ENVIRONMENTAL REPORTS

Review Article
ISSN: 3041-556X
Journal homepage: https://er.researchfloor.org/

Lead and cadmium concentrations in drinking water and their potential risks for children

M. M. Abdulrasool

Department of Chemistry, College of Science, University of Kerbala, Kerbala, Iraq

Citation: M. M. Abdulrasool (2023). Lead and cadmium concentrations in drinking water and their potential risks for children. *Environmental Reports; an International Journal*. **DOI: https://doi.org/10.51470/ER.2023.4.2.29**

Corresponding Author: **M. M. Abdulrasool** | E-Mail: **(mustafa.abdulrasool@uokerbala.edu.in)**

Received 30 March 2023 | Revised 28 April 2023 | Accepted 30 May 2023 | Available Online June 29 2023

ABSTRACT

Lead (Pb) and cadmium (Cd) contamination in drinking water represents a continuing global public health concern. These toxic metals persist in the environment, lack biological utility, and accumulate in the human body, posing long-term health risks. Children are especially vulnerable due to their higher rates of absorption and developing organ systems. This review synthesizes current knowledge on the occurrence, sources, and pathways of lead and cadmium in drinking water, with particular emphasis on their toxicological effects in children. It also compares international guidelines, summarizes health risk assessment approaches, and identifies gaps in monitoring and mitigation strategies. Evidence shows that exposure to lead in drinking water is strongly linked to neurodevelopmental deficits, anemia, and renal dysfunction, whereas cadmium primarily affects renal and skeletal systems. Despite international regulatory standards, exceedances are widely reported, particularly in low- and middle-income countries with limited monitoring capacity. Future efforts should focus on low-cost monitoring tools, integrated risk assessment frameworks, and stricter policy enforcement to safeguard child health.

Keywords: *Lead, Cadmium, Drinking water, Children, Risk assessment, Public health.*

Introduction

The provision of safe drinking water is fundamental to human health and development, yet contamination by toxic heavy metals remains a persistent challenge. Among these, lead (Pb) and cadmium (Cd) are of particular concern because of their environmental persistence, bioaccumulative properties, and toxicity even at low concentrations. Unlike essential trace elements, lead and cadmium have no beneficial biological role and can exert harmful effects at very low levels of exposure [1]. Children are widely recognized as the most vulnerable group to heavy metal exposure. They have higher water intake per unit of body weight, greater gastrointestinal absorption rates, and immature detoxification systems compared with adults. Moreover, developmental processes in the nervous system, kidneys, and skeletal tissues make them more susceptible to toxic insults during critical growth phases [2]. As a result, chronic exposure to even low concentrations of lead and cadmium in drinking water can produce lifelong health consequences.

The contamination of drinking water with lead and cadmium arises from a combination of natural and anthropogenic activities. Natural contributions stem from the geochemical weathering of rocks and mineral deposits. However, anthropogenic drivers dominate in most contexts, including industrial effluents, mining operations, urban runoff, agricultural practices, and corrosion of lead-based plumbing. Regions with inadequate regulatory oversight or aging infrastructure face heightened risks.

This review synthesizes research on lead and cadmium concentrations in drinking water, focusing on children's vulnerability [3]. It examines sources and pathways of exposure, toxicological impacts, international regulatory standards, and health risk assessment frameworks. It also highlights mitigation strategies and identifies gaps that require further research and policy action.

Table 1. International Guideline Values for Lead and Cadmium in Drinking Water

Organization/Regulatory Body	Lead (Pb) Limit (µg/L)	Cadmium (Cd) Limit (µg/L)	Notes
World Health Organization (WHO)	10	3	Updated in 2017 guidelines
United States Environmental Protection Agency (USEPA)	15 (action level)	5	Not a maximum contaminant level (MCL) but action-trigger level for Pb
European Union (EU Directive 2020/2184)	10	5	Applies across member states
Bureau of Indian Standards (BIS)	10	3	Adopted from WHO guidelines
China (GB 5749-2022)	10	5	National drinking water standards
South Africa (SANS 241)	10	5	Based on WHO standards

Table 2. Major Sources of Lead and Cadmium in Drinking Water

Source Category	Lead (Pb)	Cadmium (Cd)
Plumbing and Infrastructure	Corrosion of lead pipes, solder, and fixtures	Leaching from galvanized pipes and fittings
Industrial Activities	Battery recycling, smelting, pigment and paint production	Electroplating, battery manufacturing, pigment industries
Agriculture	Runoff from lead-containing pesticides (historical use)	Phosphate fertilizers contaminated with cadmium
Mining and Resource Extraction	Lead ore mining and artisanal operations	Zinc and lead ore mining; coal combustion residues
Urban Runoff	Contaminated dust, residues from paints and fuels	Industrial effluents and urban sewage discharge

Table 3. Health Impacts of Lead and Cadmium Exposure in Children

System/Organ	Lead (Pb) Effects	Cadmium (Cd) Effects
Nervous System	Reduced IQ, attention deficits, behavioral problems, learning difficulties	Limited evidence; indirect effects via hypoxia and oxidative stress
Hematological System	Anemia due to inhibition of heme synthesis	Not a major direct effect
Renal System	Chronic kidney disease, impaired glomerular filtration	Tubular dysfunction, proteinuria, chronic kidney damage
Skeletal System	Disrupted bone growth in severe cases	Bone demineralization, fractures, impaired skeletal development
Cardiovascular System	Elevated blood pressure, long-term cardiovascular risk	Hypertension linked to chronic exposure
Growth and Development	Impaired physical development	Stunted growth, low birth weight associations

Table 4. Risk Assessment Indicators Commonly Used for Lead and Cadmium in Children

Parameter	Description	Interpretation
Estimated Daily Intake (EDI)	Amount of metal ingested daily via water (mg/kg/day)	Compared with reference dose (RfD)
Hazard Quotient (HQ)	Ratio of EDI to RfD	HQ > 1 indicates potential non-carcinogenic risk
Hazard Index (HI)	Cumulative HQ for multiple pollutants	HI > 1 suggests combined health risk
Carcinogenic Risk (CR)	Probability of cancer occurrence over a lifetime	Acceptable range: $10^{-6} – 10^{-4}$
Target Hazard Dose (THD)	Benchmark safe dose from regulatory agencies	Used in HQ calculations

Sources and Pathways of Lead and Cadmium in Drinking Water

Lead

The contamination of drinking water with lead (Pb) remains a widespread public health issue, particularly in regions with aging infrastructure or weak water quality monitoring. One of the most significant pathways of lead entry into water systems is through plumbing materials [4]. Historically, lead pipes, lead-based solder, and brass fixtures containing lead were widely used in domestic and municipal water distribution systems. When water has high acidity or low mineral content, it accelerates the corrosion of these materials, leading to the leaching of lead into drinking water. Even in countries that have banned the use of lead pipes, older housing stock and neglected infrastructure continue to pose risks. The well-documented crisis in Flint, Michigan, highlights how inadequate corrosion control measures can lead to widespread lead exposure through municipal water systems.

Another major pathway involves industrial activities [5]. Effluents from industries such as battery recycling, metal smelting, and pigment manufacturing are often discharged into rivers, lakes, or groundwater. Without stringent wastewater treatment, these effluents introduce lead particles into aquatic systems, which can infiltrate drinking water sources. Industrial contamination is particularly problematic in regions where environmental regulations are poorly enforced or where informal and small-scale industries operate outside the regulatory framework.

Urban runoff is also an important contributor. Lead-based paints, once widely used in construction, deteriorate over time, releasing particles that accumulate in soils and dust. Rainfall and stormwater wash these residues into drainage systems, where they can eventually enter surface water sources used for drinking [6]. Similarly, residues from fuels—especially in countries that phased out leaded gasoline only recently—remain in urban soils and contribute to runoff contamination. In addition, construction waste, demolition activities, and improper disposal of lead-containing materials amplify this problem in rapidly urbanizing areas [7]. The persistence of lead in the environment means that even past uses continue to pose long-term risks. Once deposited in soils or sediments, lead can be mobilized under changing pH or redox conditions and find its way into groundwater or surface water used for human consumption [8]. Consequently, drinking water contamination is not only a function of current industrial activity but also of historical practices.

Cadmium

Cadmium (Cd) contamination of drinking water, while less publicized than lead, is equally concerning due to its toxicity and persistence. One of the principal sources of cadmium in water systems is industrial discharge. Industries involved in electroplating, battery manufacturing, pigment production, and metal smelting release cadmium as a byproduct [9]. Wastewater from such processes, if inadequately treated, enters aquatic ecosystems and contaminates drinking water sources. Mining operations, especially those extracting zinc and lead ores, also contribute significantly, as cadmium often occurs as an impurity in these deposits. Tailings and waste rock piles can leach cadmium into groundwater over time.

Agricultural practices represent another important pathway. Phosphate fertilizers are widely used to enhance crop yields, yet many phosphate rock deposits naturally contain cadmium. When applied over large areas, cadmium can accumulate in agricultural soils and leach into nearby water bodies, eventually contaminating drinking water [10]. Irrigation practices can exacerbate this problem by facilitating the movement of cadmium from soils into groundwater systems.

In urban and peri-urban areas, sewage sludge and solid waste also act as sources of cadmium. Industrial effluents discharged into municipal wastewater can increase cadmium concentrations in sludge, which, when used as fertilizer or improperly disposed of, contaminates surrounding soils and water systems [11]. Combustion of fossil fuels, particularly coal, releases cadmium into the atmosphere, where it can settle onto land and water surfaces, contributing to diffuse pollution.

The mobility of cadmium in aquatic environments depends strongly on pH and water chemistry. Acidic conditions enhance the solubility of cadmium, increasing its availability in water [12]. This is particularly relevant in areas affected by acid mine drainage or acid rain. Unlike lead, which tends to bind strongly to sediments, cadmium remains relatively mobile, increasing the likelihood of its transport through water systems and subsequent uptake in drinking supplies [13]. Both lead and cadmium enter drinking water through multiple, often overlapping pathways linked to industrialization, agriculture, urbanization, and legacy practices. While lead is closely associated with corroded plumbing and urban runoff, cadmium contamination is strongly tied to industrial discharges and fertilizer use [14]. Their persistence and toxicity demand robust monitoring and intervention strategies, particularly in vulnerable regions of the Global South where regulation and infrastructure are inadequate. Understanding these pathways is essential for designing preventive measures and safeguarding children's health.

Cadmium

Cadmium (Cd) is a non-essential, highly toxic heavy metal that has attracted increasing concern due to its persistence in the environment and its potential to contaminate drinking water. Unlike other contaminants that degrade or dissipate, cadmium tends to accumulate in soils and aquatic systems, creating long-term exposure risks for human populations [15]. Children are particularly vulnerable because of their higher relative intake of water and their developing physiological systems. The pathways of cadmium into drinking water are diverse, but three sources dominate: industrial effluents, agricultural inputs, and mining activities.

Industrial effluents are among the most recognized contributors of cadmium pollution in water systems. Industries such as electroplating, nickel–cadmium battery production, pigment manufacturing, and plastics processing frequently generate wastewater containing cadmium [16]. If untreated or insufficiently treated, these effluents enter rivers, lakes, or groundwater, where cadmium remains soluble under a wide range of conditions. Small- and medium-scale enterprises, often operating with limited regulatory oversight, represent a significant problem in the Global South. Informal or artisanal workshops may lack effective wastewater treatment facilities, leading to the direct discharge of cadmium-rich effluents into surrounding water bodies. Over time, this contamination can infiltrate community drinking water sources, particularly where surface water is used without adequate purification.

Agricultural inputs represent another critical pathway. Phosphate fertilizers, derived from phosphate rock deposits, naturally contain trace levels of cadmium. The repeated and large-scale application of such fertilizers increases cadmium concentrations in agricultural soils. Under conditions of irrigation and rainfall, cadmium can leach from soils into surface and groundwater systems, which may serve as sources of drinking water [17]. The problem is amplified in intensive farming regions where fertilizer use is continuous and unregulated. Moreover, cadmium in soil can persist for decades, creating a chronic source of contamination even after fertilizer application has ceased. In some areas, sewage sludge used as fertilizer also contains cadmium, especially when industrial wastewater is mixed into municipal sewage streams.

Mining activities further intensify cadmium exposure risks. Cadmium is commonly associated with zinc, lead, and copper ores, and is released during their extraction and processing. Mining waste, such as tailings and overburden, often contains elevated cadmium concentrations that can leach into nearby rivers or aquifers, particularly under acidic conditions [18]. Artisanal and small-scale mining is of particular concern because it frequently lacks waste management systems, leading to uncontrolled contamination of soil and water. In some regions, acid mine drainage mobilizes cadmium into groundwater, where it may persist for long periods and contaminate wells used for drinking. The mobility of cadmium in aquatic systems is influenced by several factors, including pH, redox potential, and water hardness. Acidic conditions enhance cadmium solubility, increasing its concentration in drinking water. Unlike lead, which strongly adsorbs to sediments, cadmium remains relatively mobile, allowing it to travel longer distances in water systems and increasing the likelihood of human exposure. This mobility underscores the importance of monitoring cadmium not only near point sources but also in downstream drinking water supplies, c. Cadmium contamination in drinking water stems from a combination of industrial, agricultural, and mining sources, often operating simultaneously in the same regions. Its persistence, mobility, and bioaccumulation potential make it a serious public health hazard [19]. Understanding these pathways is essential for designing effective policies and remediation strategies aimed at reducing cadmium exposure, particularly in vulnerable populations such as children.

Health Impacts in Children

Exposure to heavy metals such as lead (Pb) and cadmium (Cd) through drinking water presents significant health risks, particularly for children. Due to their smaller body mass, higher gastrointestinal absorption rates, and ongoing developmental processes, children are far more vulnerable than adults to the toxic effects of these contaminants [20]. Even low-level, chronic exposures can have lifelong consequences, often manifesting as neurological, renal, skeletal, and developmental impairments.

Lead

Neurotoxicity is the most widely documented and concerning effect of lead exposure in children. Lead interferes with synapse formation, neurotransmitter release, and myelination of the developing brain. Studies show that blood lead levels below 5 μg/dL—previously considered safe—are linked to measurable declines in IQ, reduced attention spans, learning difficulties, and increased behavioral disorders, including aggression and hyperactivity [21]. These neurological impairments are irreversible and can persist into adulthood, affecting educational achievement and socioeconomic potential.

Hematological effects of lead arise from its interference with heme synthesis. Lead inhibits enzymes such as delta-aminolevulinic acid dehydratase (ALAD) and ferrochelatase, impairing hemoglobin production. This disruption often manifests as microcytic, hypochromic anemia. In children, anemia not only compromises oxygen transport but also exacerbates cognitive and developmental deficits, as reduced oxygen delivery impairs brain and tissue function.

Renal and cardiovascular outcomes are additional concerns. Chronic lead exposure contributes to tubular dysfunction, reduced glomerular filtration rate, and early-onset hypertension [3]. While these outcomes often become clinically apparent in adulthood, the pathological processes can begin in childhood, setting the stage for chronic kidney disease and cardiovascular morbidity later in life.

Cadmium

Renal toxicity is the hallmark effect of cadmium exposure. Cadmium accumulates in the renal cortex, where it binds to metallothionein and induces progressive tubular damage. Early signs include proteinuria, glucosuria, and aminoaciduria, reflecting impaired proximal tubule function. In children, these effects can compromise kidney development and predispose them to chronic renal disease in adulthood.

Skeletal effects are another significant outcome of cadmium toxicity. Cadmium interferes with calcium metabolism and vitamin D activity, leading to bone demineralization [7]. In growing children, this manifests as impaired skeletal growth, delayed bone maturation, and an increased risk of fractures. In severe cases, chronic cadmium exposure has been associated with osteomalacia and skeletal deformities, as observed historically in "Itai-itai disease" in Japan. While that epidemic primarily affected adults, its mechanisms underscore cadmium's potential to disrupt bone health across all ages.

Developmental outcomes include associations with impaired growth and respiratory health. Epidemiological studies suggest that cadmium exposure may contribute to reduced birth weight, stunted postnatal growth, and increased susceptibility to respiratory conditions such as asthma and reduced lung function [5]. These effects may stem from cadmium-induced oxidative stress, endocrine disruption, and impaired nutrient metabolism during critical growth periods.

Comparative Perspective

While both lead and cadmium exert toxic effects on multiple organ systems, their health impacts differ in emphasis. Lead predominantly affects the nervous system and hematological functions, with profound consequences for cognitive and behavioral development. Cadmium, by contrast, exerts its strongest effects on the renal and skeletal systems, with long-term risks for growth, bone integrity, and kidney function [6]. Together, these metals represent a dual threat to children's health, underscoring the importance of stringent monitoring and intervention strategies in drinking water safety.

International Standards, Guidelines, and Risk Assessment Approaches

International Standards and Guidelines

To mitigate the health risks of lead and cadmium in drinking water, several international organizations and regulatory bodies have established guideline values. The World Health Organization (WHO) recommends a maximum concentration of 10 μg/L for lead and 3 μg/L for cadmium in drinking water [7]. These thresholds are based on extensive toxicological data and are designed to minimize risks of neurotoxicity, renal impairment, and developmental effects, particularly in children.

The United States Environmental Protection Agency (USEPA) employs an action level rather than a strict maximum contaminant limit (MCL). For lead, the action level is 15 μg/L, which, if exceeded in more than 10% of sampled homes, triggers mandatory treatment and remediation measures. For cadmium, the USEPA sets a maximum contaminant level at 5 μg/L.

The European Union (EU) has harmonized its standards with the WHO, setting maximum allowable levels of 10 μg/L for lead and 5 μg/L for cadmium in drinking water across member states [12]. Despite these benchmarks, exceedances are common in many parts of Asia, Africa, and Latin America, where aging infrastructure, artisanal mining, industrial discharges, and weak enforcement mechanisms contribute to contamination. For example, studies in rural India and Nigeria have documented lead concentrations several-fold higher than WHO limits, while elevated cadmium levels are frequently reported in mining-intensive areas of China and South America. This disparity highlights the gap between international standards and local realities in the Global South.

Risk Assessment Approaches

Risk assessment provides a structured framework for evaluating the potential health effects of lead and cadmium exposure in drinking water. The process typically involves four steps:

1. Hazard Identification – Establishes the toxicological properties of lead and cadmium, including their critical target organs and potential for chronic health effects. For children, neurotoxicity (lead) and renal damage (cadmium) are of primary concern.

2. Exposure Analysis – Estimates the amount of contaminant intake based on water consumption rates, body weight, and contaminant concentration. Children generally exhibit higher exposure levels per unit body weight due to greater fluid intake relative to body size.

3. Dose–Response Modeling – Examines the relationship between exposure levels and health effects. For lead, no safe threshold has been identified, with adverse outcomes observed even at very low blood concentrations. For cadmium, dose–response models link chronic ingestion to renal and skeletal toxicity.

4. Risk Characterization – Integrates exposure and dose–response data to estimate health risks. Commonly used tools include the Hazard Quotient (HQ) and Hazard Index (HI) for non-carcinogenic risks. An HQ or HI greater than 1 suggests that exposure exceeds the safe threshold. In many mining and industrial regions, children's HQ values for lead and cadmium are significantly above this benchmark. For cadmium, lifetime cancer risk assessments are also performed, given its classification as a human carcinogen, r. Risk assessment studies consistently demonstrate that children living near industrial hotspots or using poorly regulated water supplies are at heightened risk of both immediate and long-term health consequences [14-16]. The combination of weak enforcement of standards and high vulnerability of children underscores the urgent need for preventive interventions.

Mitigation Strategies and Knowledge Gaps

Mitigation Strategies

Addressing the risks posed by lead and cadmium in drinking water requires interventions across multiple scales, from infrastructure development to household-level solutions.

Water infrastructure upgrades are a primary strategy. In many older systems, lead pipes, solder, and fixtures remain significant sources of contamination. Replacing these with safer materials, alongside modernization of water distribution systems, can substantially reduce lead exposure [12]. For cadmium, preventing contamination often involves improving wastewater management near mining, industrial, and agricultural zones to prevent leaching into groundwater sources.

Treatment technologies are widely applied to reduce heavy metal concentrations. Advanced methods such as reverse osmosis, ion exchange, and activated carbon filtration demonstrate high efficiency in removing both lead and cadmium. However, their costs can be prohibitive in low-income settings [13]. As a result, there is growing interest in developing low-cost alternatives, including biosorbents derived from agricultural waste, ceramic filters, and nanomaterial-based adsorbents, which can be applied at both community and household scales.

Policy enforcement and regulation remain critical. Many countries have adopted drinking water standards aligned with WHO or USEPA guidelines, yet weak enforcement and limited monitoring capacity often undermine compliance. Strengthening regulatory frameworks, ensuring routine water quality assessments, and enforcing penalties for non-compliance in industrial and municipal effluents are essential measures [9].

At the community level, interventions such as the provision of low-cost filters, point-of-use treatment devices, and awareness programs can help mitigate risks, especially in vulnerable rural and peri-urban areas. Public health campaigns aimed at educating families about the dangers of lead and cadmium exposure and practical mitigation strategies have proven effective in reducing exposure at the household level [8]. Finally, research priorities focus on the development of affordable, rapid detection methods for heavy metals, including portable field kits and sensor technologies. Coupling these with integrated ecological–health monitoring systems could provide early warnings of contamination events and support timely interventions.

Knowledge Gaps and Research Needs

Despite extensive research on heavy metals, significant knowledge gaps remain in understanding and addressing the risks of lead and cadmium exposure in drinking water.

1. Limited longitudinal studies: While cross-sectional studies link lead and cadmium exposure with immediate health outcomes, there is a lack of long-term cohort studies following children exposed in early life to assess developmental, cognitive, and metabolic impacts in adulthood.

2. Inadequate data on combined effects: Most studies assess lead and cadmium independently, yet populations are often exposed to mixtures of metals and co-contaminants such as arsenic, fluoride, or pesticides. Understanding these combined or synergistic effects remains a major research challenge.

3. Scarcity of monitoring systems in underserved regions: Rural communities and informal urban settlements in the Global South often lack systematic monitoring of water quality. This creates substantial blind spots in exposure assessment and risk management.

4. Deficiencies in risk communication: Even when contamination is documented, communities frequently lack accessible tools to understand risks and adopt mitigation measures. Developing community-based communication platforms, leveraging mobile technologies, and involving local health workers could bridge this gap.

Addressing these gaps requires interdisciplinary collaboration among environmental scientists, public health experts, engineers, and policymakers. Without such efforts, the risks posed by lead and cadmium in drinking water will remain a persistent challenge, especially for vulnerable child populations.

Conclusion

Lead and cadmium contamination in drinking water continues to pose a significant global health risk, with children representing the most vulnerable population. Both metals persist in the environment, bioaccumulate in biological systems, and exert chronic toxic effects even at low concentrations. Despite the existence of international guidelines such as those from the World Health Organization, exceedances are widespread, particularly in low- and middle-income countries where infrastructure deficits, weak regulatory enforcement, and limited monitoring capacity exacerbate risks. Protecting children from these exposures requires a coordinated, multi-level response. Investments in safe water infrastructure, including the replacement of lead-containing materials and improved wastewater management, are foundational. Complementary to these are affordable and accessible treatment technologies, ranging from advanced filtration to community-based solutions adapted for resource-limited settings. Equally important is the role of policy, with stronger enforcement of industrial discharge regulations and the integration of water safety into public health priorities. Community engagement, through awareness programs and locally appropriate interventions, can further reduce household-level risks. Ultimately, safeguarding child health demands a shift toward proactive prevention and equitable access to safe water. Integrating technological innovation, governance, and public participation provides a pathway to reducing the intergenerational impacts of lead and cadmium exposure.

References

1. Decharat, S., & Pan-In, P. (2020). Risk assessment of lead and cadmium in drinking water for school use in Nakhon Si Thammarat Province, Thailand. *Environmental Analysis, Health and Toxicology*, *35*(1), e2020002.

2. Ahmed, J., Wong, L. P., Chua, Y. P., Channa, N., Memon, U. U. R., Garn, J. V., ... & VanDerslice, J. A. (2021). Heavy metals drinking water contamination and health risk assessment among primary school children of Pakistan. *Journal of Environmental Science and Health, Part A*, *56*(6), 667-679.

3. Rahman, M. A., Islam, M. R., Kumar, S., & Al-Reza, S. M. (2021). Drinking water quality, exposure and health risk assessment for the school-going children at school time in the southwest coastal of Bangladesh. *Journal of Water, Sanitation and Hygiene for Development*, *11*(4), 612-628.

4. Lobo, G. P., Laraway, J., & Gadgil, A. J. (2022). Identifying schools at high-risk for elevated lead in drinking water using only publicly available data. *Science of The Total Environment*, *803*, 150046.

5. Ryan, P. B., Huet, N., & MacIntosh, D. L. (2000). Longitudinal investigation of exposure to arsenic, cadmium, and lead in drinking water. *Environmental health perspectives*, *108*(8), 731-735.

6. Rahman, M. A., Kumar, S., Lamb, D., & Rahman, M. M. (2021). Health risk assessment of arsenic, manganese, and iron from drinking water for high school children. *Water, Air, & Soil Pollution*, *232*(7), 269.

7. Rezaei, H., Zarei, A., Kamarehie, B., Jafari, A., Fakhri, Y., Bidarpoor, F., ... & Shalyari, N. (2019). Levels, distributions and health risk assessment of lead, cadmium and arsenic found in drinking groundwater of Dehgolan's villages, Iran. *Toxicology and environmental health sciences*, *11*(1), 54-62.

8. Olympio, K. P. K., da Rocha Silva, J. P., da Silva, A. S., de Oliveira Souza, V. C., Buzalaf, M. A. R., Barbosa Jr, F., & Cardoso, M. R. A. (2018). Blood lead and cadmium levels in preschool children and associated risk factors in São Paulo, Brazil. *Environmental Pollution*, *240*, 831-838.

9. Iyare, P. U. (2019). The effects of manganese exposure from drinking water on school-age children: A systematic review. *Neurotoxicology*, *73*, 1-7.

10. Endale, Y. T., Ambelu, A., Mees, B., & Du Laing, G. (2021). Exposure and health risk assessment from consumption of Pb contaminated water in Addis Ababa, Ethiopia. *Heliyon*, *7*(9).

11. Schoeters, Greet, Elly Den Hond, Moniek Zuurbier, Rima Naginiene, Peter Van Den Hazel, Nikolaos Stilianakis, Roberto Ronchetti, and Janna G. Koppe. "Cadmium and children: exposure and health effects." *Acta Paediatrica* 95 (2006): 50-54.

12. Gao, Y., Li, X., Dong, J., Cao, Y., Li, T., & Mielke, H. W. (2020). Snack foods and lead ingestion risks for school aged children: A comparative evaluation of potentially toxic metals and children's exposure response of blood lead, copper and zinc levels. *Chemosphere*, *261*, 127547.

13. Llobet, J. M., Falco, G., Casas, C., Teixido, A., & Domingo, J. L. (2003). Concentrations of arsenic, cadmium, mercury, and lead in common foods and estimated daily intake by children, adolescents, adults, and seniors of Catalonia, Spain. *Journal of agricultural and food chemistry*, *51*(3), 838-842.

14. Olufemi, A. C., Mji, A., & Mukhola, M. S. (2022). Potential health risks of lead exposure from early life through later life: implications for public health education. *International journal of environmental research and public health*, *19*(23), 16006.

15. Donangelo, C. M., Kerr, B. T., Queirolo, E. I., Vahter, M., Peregalli, F., Mañay, N., & Kordas, K. (2021). Lead exposure and indices of height and weight in Uruguayan urban school children, considering co-exposure to cadmium and arsenic, sex, iron status and dairy intake. *Environmental research*, *195*, 110799.

16. Oulhote, Y., Mergler, D., Barbeau, B., Bellinger, D. C., Bouffard, T., Brodeur, M. È., & Bouchard, M. F. (2014). Neurobehavioral function in school-age children exposed to manganese in drinking water. *Environmental health perspectives*, *122*(12), 1343-1350.

17. Paoliello, M. M. B., De Capitani, E. M., Da Cunha, F. G., Matsuo, T., de Fátima Carvalho, M., Sakuma, A., & Figueiredo, B. R. (2002). Exposure of children to lead and cadmium from a mining area of Brazil. *Environmental Research*, *88*(2), 120-128.

18. Lim, C. S., Shaharuddin, M. S., & Sam, W. Y. (2012). Risk assessment of exposure to lead in tap water among residents of Seri Kembangan, Selangor state, Malaysia. *Global journal of health science*, *5*(2), 1.

19. Fakhri, Y., Mohseni, S. M., Jafarzadeh, S., Langarizadeh, G., Moradi, B., Zandsalimi, Y., & Mirzaei, M. (2015). Assessment of carcinogenic and non-carcinogenic risk lead in bottled water in different age groups in Bandar Abbas Ciry, Iran. *Global journal of health science*, *7*(4), 286.

20. Nordberg, G. F. (1990). Human health effects of metals in drinking water: relationship to cultural acidification. *Environmental Toxicology and Chemistry: An International Journal*, *9*(7), 887-894.

21. Wright, R. O., Amarasiriwardena, C., Woolf, A. D., Jim, R., & Bellinger, D. C. (2006). Neuropsychological correlates of hair arsenic, manganese, and cadmium levels in school-age children residing near a hazardous waste site. *Neurotoxicology*, *27*(2), 210-216.