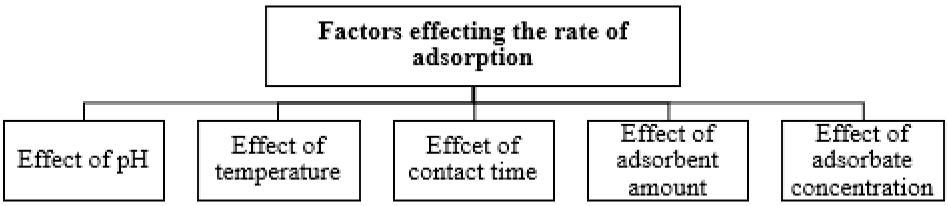

Figure 3:

Table 1: Comparison of adsorption capacities of different adsorbents with different heavy metals.

Adsorbent	Heavy metal	Adsorption capacity mg/g	Reference
Coffee residues	Zn (II)	13	[24]
	Cu (II)	31	
	Ni (II)	11	
Orange peel	Ni (II)	15	[24]

Neem bark	Cr (VI)	20	[24]
Guava seeds	Cr (VI)	10.5	[25]
Papaya seed	Cu (II)	212.7	[25]
Orange waste	Cd (II)	48	[24]
Banana peels	Pb (II)	8	[26]
	Ni (II)	7	
	Zn (II)	6	
	Cu (II)	5	
Orange peels	Pb (II)	8	[27]
	Ni (II)	6	
	Zn (II)	5	
	Cu (II)	4	
Avocado peel	Pb (II)	4.93	[28]
	Ni (II)	9.82	
	Cr (II)	4.89	
dragon fruit peel	Pb (II)	4.6	[28]
	Ni (II)	7.59	
	Cr (II)	0.29	
Mango peel	Cd (II)	68.92	[29]
	Pb (II)	99.02	
	Cu (II)	46.09	
	Ni (II)	39.75	
	Zn (II)	28.21	
Eucalyptus bark	Cr (VI)	45	[25]
Cabbage waste	Pb (II)	8.738	[30]
	Cd (II)	5.152	
Cauliflower waste	Pb (II)	9.457	[30]
	Cd (II)	7.164	

Table 2: Modification in adsorbents and comparison of their adsorption capacity.

Adsorption capacity								
Adsorbent	**Cu (II)**	**Co (II)**	**Ni (II)**	**Zn (II)**	**Pb (II)**	**Cd (II)**	**Hg (II)**	**Reference**
Acid-treated banana peel	2.14	1.44	3.14	2.75	4			[31]
Alkali-treated banana peel	2	1.4	3.08	2.25	3.65			[31]
Acid-treated orange peel	1.85	1.25	2.14	2.75	3.2			[31]
Alkali-treated orange peel	1.55	1.15	2.05	2.65	2.85			
Orange fruit peel waste modified with Methyl acrylate			162.6		476.1	293.3		[31]
Cashew nutshell modify with H2SO4					8.73			[31]
Rice husk with Sulfuric acid							384.6	[32]

Future Perspectives

The adsorbents presented in this review paper for the efficient removal of metals by agricultural waste is inexpensive, readily available, and have been shown to be a good alternative to the pricey commercial adsorbents. Numerous studies have found that altering various adsorbents can increase their removal efficiency for metal exclusion; nevertheless, little study has been done in this area. Therefore, the long-term goals might be to increase the percentage of heavy metals removed by these adsorbents using a variety of techniques, such as chemical modification, physical modification, metal ion recovery, and adsorbent regeneration, followed by the possible uses of these adsorbents for effective metal adsorption.

Conclusion

Adsorption is a more effective method for removing heavy metals than osmosis, flotation, ion exchange, coagulation, flocculation, and precipitation. The removal of heavy metal ions from water system at trace amounts cannot be accomplished using these traditional methods.

Because the cost of treating wastewater increases when commercially available activated carbons are used, researchers are concentrating on finding practical, low-cost adsorbents for metal adsorption. Agricultural wastes are in excess and renewable, so they are proved to be a good alternative for high-cost adsorbents for wastewater treatment.

This review discusses the use of newly developed, inexpensive, agriculturally based adsorbents for the removal of different metals from aqueous solutions. When used for metal sequestration, the majority of bioadsorbents clearly demonstrated effective adsorption capacity. These substances can therefore be used as a substitute for activated carbons that are sold commercially.

Statements And Declarations

Author declared no conflict of interest regarding the publication of this review paper.

Competing Interest

The work is not funded by any institution.

Consent For Publication

Not applicable.

Authors Contribution

Navak Badr designed and drafted the manuscript.

References

1. Dwivedi AK (2017) Researches in water pollution: A review. International Research Journal of Natural and Applied Sciences 4(1): 118-142.
2. Chaudhry FN, Malik M (2017) Factors affecting water pollution: a review. J Ecosyst Ecography 7(1): 225-231.
3. Zamoram Ledezma C, Negrete Bolagay D, Figueroa F, Zamora Ledezma E, Ming N (2021) Heavy metal water pollution: A fresh look about hazards, novel and conventional remediation methods. Environmental Technology & Innovation 22: 101504.
4. Fatima S, Muzammal M, Rehman A, Rustam SA, Shehzadi Z, et al. (2020) Water pollution on heavy metals and its effects on fishes. Int J Fish Aquat Stud 8(3): 6-14.
5. Wang Z, Luo P, Zha X, Xu C, Kang S, et al. (2022) Overview assessment of risk evaluation and treatment technologies for heavy metal pollution of water and soil. Journal of Cleaner Production 379: 134043.
6. Zaimee ZA, Sarjadi MS, Rahman ML (2021) Heavy metals removal from water by efficient adsorbents. Water 13(19): 2659.
7. Ince M, Ince OK (2017) An overview of adsorption technique for heavy metal removal from water/wastewater: a critical review. International Journal of Pure and Applied Sciences 3(2): 10-19.
8. Afroze S, Sen TK (2018) A review on heavy metal ions and dye adsorption from water by agricultural solid waste adsorbents. Water, Air, & Soil Pollution 229: 1-50.
9. Chakraborty R, Asthana A, Singh AK, Jain B, Susan ABH (2022) Adsorption of heavy metal ions by various low-cost adsorbents: a review. International Journal of Environmental Analytical Chemistry 102(2): 342-379.
10. Jyothi NR (2020) Heavy metal sources and their effects on human health. Heavy Metals-Their Environmental Impacts and Mitigation.
11. Ferreira LM, Cunha-Oliveira T, Sobral MC, Abreu PL, Alpoim MC, et al. (2019) Impact of carcinogenic chromium on the cellular response to proteotoxic stress. International journal of molecular sciences 20(19): 4901.
12. Rahman Z, Singh VP (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(7): 419. Benbrahim Tallaa L, Waalkes M (2009) Inorganic arsenic and human prostate cancer. Ciência & Saúde Coletiva 14: 307-318.
13. Benbrahim Tallaa L, Waalkes M (2009) Inorganic arsenic and human prostate cancer. Ciência & Saúde Coletiva 14: 307-318.
14. Santana AB, Spelta LEW, Sobalvarro JVM, Podestá MHMC, Garcia RCT, et al. (2023) Gestational lead exposure and its effects on fetal/infant development-a systematic review. Reproductive Toxicology 117:108342.
15. Silbergeld EK (2003) Facilitative mechanisms of lead as a carcinogen. Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis 533(1-2): 121-133.
16. Hartwig A (2013) Cadmium and cancer. Cadmium: from toxicity to essentiality pp. 491-507.
17. Li G, Yan L, Chen X, Lam SS, Rinklebe J, et al. (2023) Phytoremediation of cadmium from soil, air and water. Chemosphere 138058.
18. Razzak SA, Faruque MO, Alsheikh Z, Alsheikhmohamad L, Alkuroud D, et al. (2022). A comprehensive review on conventional and biological-driven heavy metals removal from industrial wastewater. Environmental Advances 7: 100168.
19. She Y, Shao L, Yi M, Fang Y, Qin L, et al. (2025) Efficient and Inexpensive Preparation of Mesoporous Silica Microspheres and Their Highly Selective Adsorption-Cycling Performance for Ga (Iii) in Acidic Solutions. Chemical Engineering Journal 511: 162007.
20. Ahmed MB, Johir MAH, Zhou JL, Ngo HH, Nghiem LD, et al. (2019) Activated carbon preparation from biomass feedstock: clean production and carbon dioxide adsorption. Journal of Cleaner Production 225: 405-413.
21. Saheed IO, Da Oh W, Suah FBM (2021) Chitosan modifications for adsorption of pollutants-A review. Journal of hazardous materials 408: 124889.
22. Kausar A, Iqbal M, Javed A, Aftab K, Bhatti HN, et al. (2018) Dyes adsorption using clay and modified clay: A review. Journal of Molecular Liquids: 256: 395-407.

23. Sun P, Bhattacharjee N, Einkauf JD, Doughty B (2025) Bulk Anion Recognition Kinetically Holds Back Interfacial Adsorption. The journal of physical chemistry letters 16(8):2128-2135.

24. Meez E, Rahdar A, Kyzas GZ (2021) Sawdust for the removal of heavy metals from water: a review. Molecules 26(14): 4318.

25. Jain CK, Malik DS, Yadav AK (2016) Applicability of plant based biosorbents in the removal of heavy metals: a review. Environmental Processes 3: 495-523.

26. Al Azzawi M, Shartooh S, Al Hiyaly S (2013) The Removal of Zinc, Chromium and Nickel from Industrial Waste-Water Using Banana Peels. Iraqi Journal of Science 54(1): 72-81.

27. Li X, Tang Y, Cao X, Lu D, Luo F, Shao W (2008) Preparation and evaluation of orange peel cellulose adsorbents for effective removal of cadmium, zinc, cobalt and nickel. Colloids and surfaces A: Physicochemical and Engineering aspects 317(1-3): 512-521.

28. Mallampati R, Xuanjun L, Adin A, Valiyaveettil S (2015) Fruit peels as efficient renewable adsorbents for removal of dissolved heavy metals and dyes from water. ACS Sustainable Chemistry & Engineering 3(6): 1117-1124.

29. Malik D, Jain C, Yadav AK (2017) Removal of heavy metals from emerging cellulosic low-cost adsorbents: a review. Applied water science 7: 2113-2136.

30. Hossain M, Ngo H, Guo W, Nguyen T, Vigneswaran S (2014) Performance of cabbage and cauliflower wastes for heavy metals removal. Desalination and Water Treatment 52(4-6): 844-860.

31. Annadurai G, Juang RS, Lee D (2003) Adsorption of heavy metals from water using banana and orange peels. Water science and technology 47(1): 185-190.

32. Mathew S, Soans JC, Rachitha R, Shilpalekha M, Gowda SGS, et al (2023) Green technology approach for heavy metal adsorption by agricultural and food industry solid wastes as bio-adsorbents: A review. Journal of Food Science and Technology 60(7): 1923-1932.