**Levels of Heavy Metal Concentration in Wastewater from Pharmaceutical Industries in Anambra State, South-East Nigeria**

**Abstract**

Improper treatment and disposal of wastewater from pharmaceutical companies can contaminate nearby water bodies and surrounding ecosystems as a result of the release of pollutants such as heavy metals. The aim of this study is to investigate the levels of heavy metals in wastewater effluents from pharmaceutical companies in Anambra State, South-East Nigeria. Atomic Absorption Spectrometer (AAS) was used for the determination of heavy metals.Heavy metalconcentration ranged from ND (not detected) for Pb, Cr, Cd and Cu in all the samples to 3.916 ppm for Fe in Chez Resources Pharmaceutical Limited. The mean value of heavy metals across the samples is in the order Fe (12.727 ppm) > Zn (8.620 ppm) > Mn (1.925 ppm) > Co (1.194 ppm) > Ni (1.087 ppm) > Pb (ND) = Cr (ND) = Cu (ND). The study has shown that wastewater of all the studied pharmaceutical industries is free from Pb, Cr, Cd and Cu. The concentrations of Co across the sampling points are above the permissible limits recommended by United States Environmental Protection Agency (USEPA) except in B. Zn in all the samples is below the World Health Organization (WHO) recommended limit except in D. Fe is above WHO limit in all the samples while Mn concentration in all the samples is below WHO limit except in E and Ni in all the samples is above the WHO limit except in B. Hence, there is the need for pharmaceutical and allied industries to monitor and treat their industrial effluents regularly.

**Keywords**: Wastewater, pharmaceutical companies, heavy metals, permissible limits, human health, Anambra State

**Introduction**

Water is necessary for life because it is used for drinking, bathing and other household activities (Hutton and Chase, 2017; Dinka, 2018) as well as its usefulness in industry and agriculture (Buettner 2020). Lack of potable water has become a global concern and depending on the source as reported in some literature, it may contain a wide range of contaminants and pollutants such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), radioactive materials, herbicides, pesticides, per- and polyfluoroalkyl substances (PFAS) commonly called forever chemicals etc. (Okafor et al 2022; (Syafrudin et al., 2021; Mugudamani et al., 2023; Monk et al., 2025; de Jesus et al., 2023; Alfarsi et al., 2025; Shapiro et al., 2025).

Wastewater is often characterized by its physicochemical properties, which include its pH, dissolved oxygen content, total dissolved particles, and heavy metals (Tadesse et al., 2018). To improve water quality and lessen environmental pollution, techniques for handling and treating wastewater abound. Some of these techniques include using sump pumps that clean the water or using bacteria that can withstand heavy metals. The need for clean water has increased due to global population growth and ongoing urbanization, which has also increased the amount of wastewater that needs to be treated (Bolong et al., 2009). Wastewater is assessed and methods are suggested to recover the valuable compounds to a significant degree from a variety of water-intensive industries, including bulk pharmaceuticals, related pharmaceutics, and active pharmaceutical ingredients (Gadipelly et al., 2014).

It is impossible to completely remove drugs from wastewater using a single method. According to Rostam et al. (2020), membrane reactors, advanced post-treatment methods, and traditional treatment methods appear to be the most efficacious wastewater treatment technologies. Small-scale enterprises that release their wastewater into nearby watercourses without first treating it to lessen the final discharge are the ones who cause problems with effluent treatment. This is a result of poor and improper inspections carried out by regulatory agencies. Since pharmaceutical wastewater may comprise organic solvents, catalysts, additives, reactants, intermediates, raw materials, and active pharmaceutical ingredients, handling it might be difficult (Odika et al., 2020).

Drugs can enter the water through a variety of channels, including the sewer, industrial and hospital waste, and excretion. From the point of production to the point of use or disposal, these routes span a range of times. The expansion of industrial and agricultural operations contributes to global problems such as water contamination and limited access to clean water (Wang et al., 2019).

The rate of industrial growth worldwide is increasing quickly, which is detrimental to the environment. The untreated release of contaminated wastewater into the aquatic environment is the cause of these effects. The automotive, battery, chemical, pharmaceutical, electroplating, galvanizing, coating, paint, and electronics industries are the main sources of heavy metal pollution from industrial effluent. Duruibe et al. (2007) state that arsenic, cadmium, copper, chromium, lead, mercury, nickel, and zinc are commonly found in heavy metal-contaminated wastewater.

Heavy metals are poisonous and persistent and therefore can have negative effects on both biotic and abiotic components of the ecosystem when they find their way into food chains. Heavy metals have been demonstrated to have negative effects on the environment and living beings because water is a transport for pollutants (Veado et al., 2000; Goodyear and McNeill, 1999). Through watery media, the pollutants can infiltrate the biological system and over time, through processes of bioaccumulation and biomagnification, reach high concentrations. When heavy metal poisoning affects humans as the top consumer in the food chain and reaches a significant trophic level, health could be at risk.

Heavy metals are persistently hazardous compounds due to their stability as metal ions that cannot be eliminated or degraded in the surroundings. The air, soil, and water containing heavy metals pose a health risk to people in general. According to the United Nations Commission on Sustainable Development (2010), untreated wastewater containing heavy metals from anthropogenic sources and widespread improper disposal are the causes of the presence of heavy metal contaminants in water, which is an indicator of global industrialization. Waterways are a common route for pollutants to move, and they can be harmful to both the environment and living creatures (Harrison, 2001). Heavy metals can bioaccumulate in quantifiable and detectable concentrations over time. By the mechanisms of food chains and trophic levels, the bioaccumulation of heavy metals in an organism's target organ or tissue can be harmful to human health. Trace levels of heavy metals are inadvertently absorbed by humans through their diet, breathing, and skin. Trace elements are needed for the human body's metabolism to stay steady. However, trace levels of heavy metals are dangerous because they tend to bioaccumulate and biomagnify. Due to bio-accumulation and bio-magnification, the concentration of heavy metals in a biological organism or targeted organ rises over time and may be harmful to health (Mata et al., 2008).

According to the United Nations Environmental Programme (2007), acute exposure to high levels of heavy metals can cause gastrointestinal abnormalities, dermatitis, anorexia, nausea, and vomiting. It can as well lead to deficiencies in certain nutrients, Parkinson's disease, cancer, skin conditions, irregularities in the respiratory system, problems with the intestines and stomach, damage to the central nervous system, blood diseases, and infertility (Lesmana et al., 2009).

Studies on negative ecological and health effects of exposure to heavy metal contamination of water (Okafor et al., 2023; Xu et al., 2024), soil (Priya et al., 2023; Parvez et al., 2023), sediment (Okafor et al., 2024), beverage (Okafor et al., 2016; Okafor et al., 2020; Okafor et al., 2021; Okafor et al., 2022), air (Bayo Jimenez et al., 2023; Tchounwou et al., 2012) etc. have been documented. Moreover, heavy metal contamination of pharmaceutical wastewater in some parts of Nigeria and beyond has also been reported (Oladimeji et al., 2023; Shokri et al., 2016; Anyakora et al., 2011). Nonetheless, literature is scarce on the presence of heavy metals in pharmaceutical wastewater from pharmaceutical industries in Anambra State, South-East Nigeria; hence, this study.

**Materials and Methods**

**Sample Collection**

Samples were collected on March 26, 2024, using previously cleaned glass bottles. At each sampling point, the bottle was rinsed twice with the wastewater to be collected. The wastewater samples were collected from five pharmaceutical industries around Anambra State viz: Kingsize Pharmaceutical Nig. Ltd. Obosi, Alben Healthcare Industries Ltd. Ogidi, New Divine Favour Pharmaceuticals Ltd. Nkpor, Chez Resources Pharmaceutical Company Ltd. Onitsha and Chazmax Pharmaceutical Industries Ltd Onitsha. The samples were packaged and delivered to the Nigerian Institute of Oceanography and Marine Research's Central Laboratory at Victoria Island, Lagos, for heavy metal analysis.

**Heavy Metal Analysis**

The analysis required the use of high-quality analytical reagents, which were sourced from BDH Chemical Ltd in the UK and Sigma-Aldrich Chemie GmbH in Germany. To clean the glassware and sample bottles, detergents and deionized water were utilized, after which they were allowed to soak overnight in a solution of 10% HNO3 combined with 1% HCl. This was followed by rinsing with deionized water. The analysis of heavy metals was conducted using the Atomic Absorption Spectrophotometric method, as modified from the work of several authors (Assubaie 2015; Ipeaiyeda 2017; Okafor et al. 2022a; b).

**Results and Discussion**

The results of heavy metal concentrations of water samples from some pharmaceutical industries in Anambra State are shown in Table 1. The results showed that there was no lead in any of the samples. This is within the permissible limit of 0.01 ppm set by the World Health Organization. The primary sources of lead, the majority of which eventually find their way into natural water systems, include several industrial fuels, leaded gasoline, and mining sources (Mahmud et al., 2016).

**Table 1: Heavy Metal Concentrations of Water Samples from Some Pharmaceutical Industries in Anambra State.**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Heavy Metal Concentration (ppm)****Sampling Point** | **Pb** | **Co** | **Zn** | **Fe** | **Cr** | **Mn** | **Cd** | **Ni** | **Cu** |
| A (Kingsize Pharm. Nig. Ltd.) | ND | 0.112 | 0.715 | 0.979 | ND | 0.144 | ND | 0.198 | ND |
| B (Alben Healthcare Ind. Ltd.) | ND |  0.063 | 0.738 | 0.490 | ND | 0.105 | ND | 0.007 | ND |
| C (New Divine Favour Pharm. Ltd.) | ND | 0.161 | 0.950 | 3.566 | ND | 0.232 | ND | 0.239 | ND |
| D (Chez Resources Pharm. Ltd.) | ND | 0.551 | 3.403 | 3.916 | ND | 0.329 | ND | 0.363 | ND |
| E (Chazmax Pharm. Ind. Ltd.) | ND | 0.307 | 2.814 | 3.776 | ND | 0.485 | ND | 0.280 | ND |
| ∑CHMs | 0.000 | 1.194 | 8.620 | 12.727 | 0.000 | 1.295 | 0.000 | 1.087 | 0.000 |
| WHOPL | 0.01 | 0.10\* | 3.00 | 0.30 | 0.05 | 0.40 | 0.003 | 0.07 | 2.00 |

ND = Not Detectable, CHMs = Concentration of Heavy Metals, WHOPL = World Health Organization Permissible Limit, \*USEPA Permissible Limit.

Furthermore, sample B had the lowest cobalt levels (0.063 ppm), while sample D had the highest (0.551 ppm). It was found that most of the results were greater than the United State Environmental Protection Agency (USEPA) approved effluent water limit of 0.10 ppm. One distinguishable feature of cobalt exposure-related hepatotoxicity and carcinogenesis is reversible systolic cardiac depression, which sets it apart from other cardiomyopathy disorders. Cardiomyopathy brought on by cobalt can be progressively and fatally deadly. However, survivors usually regain cardiac function (Packer, 2016). Moreover, Sample A had the lowest zinc value (0.715 ppm) and Sample D the highest (3.403 ppm).

This demonstrated that the result is within the acceptable or permitted range set by the WHO.

The WHO allows for a maximum of 0.005 ppm of iron, which means that all of the samples were above this limit. Too much iron has been associated with a higher risk of heart disease, gestational diabetes, and potentially fatal outcomes, in addition to oxidative stress and cellular damage (Quezada-Pinedo et al., 2021). Regardless, no chromium was detected, which is in line with the WHO's maximum allowable level of 0.05 ppm. For non-occupational human populations, the main routes of exposure are through the consumption of chromium-containing food and water or by skin contact with objects that contain chromium (Nickens et al., 2010). Additionally, the metallurgical, refractory, and chemical industries release a substantial amount of Cr into the soil, ground water, and atmosphere. This leads to health problems for humans, animals, and marine life (Fang et al., 2014).

Further analysis of the manganese concentrations revealed that sample E (0.485 ppm) had the highest concentration of the mineral, whereas sample B (0.105 ppm) had the highest concentration. According to these findings, every sample went above the allowable level. Furthermore, there was no cadmium detected, which is within the WHO's allowed level of 0.003 ppm. Cadmium is absorbed by surface runoff and industrial waste, contaminating the soil and sediments in the aquatic environment. A person may get cadmium poisoning from eating contaminated food, drinking contaminated water, or breathing in contaminated air. According to Hayat *et* *al*. (2018), cadmium has no properties that are advantageous for plant growth or metabolic activities. Additionally, samples C, D, and E had the greatest concentrations of nickel, exceeding the WHO limit by 0.219, 0.343, and 0.260, respectively. Cadmium has no qualities that are beneficial for plant growth or metabolic processes, according to Hayat et al. (2018). Furthermore, the highest quantities of nickel were found in samples C, D, and E, which exceeded the WHO limit by 0.219, 0.343, and 0.260, respectively. Nickel is a naturally occurring element with a wide range of industrial applications. According to Li et al. (2016), it reaches the atmosphere from both natural and artificial sources.

Nickel has a wide range of industrial applications and is a naturally occurring element. It is released into the atmosphere by both human and natural sources (Li et al., 2016). Due to the inhalation of contaminated air, it has numerous negative effects on humans, including allergies, lung and nasal cancer, kidney, and cardiovascular diseases (Genchi *et* *al*., 2020). Copper was likewise not found. This is in compliance with the 0.002 ppm WHO permitted level. Cu negatively affects male reproductive function, resulting in a drop-in sperm motility and count (Tvrda et al., 2015).

Nickel is a naturally occurring element with a wide range of industrial applications. Both natural and human-caused sources emit it into the atmosphere (Li et al., 2016). Humans who breathe in contaminated air are at risk for a variety of illnesses, including as allergies, kidney, lung, and nasal cancer, as well as cardiovascular problems (Genchi et al., 2020). Copper was also not discovered. This complies with the WHO-permitted threshold of 0.002 ppm. Cu negatively affects male reproductive function, resulting in a drop in sperm motility and count (Tvrda *et* *al*., 2015).

**References**

Alfarsi A, Kumar A, Gismelseed AM, Al Azkawi A, Al Mahdouri M, Al Mabsali FN, Babu S, Al Harthy Y, Al Hosni M, Nugegoda D (2025). Pharmaceuticals and radiopharmaceuticals in wastewater treatment plants: insights from an Arabian Peninsula nation. Environ Sci Pollut Res Int. 32(15):9844-9871. <https://doi.org/10.1007/s11356-025-36287-6>

Anyakora C, Nwaeze K, Awodele O, Nwadike C, Arbabi M, and Coker H (2011). Concentrations of heavy metals in some pharmaceutical effluents in Lagos, Nigeria. Journal of Environmental Chemistry and Ecotoxicology 3(2), 25-31. <http://www.academicjournals.org/jece>

Assubaie FN (2015) Assessment of the levels of some heavy metals in water in Alahsa Oasis farms, Saudi Arabia, with analysis by atomic absorption spectrophotometry. Arab J Chem 8(2):240–245. <https://doi.org/10.1016/j.arabjc.2011.08.018>

Bayo Jimenez MT, Hahad O, Kuntic M, Daiber A, Münzel T. Noise, Air, and Heavy Metal Pollution as Risk Factors for Endothelial Dysfunction. Eur Cardiol. 2023 Apr 4;18:e09. doi: 10.15420/ecr.2022.41.

Bolong, N., Ismail, A.F., Salim, M.R., Matsuura, T. (2009). A review of the effects of emerging contaminants in wastewater and options for their removal. [Desalination](https://www.sciencedirect.com/journal/desalination)[. 239(1–3](file:///C%3A%5CUsers%5Cuser%5CAppData%5CRoaming%5CMicrosoft%5CWord%5C.%20239%281%E2%80%933)): 229-246. <https://doi.org/10.1016/j.desal.2008.03.020>

## Buettner, T. (2020). World population prospects-a long view. Economie et stastistique/economics and statistics 520-521,9-27. Doi.org/10.24187/ecostat.2020.520d.2030.

## de Jesus RA, Barros GP, Bharagava RN, Liu J, Mulla Azevedo LCB, Ferreira LFR (2023). Occurrence of pesticides in wastewater: Bioremediation approach for environmental safety and its toxicity In: Advances in Chemical Pollution, Environmental Management and Protection, Vol. 9: 17–33. Editor(s): Luiz Fernando Romanholo Ferreira, Ajay Kumar, Muhammad Bilal. <https://doi.org/10.1016/bs.apmp.2022.10.002>

## Dinka, M. O. (2018). Safe Drinking Water: Concepts, Benefits, Principles and Standards. InTech. https://doi.org/10.5772/intechopen.71352

## Duruibe, J. O., Ogwuegbu, M. O. C., and Egwurugwu, J. N. (2007). Heavy metal pollution and human biotoxic effects. International Journal of Physical Sciences. 2 (5): 112-118

Fang, Z., Zhao, M., Zhen, H., Chen, L., Shi, P., and Huang, Z. (2014). Genotoxicity of tri-and hexavalent chromium compounds in vivo and their modes of action on DNA damage in vitro. *PloS One*. 9 (8). e103194. doi:10.1371/journal.pone.0103194

Gadipelly, C., Pérez-González, A., Yadav, G. D., Ortiz, I., Ibáñez, R., Rathod, V. K., and Marathe, K. V. (2014). Pharmaceutical industry wastewater: review of the technologies for water treatment and reuse. IndustrialandEngineeringChemistryResearch, *53*(29), 11571-11592.

Genchi, G., Carocci, A., Lauria, G., Sinicropi, M.S., and Catalano, A. (2020), Nickel: Human health and environmental toxicology. *Int. J. Environ. Res. Public Health*. 17(3). DOI: 10.3390/ijerph17030679

Goodyear, K.L., and McNeill, S. (1999). Bioaccumulation of heavy metals by aquatic macro-invertebrates of different feeding guilds: a review. [Science of The Total Environment](https://www.sciencedirect.com/journal/science-of-the-total-environment). [229(1–2](https://www.sciencedirect.com/journal/science-of-the-total-environment/vol/229/issue/1)): 1-19. [doi.org/10.1016/S0048-9697(99)00051-0](https://doi.org/10.1016/S0048-9697%2899%2900051-0)

Hayat, M.T., Nauman, M., Nazir, N., Ali, S., and Bangash, N. (2019) Environmental hazards of cadmium: past, present, and future. *Cadmium Toxicity and Tolerance in Plants from Physiology to Remediation*. 63–183, DOI: 10.1016/B978-0-12-814864-8.00007-3.

Harrison, N. (2001) Inorganic Contaminants in Food: Metals and Metalloids. *In: Watson, D, Ed., Food Chemical Safety, Contaminants vol 1*

Hutton G and Chase C (2017). Water supply, sanitation, and hygiene. In: Mock CN, Nugent R, Kobusingye O, Smith KR, editors. Injury Prevention and Environmental Health. 3rd ed. Washington (DC): The International Bank for Reconstruction and Development / The World Bank.

Ipeaiyeda AR (2017) Ayoade AR (2017) Flame atomic absorptionspectrometric determination of heavy metals in aqueous solutionand surface water preceded by co-precipitation procedure withcopper (II) 8-hydroxyquinoline. Appl Water Sci 7:4449–4459.https:// doi. org/ 10. 1007/ s13201- 017- 0590-9

Lesmana, S.O., Febriana, N., Soetaredjo, F.N., Sunarso, J., and Ismadji, S. (2009). Studies on potential applications of biomass for the separation of heavy metals from water and wastewater. [Biochemical Engineering Journal](https://www.sciencedirect.com/journal/biochemical-engineering-journal). [44(1](https://www.sciencedirect.com/journal/biochemical-engineering-journal/vol/44/issue/1)): 19-41. <https://doi.org/10.1016/j.bej.2008.12.009>

[Karyab](https://link.springer.com/article/10.1186/2052-336X-11-25#auth-Hamid-Karyab-Aff1), H.,  [Yunesian](https://link.springer.com/article/10.1186/2052-336X-11-25#auth-Masud-Yunesian-Aff1-Aff3), M., [Nasseri](https://link.springer.com/article/10.1186/2052-336X-11-25#auth-Simin-Nasseri-Aff1-Aff2), S., [Mahvi](https://link.springer.com/article/10.1186/2052-336X-11-25#auth-Amir_Hosein-Mahvi-Aff1-Aff2), A. H., [Ahmadkhaniha](https://link.springer.com/article/10.1186/2052-336X-11-25#auth-Reza-Ahmadkhaniha-Aff4), R., [Rastkari](https://link.springer.com/article/10.1186/2052-336X-11-25#auth-Noushin-Rastkari-Aff3), N., and [Nabizadeh](https://link.springer.com/article/10.1186/2052-336X-11-25#auth-Ramin-Nabizadeh-Aff1), R. (2013). Polycyclic Aromatic Hydrocarbons in drinking water of Tehran, Iran. Journal of Environmental Health Sciences and Engineering. 11:25. <http://www.ijehse.com/content/11/1/25>

Li, M., Pi, H., Yang, Z., Reiter, R.J., Xu, S., Chen, X., Chen, C., Zhang, L., Yang, M., Li, Y., Guo, P., Li, G., Tu, M., Tian, L.I., Xie, J., He, M., Lu, Y., Zhong, M., Zhang, Y., Yu, Z., Zhou, Z. (2016). Melatonin antagonizes cadmium-induced neurotoxicity by activating the transcription factor EB- dependent autophagy–lysosome machinery in mouse neuroblastoma cells, *J. Pineal Res*, 61 (3):353-369. doi:10.1111/jpi.12353

Mahmud, H.N.M.E., Huq, A.K.O., and Yahya R.B. (2016), The removal of heavy metal ions from wastewater/aqueous solution using poly-pyrrole-based adsorbents: a review. *The Royal Society of Chemistry*. 6. 14778–14791. DOI: 10.1039/c5ra24358k.

Monk JR, Hooda PS, Busquets R, Sims D (2025). Occurrence of pharmaceuticals, illicit drugs and PFAS in global surface waters: A meta-analysis-based review, Environmental Pollution, 378(2025). <https://doi.org/10.1016/j.envpol.2025.126412>

Mugudamani I, Oke SA, Gumede TP, Senbore S. (2023). Herbicides in water sources: communicating potential risks to the population of Mangaung metropolitan municipality, South Africa. Toxics. 11(6):538. <https://doi.org/10.3390/toxics11060538>

Nickens, K. P., Patierno, S. R., and Ceryak, S. (2010). Chromium genotoxicity: a double-edged sword. *Chem Biol Interact.* 188 (2): 276–288. doi:10.1016/j.cbi.2010.04.018.

Odika, I. M., Nwansiobi, C. G., Nwankwo, N. V., Ekwunife, C. M., and Onuoha, U. M. (2020). A Review on Treatment Efficiency of Pharmaceutical Effluents Using Natural Coagulants. *Chemistry*, *4*(2), 54-61.

Okafor VN, Eboatu AN, Omuku PE (2016) Comparative studies of bitterness, phytochemical and mineral contents of hop extracts and extracts from four selected tropical plants. Asian J Med Health

Res 1(6):1–15.

Okafor VN, Omokpariola DO, Obumselu OF, Eze GC. (2023). Exposure risk to heavy metals through surface and groundwater used for drinking and household activities in Ifite Ogwari, Southeastern Nigeria. Appl Water Sci. https:// doi. org/ 10. 1007/ s13201- 023- 01908-3.

Okafor VN, Omokpariola DO, Igbokwe EC, Theodore CM, Chukwu NG (2022a). Determination and human health risk assessment of polycyclic aromatic hydrocarbons (PAHs) in surface and groundwaters from Ifite Ogwari, Anambra State, Nigeria. Int J Environ Anal Chem. https:// doi. org/ 10. 1080/ 03067 319. 2022. 20385 87

Okafor VN, Omokpariola DO, Tabugbo BI and Okoliko GF (2024). Ecological and health risk assessments of heavy metals in surface water sediments from Ifite Ogwari community in Southeastern Nigeria. Discover Environment (2024) 2:93 | <https://doi.org/10.1007/s44274-024-00098-2>

Okafor VN, Omokpariola DO, Okabekwa CV, Umezinwa EC (2022b) Heavy metals in alcoholic beverages consumed in Awka, South-East Nigeria: carcinogenic and non-carcinogenic health risk assessments. Chemistry Africa. https:// doi. org/ 10. 21203/ rs.3.rs- 17166 86/ v1

Okafor VN, Tabugbo IB, Anyalebechi RI, Okafor UW, Obiefuna JN (2020) A review of Nigerian potential hop substitutes in beer brewing: 1983–2020. Int Res J Pure Appl Chem 21(15):50–73

Okafor VN, Umennadi PU, Odidika CC, Vinna DC (2021) Metals and polycyclic aromatic hydrocarbons (PAHs) in Beer: a review. J Chem Soc Nigeria 46(4):0688–0697. https:// doi. org/ 10. 46602/jcsn. v46i4. 646

Oladimeji TE, Oyedemi M, Emetere ME, Agboola O, Adeoye JB, Odunlami OA (2023).

Review on the impact of heavy metals from industrial wastewater effluent and removal technologies, Heliyon, 10(23), e40370. <https://doi.org/10.1016/j.heliyon.2024.e40370>.

Packer, M. (2016). Cobalt cardiomyopathy: a critical reappraisal in light of a recent resurgence. *Circulation Heart Failure*. 9 (12). doi:10.1161/CIRCHEARTFAILURE.116.003604.

Parvez M, Nawshin S, Sultana S, Hossain M, Rashid K, Md. Harunor H, Md. Ahasan N, Zarin T, Khan R (2023). Evaluation of Heavy Metal Contamination in Soil Samples around Rampal, Bangladesh. https://doi.org/10.1021/acsomega.2c07681

Priya AK, Muruganandam M, Ali SS, Kornaros M. Clean-Up of Heavy Metals from Contaminated Soil by Phytoremediation: A Multidisciplinary and Eco-Friendly Approach. Toxics. 2023 May 2;11(5):422. doi: 10.3390/toxics11050422.

Quezada-Pinedo, H.G., Cassel, F., Duijts, L., Muckenthaler, M.U., Gassmann, M., Jaddoe, V.W., Reiss, I.K., Vermeulen, M.J. (2021). Maternal Iron Status in Pregnancy and Child Health Outcomes after Birth: A Systematic Review and Meta-Analysis. *Nutrients*. 13(7). doi:10.3390/nu13072221.

Rostam, A. B., and Taghizadeh, M. (2020). Advanced oxidation processes integrated by membrane reactors and bioreactors for various wastewater treatments: A critical review. *Journal of Environmental Chemical Engineering*, *8*(6), 104566.

Shapiro EF, Lin ZW, Cifuentes ES, Barajas-Rodriguez FJ, Gwinn R, Dichtel WR, Packman AI (2025). Removal of PFAS and pharmaceuticals from municipal wastewater using a novel β-cyclodextrin adsorbent over distinct contact times. Water Res. 282:123631. <https://doi.org/10.1016/j.watres.2025.123631>

Shokri F, Ziarati P, Mousavi Z. Removal of Selected Heavy Metals from Pharmaceutical Effluent by Aloe Vera L. Biomed Pharmacol J 2016;9(2)

Syafrudin M, Kristanti RA, Yuniarto A, Hadibarata T, Rhee J, Al-Onazi WA, Algarni TS, Almarri AH, Al-Mohaimeed AM (2021). Pesticides in drinking water-A review. Int J Environ Res Public Health. 18(2):468. <https://doi.org/10.3390/ijerph18020468>

Tadesse, M., Tsegaye, D., and Girma, G. (2018). Assessment of the level of some physico-chemical parameters and heavy metals of Rebu river in oromia region, Ethiopia. *MOJ Biology and Medicine*, *3*(3), 99-118.

Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ (2012). Heavy metal toxicity and the environment. Exp Suppl. 101:133-64. https://doi.org/10.1007/978-3-7643-8340-4\_6.

Tvrda, E., Peer, R., Sikka, S.C., and Agarwal, A. (2015). Iron and Copper in Male Reproduction: A Double-Edged Sword. *J. Assist. Reprod. Genet*. 32(2):3–16. doi:10.1007/s10815-014-0344-7.

UNEP, 2007, Global Mercury Assessment, Geneva Switzerland, Taken 2008-05-10 from <http://www.chem.unep.ch/mercury/Report/Chapter6.htm>

Veado, M. A., de Oliveira, A. H., Revel, G., Pinte, G., Ayrault, S., and Toulhoat, P. (2000). Study of water and sediment interactions in the Das Velhas River, Brazil – Major and trace elements. [Environmental Monitoring and Assessment](https://www.springer.com/journal/10661/). 26 (2)

Wang, J., Liu, X., Liu, G., Zhang, Z., Cui, B., Bai, J., and Zhang, W., 2019. Size effect of polystyrene microplastics on sorption of phenanthrene and nitrobenzene. Ecotoxicology Environmental Safety, vol 173, pg 331–338.doi.org/10.1016/j.ecoenv.2019.02.037.

Xu, W., Jin, Y., & Zeng, G. (2024). Introduction of heavy metals contamination in the water and soil: a review on source, toxicity and remediation methods. *Green Chemistry Letters and Reviews*, *17*(1). https://doi.org/10.1080/17518253.2024.2404235