Lead Contamination in India: Persistence in Drinking Water and Health Impact

by

Dr Kriti Akansha, Piyush Mohapatra, Avanti Roy Basu, Vidhi Mathur, Dr Deepak Marathe, Dr Amit Mehrotra, Dr Girija K Bharat

Executive Summary

Lead (Pb) is a non-essential, toxic metal that persists in the environment with no known safe level of human exposure. It remains an important but under-recognized contaminant in drinking water, soil and consumer products in India. Contamination hotspots have developed throughout the country as a result of legacy uses in plumbing, paints, batteries and PVC stabilisers, as well as a large and largely informal battery recycling and manufacturing sector. It is estimated that lead exposure contributes to about 3.5 million deaths (5.8% of all deaths) and 71.5 million DALYs globally each year, with the highest burden in low- and middle-income countries (GBD, 2023). UNICEF (2020) estimated that 800 million children worldwide have elevated blood lead levels. In India, drinking water is a significant route of exposure. A key factor is the corrosion of ageing lead pipes, solder and fittings, exacerbated by intermittent supply and uneven oversight. Other sources include substandard PVC pipes (35-40% of the unorganised market segment) (IMARC, 2025) and informal recycling of lead-acid batteries.

Lead, once absorbed, is stored in bone for 20-30 years (Babu et al., 2024; Todd, 1991) and can remobilise during pregnancy and lactation to be transferred to the foetus and infant (ATSDR, n.d.; CDC, 2024). It has an impact on almost all organ systems, and the developing nervous systems of children are particularly vulnerable to irreversible cognitive and behavioural damage (WHO, 2024). Two national case studies illustrate this: in Bihar, 94% of lactating mothers and 41% of infants exceeded WHO blood/urine lead thresholds, mainly due to contaminated food, spices, cosmetics and traditional medicines rather than water (Chayal, 2025); in Chennai, 49% of 300 adults sampled had blood lead levels above 5 µg/dL, associated with industrial proximity, lead-based paint and metal cookware (Babu et al., 2024). The Flint, Michigan crisis is used as a cautionary international case study for illustrating the way one infrastructure decision without corrosion control turned into a public health crisis with lessons that are long-lasting for monitoring, transparency, and inter-agency coordination (NRDC, 2025; CDC, 2024).

India's regulatory response includes BIS IS 10500:2012 (10 µg/L limit for lead, no relaxation) and the Lead Stabiliser in PVC Pipes and Fittings Rules, 2021 (capping lead extraction at 1 ppm) along with the Jal Jeevan Mission, which has connected 157.2 million rural households to tap water and is estimated to have averted 14 million DALYs, supported by over 2,800 water-testing laboratories nationally (PIB, 2025). However, gaps remain. Lead was still found in excess of permissible limits in 0.95% of pre-monsoon and 0.79% of post-monsoon samples from 2,537 samples collected by the Central Ground Water Board for its 2025 assessment (Central Ground Water Board, 2025).

Key challenges constraining progress include ageing and poorly documented urban plumbing infrastructure, fragmented and inconsistently enforced regulation spanning water, product safety and industrial sectors, low public awareness of non-obvious exposure pathways, and insufficient monitoring data, particularly for distribution networks and biological surveillance. The report recommends stronger risk-based enforcement, nationwide water testing, long-term research and surveillance, safer alternatives to lead-based PVC, and greater community participation to improve implementation of India's existing standards.

Table of Contents

1. Introduction

Lead (Pb) is a naturally occurring, non-essential toxic heavy metal with no known biological function. It possesses important physicochemical properties such as softness, malleability, ductility, low electrical conductivity and resistance to corrosion, which have driven its widespread industrial use and made its complete phase-out difficult (Wani et al., 2015). The legacy and ongoing use of lead in plumbing, gasoline, paints, ceramics, cosmetics, solders and batteries has led to pervasive environmental contamination, elevated human exposure, and major public health burdens worldwide (NIEHS, 2026). It is toxic to humans, especially to children and adolescents, as it is quickly absorbed, leading to detrimental effects on health (Kumar et al., 2023).

Although lead constitutes only about 0.002% of the Earth's crust and occurs naturally in soils through weathering and pedogenic processes, most lead present in air, water, soil, and biota today is attributable to anthropogenic activities such as mining, smelting, manufacturing, informal recycling, and legacy uses of leaded products (Toxics Link, 2025). In India, these pathways are amplified by high demand for lead in the battery sector and a substantially unregulated recycling and manufacturing sector, both of which contribute to significant contamination hotspots. Additionally, the use of lead in building materials and consumer products, such as PVC pipes, bolts, brass fittings, toys, and ceramics, has vastly expanded the range of exposure (Ericson et al., 2018; Subramanian & Connor et al., 1991).

Lead exposure can cause a wide range of adverse health effects, including behavioural problems, learning disabilities, seizures and death. Children are particularly vulnerable to lead's toxicity and may suffer permanent health impacts, particularly affecting the development of the central nervous system (WHO, 2024). Globally, 800 million children are affected by lead poisoning (UNICEF, 2020). In adults, it can increase the risk of hypertension, cardiovascular disease and kidney damage. Exposure during pregnancy has been associated with preterm birth and impaired foetal growth (WHO, 2024). In 2023, the Institute for Health Metrics and Evaluation estimated that lead exposure accounted for approximately 5.8% of all global deaths (˜3.5 million deaths) and 2.6% (˜71.5 million) of global disability-adjusted life-years (DALYs), with substantial burdens in low- and middle-income countries (GBD, 2023).

In India, drinking water is an important exposure pathway. Lead primarily enters the drinking water through corrosion of lead-containing pipes, fittings, and solder, exacerbated by ageing infrastructure, contaminated groundwater, and inadequate routine monitoring of distribution systems (Wani et al., 2015). To address these risks, the Government of India has taken significant legislative action, including the establishment of standards such as Bureau of Indian Standards (BIS) IS 10500:2012, which specifies a maximum permissible limit for lead in drinking water of 10 µg/L (no relaxation), and national programs (for example, under Jal Jeevan Mission) which promote periodic testing. However, these need to be supplemented with actionable data, strengthened surveillance and comprehensive groundwater monitoring, particularly in industrial regions where uncertified plumbing materials are commonly used in informal sectors.

2. Sources of Lead in Drinking Water

Lead in drinking water is predominantly anthropogenic. Despite long-standing knowledge of its adverse health effects, lead was widely used in industrial products, including water distribution and plumbing systems, until recent decades. In India, legacy lead-containing infrastructure, combined with industrial emissions and waste disposal practices, continues to contribute to the contamination of drinking water sources in both urban and rural areas.

Some of the major sources of lead in drinking water in India are:

1. ***Corrosion of old pipes and plumbing systems:*** The most common sources of lead in drinking water are the corrosion of lead-containing pipes, solder, faucets, and plumbing fixtures (WHO, 2022) **(Figure 1)**. Lead enters drinking water when these materials deteriorate, and acidic or low-mineral-content water accelerates this process. Notable examples include elevated lead levels detected in residential water supplies in Hong Kong due to lead-containing solder and fittings, and the Flint water crisis in the United States, where corrosive source water increased lead leaching from ageing infrastructure (Chan et al., 2020; Ruckart et al., 2019). Similarly, in India, studies have shown that in cities like Patna, drinking water is a potent risk factor for elevated blood lead levels among children, with 21% of drinking water samples having lead levels ranging from 130 to 474 ppb attributable to either groundwater contamination or leaching of lead from lead pipes and fittings (Brown et al., 2022).

   It has been estimated that the USA may have between 6.1 and 10.2 million lead service pipes (Cornwell et al., 2016) and up to 9 million homes in the UK (Jarvis et al., 2018). Europe comprises 0-50% properties that may serve water through lead communication pipes. This proportion varies across different countries; for example, Denmark has largely removed all known pipes (Hayes et al., 2009). While this data is generally of poor quality and often relies on old information of unknown provenance, it gives a brief understanding that lead plumbing and fittings will be found in many places in old buildings (Jarvis et al., 2021). This information is rarely monitored or documented in Africa, Asia and South America. Nonetheless, lead exposure through drinking water is a known concern in many of these places.

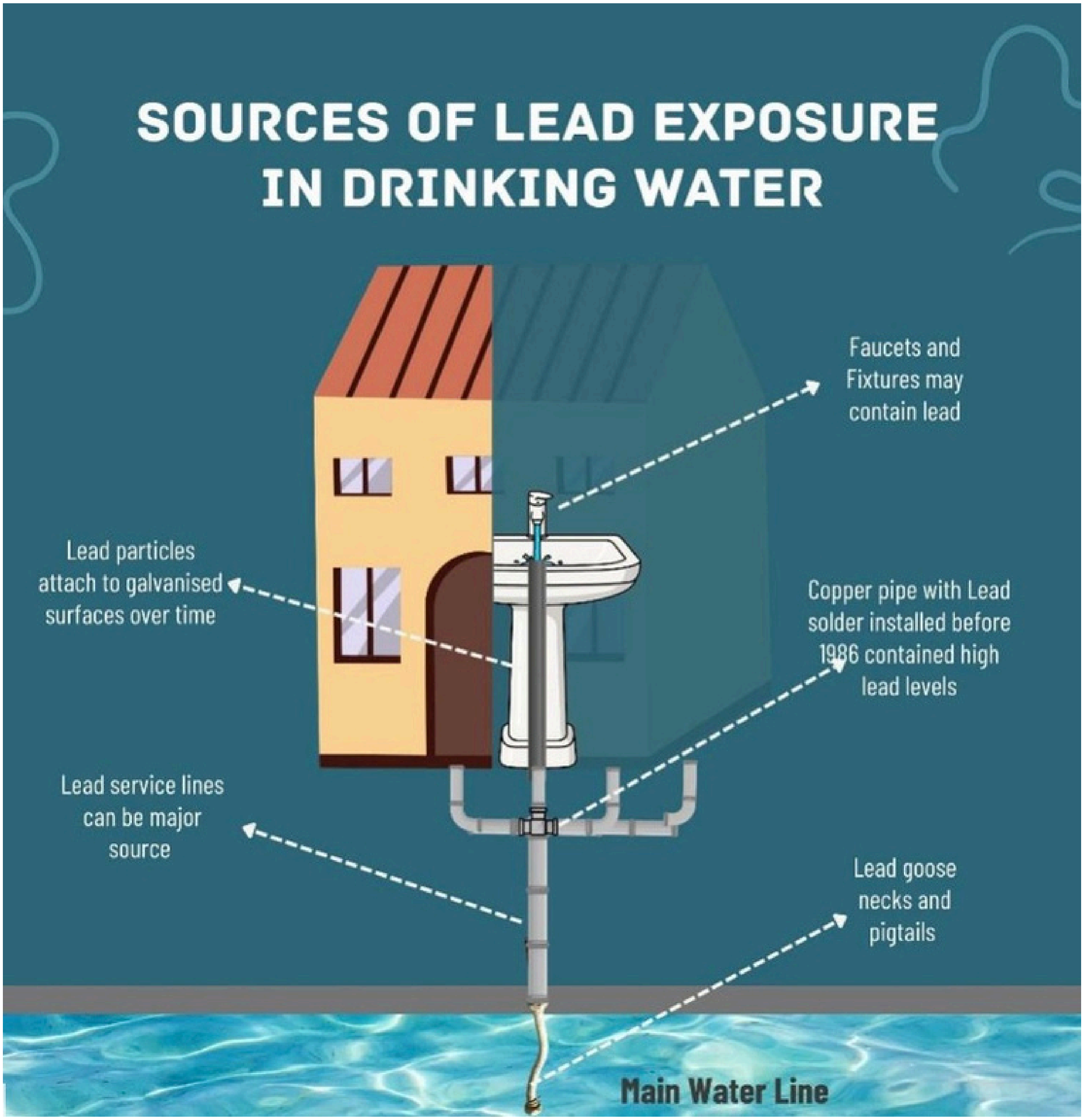

Figure 1: Sources of lead in drinking water (US EPA, 2026)

2. Industrial discharge and mining activities: Lead is typically not present in raw water sources or in water leaving drinking water treatment works (Roy et al., 2019), but localised contamination sources of water occur due to industrial activities like mining, smelting, and recycling, etc. In India, limited domestic lead mine output has increased reliance on lead recovery from used lead-acid batteries (LABs), much of which occurs through the informal sector, while informal e-waste recycling has further contributed to lead contamination of soil and water resources. Exposures from such sources are especially concerning for lower-income communities and have been associated with adverse health outcomes among residents living near industrial and high-traffic areas (Rakesh et al., 2022). The Toxics Link study on soils surrounding LAB (formal and informal) sites, in 2025, showed 52% of the soil samples contained lead concentrations of more than 5000 ppm. More than 30% of sites sampled surpassed the Central Pollution Control Board's (CPCB) permissible limits for industrial areas (600 ppm). Runoff or leaching from industries like the LAB into surface or groundwater could increase exposure. For example, a study in Chennai found that a mean blood lead level of 11.4±5.3 μg/dL among 756 children aged 3-7 years, near industrial areas and traffic zones, was associated with increased anxiety, social problems, and poorer executive function (Roy et al., 2009). Aside from industrial discharge, paint is another important source of exposure. Recent studies suggest 90% of paints sampled contained lead levels exceeding 90 ppm, with 76% having extremely high concentrations of 10,000 ppm or more (Toxics Link, 2023).

A cross-sectional study assessed blood lead levels in 2,247 school children across 10 Indian cities. The overall median blood lead level was 88 μg/L, and 82.5% of participants had levels exceeding 40 μg/L. Regional variations were significant, ranging from a median of 306 μg/L in Manipal to 48 μg/L in Dibrugarh. (Kumar et al., 2023)

3. ***Lead use in household PVC pipes:*** Access to safe and durable plumbing infrastructure is often limited by cost, leading many households to rely on low-cost and substandard materials for water distribution and storage. Pipes, fittings, solder, taps, and storage tanks used in these areas may contain lead or other hazardous metals due to poor manufacturing standards and the absence of regulatory oversight. Here, PVC plumbing pipes with lead as stabilisers could be installed by private builders and contractors with zero or minimal awareness of the hazard of lead poisoning.

The unorganised sector for PVC pipes comprises 35-40% of India's total pipe volume and is distributed through unbranded and small-scale producers. These products are typically sold at lower prices, creating competitive pressure on organised manufacturers in smaller tier-3 and tier-4 markets. Compliance with CPCB and BIS standards within this segment remains a concern (IMARC, 2025). In 2017, India's environmental apex court, the National Green Tribunal, acknowledged the potential adverse health effects of lead present in water flowing through PVC pipes, citing a study conducted by the Quality Council of India (QCI), which saw 33% of over 370 samples of water from the top 26 cities of India testing positive for harmful lead content. 31% of these samples failed the WHO standard of lead content (10 ppb), while 2% failed the Indian standards (50 ppb). They further underscored the severity of the situation by highlighting incidents of high lead concentrations in water, where 41% of groundwater samples and 15% of municipal samples tested were deemed unfit for consumption (Jan Sahyog Manch vs. Union of India & Ors., 2018). The tribunal later implicated the Ministry of Environment, Forest and Climate Change to set standards for the use of lead in PVC pipes (Singh et al., 2018).

The Lead Stabiliser in Polyvinyl Chloride (PVC) Pipes and Fittings Rules of 2021 were introduced, which restricted lead content to 1 ppm (MoEF&CC, 2021). However, the effectiveness of implementation and enforcement remains unclear, especially in the unorganised sector.

3. Environmental and Health Impacts

3.1 Toxicological Profile and Mechanisms of Toxicity

Lead (Pb) is a persistent, bioaccumulative toxic metal with no known biological function and no established safe level of human exposure. As a systemic toxicant, lead can adversely affect multiple organ systems even at relatively low exposure levels **(Figure 2)**. Human exposure occurs primarily through the ingestion of contaminated food and water and the inhalation of contaminated air and dust. Once absorbed, lead enters the bloodstream and is distributed throughout the body (Wani et al., 2015; WHO, 2024).

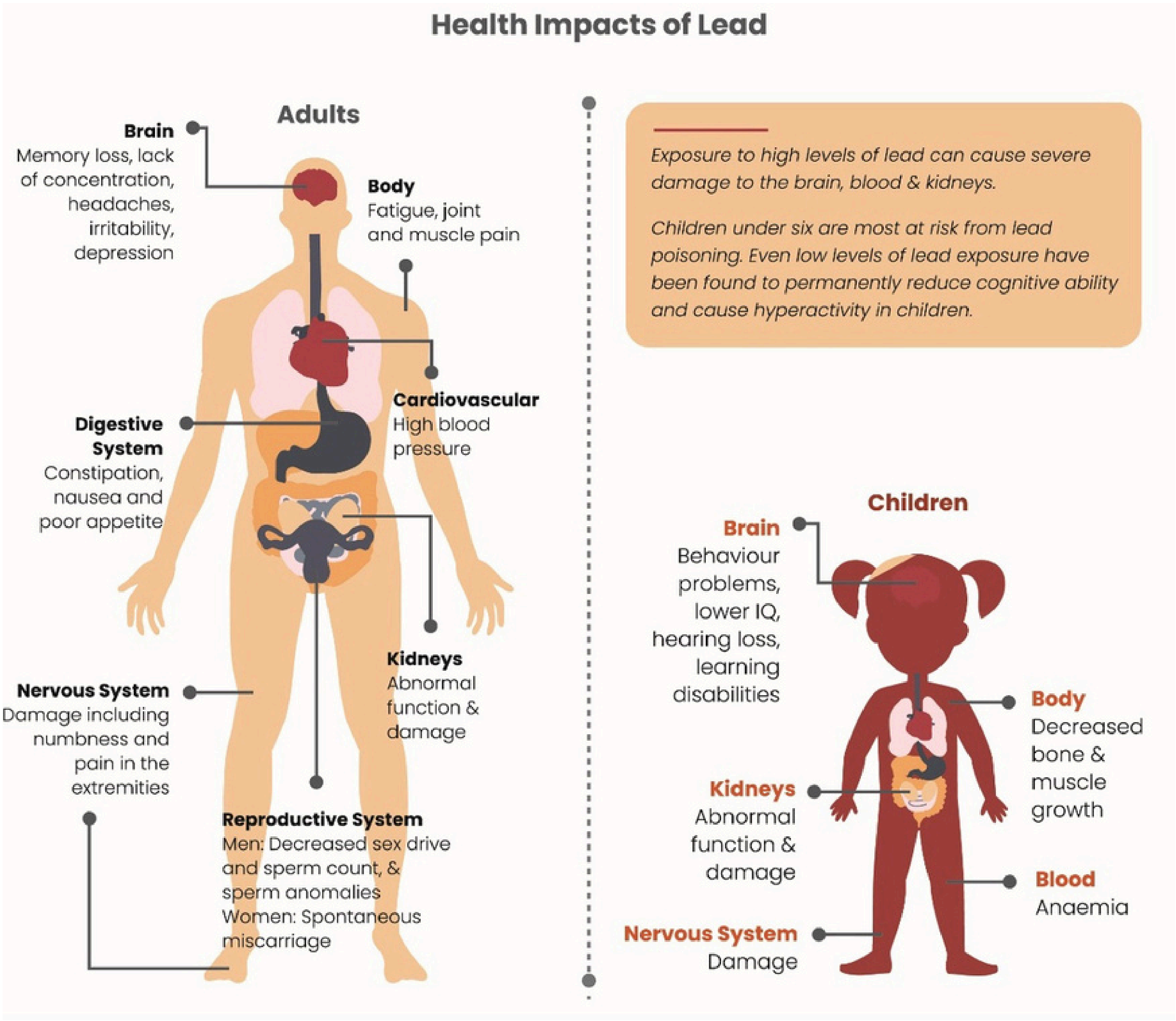

Figure 2: Effects of lead poisoning on multiorgan systems (Toxics Link, 2025)

At the cellular level, lead exerts toxicity by mimicking essential metals such as calcium, zinc, and iron. This disrupts critical physiological processes, including cell signalling, neurotransmitter release, enzymatic activity, gene expression, and DNA repair mechanisms. Lead exposure also induces oxidative stress and inflammation, resulting in cellular dysfunction and tissue damage. These mechanisms collectively underpin the wide range of health effects associated with lead exposure (Kim & Lee, 2015; Khan et al., 2020).

3.2 Biological Persistence and Bioaccumulation

3.2.1 Biological Persistence: Compartmental Distribution and Half-Life

Lead's most dangerous property from a public health standpoint is its extraordinary biological persistence. Once absorbed, it distributes across three principal compartments: blood, soft tissues, and the skeleton. Mineralising tissues, bones and teeth typically contain most of the lead body burden. The body accumulates lead over a lifetime and normally releases it very slowly. Adults typically absorb up to 20% of ingested inorganic lead after a meal and up to 60-80% on an empty stomach. Children absorb about 50% of ingested lead after a meal and up to 100% on an empty stomach (Sanders et al., 2009).

The compartmental half-lives of lead explain why past exposures continue to pose risks long after the original source is removed. The half-life of lead in erythrocytes is approximately 35 days; in soft tissues such as kidney, liver, and nervous tissue, the half-life is approximately 40 days; the half-life in bone is 20 to 30 years. This skeletal reservoir constitutes the dominant long-term burden: bones are the major reservoir of body lead, accounting for 75% in children and 90% in adults. Bone lead is a marker of past exposure with a half-life of approximately 20 to 30 years and increases with age (Babu et al., 2024; Todd, 1991).

The mobilisation of bone-stored lead during physiologically stressful states creates additional exposure vectors that extend health impacts across generations. Lead in adult bone can serve to maintain blood lead levels long after exposure has ended. It can also serve as a source of lead transfer to the foetus when maternal bone is resorbed to produce the foetal skeleton. In times of stress particularly pregnancy and lactation, the body can mobilise lead stores, thereby increasing the level of lead in the blood. (ATSDR, n.d.; CDC, 2024).

From an occupational exposure standpoint, the skeletal half-life governs the rate at which workers' blood lead levels normalise after cessation of exposure. After occupational exposure, the slow decline in blood lead, with a half-life of 5 to 19-years, reflects the long skeletal half-life. Repeated measurements of bone lead demonstrate the slow elimination of lead from bone. For compact bone, the bulk turnover rates are approximately 2% per year. While for the spine, they are about 8% . (WHO, n.d.).

3.2.2 Bioaccumulation and Trophic Transfer in Ecosystems

Lead is a non-biodegradable contaminant that persists in environmental systems and can accumulate throughout food webs. (Khan et al., 2020). In terrestrial ecosystems, the soil-to-plant pathway represents the primary route of transfer. Lead uptake by plants generally increases with soil concentration, although accumulation varies considerably among species because of differences in tolerance and uptake mechanisms. It transfers from soil to plants and further through food chains, increasing human exposure risk (Gorgees et al., 2019; Jankie et al., 2023). Experimental studies have demonstrated the transfer of lead from soil to plants and subsequently to higher trophic levels, including insects, birds, reptiles, and mammals. While accumulation patterns vary among ecosystems, lead has the potential to biomagnify in certain food chains, increasing risks to wildlife and humans who consume contaminated plants or animals (Khan et al., 2020).

Despite growing research on aquatic food webs, terrestrial pathways remain comparatively understudied. Given the importance of terrestrial food systems in global nutrition, improved understanding of lead transfer through soil-plant-animal pathways is essential for assessing long-term ecological and human health risks (Khan et al., 2020).

3.3 Environmental Contamination of Soil and Groundwater

3.3.1 Sources and Pathways of Soil Contamination

Lead contamination of terrestrial environments arises from a diverse range of anthropogenic activities that have accelerated since the onset of industrialisation. Major sources include mining, smelting, manufacturing, recycling activities, and the widespread use of lead-containing products. Review-level analyses of global soil and surface water data confirm the widespread and persistent occurrence of lead pollution. A review of 118 studies on surface water bodies and 133 studies on soils published between 2015 and 2024 found that lead concentrations frequently exceeded permissible limits, with Bangladesh, India, Pakistan, and China showing high vulnerability in both surface water and soil. The mean lead concentration in rice grains consistently surpassed the Codex Alimentarius limit across the analysed years (Babu et al., 2024; Sharma et al., 2025).

Industrial mining and smelting sites represent major hotspots of lead pollution. Heavy metal pollution has become a significant global concern, with concentrations in soils, groundwater, and mine tailings often exhibiting strong positive correlations, highlighting common sources and transport pathways, reported among the highest levels of soil contamination globally (Khan et al., 2020).

A systematic review of Indian water sources reveals significant lead contamination, particularly in industrial areas compared to municipal sites. Extremely high lead concentrations were recorded in locations like Hyderabad and Singrauli. Contamination levels fluctuate seasonally, highlighting the critical need for continuous, targeted water quality monitoring (Janaika, 2025).

3.4 Impacts on Human Health

3.4.1 Neurological Effects

The nervous system is the principal target of lead toxicity across all age groups. The main mechanism involves the substitution of lead for calcium ions, enabling it to cross the blood-brain barrier and accumulate in astroglia cells, thereby disrupting myelin formation, neurotransmitter activity and neuronal signalling (Wani et al., 2015; Kim & Lee, 2015). Exposure affects both the central and peripheral nervous systems, with children being more vulnerable because of their developing brains. Severe exposure may result in encephalopathy, while milder cases may cause headaches, irritability, tremors, and memory loss (Wani et al., 2015).

Lead poisoning affects around one in three children globally on a massive and previously unrecognised scale. Lead poisoning is a major contributor to intellectual disability among children in low- and middle-income countries. As a result, vast economic and social potential is being lost from the widespread cognitive decline and the long-term health effects caused by lead poisoning (UNICEF, 2020).

At the molecular level, lead interferes with calcium-mediated cellular functions and disrupts intracellular biological processes, contributing to neurological disorders, including cognitive impairment and behavioural abnormalities (Kim & Lee, 2015). Neuroinflammation is a key pathway in lead toxicity. Microgliosis and astrogliosis trigger inflammatory cascades that affect hippocampal function and contribute to behavioural and cardiovascular outcomes (Conterato et al., 2023).

3.4.2 Cardiovascular Effects

Cardiovascular disease represents a major component of lead-attributable mortality. (IHME, 2024). Cumulative exposure, reflected in bone lead levels, is strongly associated with increased cardiovascular mortality risk (Lustberg & Silbergeld, 2002). Lead affects cardiac function through oxidative stress, calcium signalling disruption, and interference with vascular regulation (Kim & Lee, 2015).

3.4.3 Renal and Other Systemic Effects

Chronic lead exposure contributes to progressive renal impairment and contributes to hypertension, reduced fertility, neurological disorders, and musculoskeletal pain (Wani et al., 2015). At the cellular level, lead induces oxidative stress, disrupts enzyme activity, and interferes with DNA repair mechanisms, affecting multiple organ systems (Khan et al., 2020).

4. International Case Study (Flint, Michigan, USA)

The Flint water crisis was a major public health emergency in which the drinking water supply of the city of Flint (Michigan, USA) became contaminated with toxic lead metal. Historically, for over a century, the Flint River was heavily polluted by industrial waste, sewage, and runoff, while the city itself declined economically after the collapse of its once-thriving auto industry led by General Motors. By 2011, amid severe financial distress and state control, cost-cutting decisions led to switching the city's water source (NRDC, 2025).

In April 2014, Flint changed its municipal water supply from treated water sourced through the city of Detroit originating from Lake Huron to the local Flint River. This cost-driven decision was made without an adequate corrosion control or treatment plan, causing the city's old pipes to corrode and leach lead and other pollutants into the municipal drinking water system **(Figure 3).**

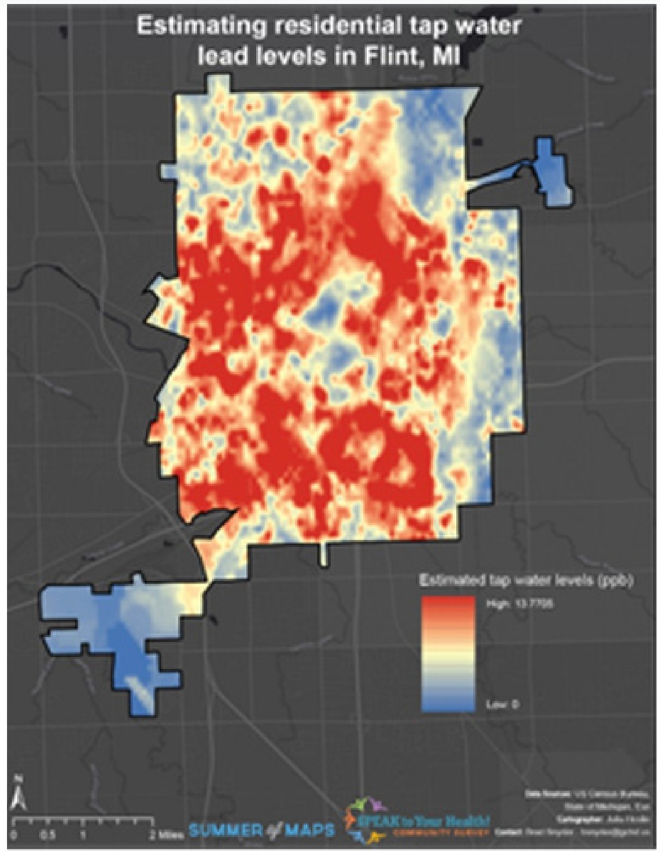

Figure 3: Map showing residential tap water lead levels in Flint, MI *(Adopted from Element 84, 2017)*

As a result, thousands of residents, including young children, were exposed to unsafe levels of lead, causing long-term health risks like developmental delays and neurological damage. This incident was coupled with delays in regulatory response, inadequate monitoring, and initial dismissal of community concerns by authorities. Thereafter, the city reconnected back to the original Detroit water system, but the damage was already done, and a state of emergency was declared on January 16, 2016. The city residents were advised not to drink municipal tap water unless filtered (through an NSF International-approved filter certified to remove lead) (CDC, 2024).

Study Finding

Impacts on physical health and safety: : Lead exposure through drinking water sources in Flint escalated into a major public health emergency with several health and safety implications. Elevated blood lead levels were recorded in children, in addition to increasing risks of developmental delays, reduced cognitive function, and long-term neurological damage. Residents reported discoloured, foul-smelling water, alongside increased safety concerns. Despite direct evidence, the initial response from the local government was delayed, and community complaints were dismissed by authorities.

Impacts on behavioural health: Beyond physical health, the crisis had psychosocial consequences. A rapid community assessment (CASPER) conducted in May 2016 (Michigan Department of Health, 2016) by agencies including the Centers for Disease Control and Prevention (CDC) and the Michigan Department of Health and Human Services revealed (CDC, 2024) the following:

- 66% of households reported at least one adult experiencing behavioural health issues "more than usual".
- 54% of households reported similar concerns among children.
- 34% of individuals reported symptoms of anxiety.
- 29% reported depression.
- 51% of households perceived a decline in physical health due to the crisis.

These findings show how environmental disasters can increase stress and cause long-term mental health challenges, particularly among vulnerable communities.

Gaps in disaster response: The Flint crisis exposed systemic gaps in water governance. Inadequate monitoring and regulatory oversight allowed lead contamination to persist in an undetected manner. The failure to implement corrosion control violated several water safety protocols. Delayed acknowledgement of risks and dismissal of citizen concerns impacted the public. Fragmented coordination across agencies hindered timely intervention.

Policy response

The sustained advocacy of Flint residents with all the media attention led to significant policy action. At the federal level, the Water Infrastructure Improvements for the Nation Act of 2016 (WIIN Act) was enacted to support recovery and strengthen drinking water infrastructure systems. Under this Act, the Lead Testing in School and Child Care Program Drinking Water grant was established in 2016 to fund states, territories, and tribes in conducting voluntary testing for lead contamination in drinking water for schools and childcare facilities. Building on this, the Infrastructure Investment and Jobs Act, 2021, expanded the scope of the program, renaming it the Voluntary School and Child Care Lead Testing and Reduction Grant Program, and allowed funding for lead remediation in addition to testing.

Additional policy and programmatic measures included the following (Ruckart et al., 2019):

- The WIIN Act also established the Lead Exposure and Prevention Advisory Committee (LEPAC) under the Federal Advisory Committee Act (1972). LEPAC was mandated to:
  - Review federal programs addressing lead exposure
  - Identify gaps in research on lead poisoning

- Recommend best practices for screening and prevention
    - Identify effective services for affected individuals and communities
- Michigan enhanced its Childhood Lead Poisoning Prevention Program (CLPPP) to expand surveillance, outreach, and health services aimed at preventing childhood lead poisoning across the state.
- A voluntary Flint Lead Exposure Registry was created to:
    - Identify and enroll affected individuals
    - Monitor health outcomes, child development, and ongoing exposure
    - Track service utilization and improve service delivery
- Increased federal and state support for improved environmental health infrastructure upgrades and enhanced monitoring activities
- Targeted behavioural health programs and improved risk communication strategies.

Key lessons learnt

The Flint crisis highlights several critical lessons:

- Even short-term changes in water source or chemical composition can destabilise infrastructure and mobilise toxic metals like lead; hence, corrosion control systems are imperative.
- Continuous and transparent water quality monitoring is critical to detect contamination early and respond effectively.
- Ageing pipelines significantly increase public health risk, particularly in the absence of preventive treatment and maintenance plans.
- Timely communication, public trust, and responsiveness to community concerns are central to preventing escalation.
- Environmental crises require integrated responses addressing both physical and mental health impacts.

For developing countries like India, where ageing infrastructure, interrupted water supply, and varied/emerging water pollutants are common, the Flint crisis serves as a precautionary example. It highlights the urgent need for proactive risk assessment and corrosion control measures, strengthened regulatory enforcement and compliance monitoring, as well as community engagement and transparent communication frameworks.

5. National Case Studies (Bihar and Tamil Nadu)

Lead poisoning is a major global public health concern, with an estimated 800 million children affected worldwide (UNICEF, 2020). In India, several states like Andhra Pradesh, Uttar Pradesh, Jharkhand, Madhya Pradesh, and Chhattisgarh have reported elevated levels of lead exposure (Chayal et al., 2025). This section discusses two such national case studies.

5.1 National Case Study 1: Lead exposure pathways and health risks among children in Bihar

This case study from Bihar provides important insights into how environmental and household factors contribute to lead exposure, particularly among children. A field-based study was conducted across six districts of Bihar – Patna, Vaishali, Saran, Nalanda, Buxar, and Bhojpur – to assess lead exposure levels in vulnerable populations (Chayal, 2025). The study covered 282 lactating mothers and their breastfed infants, marking one of the first systematic assessments of lead contamination in this region.

Study findings

Extent of Exposure: The findings revealed widespread lead exposure among the study population with biological accumulation of lead in both mothers and children **(Figure 4)**, raising serious public health concerns. In 2021, WHO's Guideline for clinical management of exposure to lead advised that when blood lead levels are ⩾5 µg/dL, the source of exposure must be identified and steps taken to stop that exposure.:

- 94% of lactating mothers' blood samples contained lead levels exceeding the WHO threshold.
- 90% of maternal urine samples also exceeded the threshold.
- Among infants, 41% of urine samples showed lead concentrations above safe limits.

Environmental Pathways: Household water sources, like handpumps, were tested. Only 6% of water samples exceeded the WHO guideline limits (10 µg/L for lead), suggesting that drinking water was not the primary source. Instead, the study pointed to multiple environmental and behavioural pathways, including:

- Consumption of lead-contaminated food items like vegetables, animal milk, and meat
- Use of adulterated turmeric and other locally sourced spices
- Intake of traditional Ayurvedic medicines, probably containing heavy metals
- Application of cosmetic products, particularly skin-lightening creams known to contain lead

These findings highlight the complexity of exposure routes, where environmental contamination intersects with dietary, cultural and other everyday practices.

Health Implications for Children: Chronic exposure to lead was associated with non-carcinogenic health risks, with Hazard Quotient (HQ) values exceeding 1 in both mothers and children, indicating a high likelihood of adverse health effects. Infants exposed through breastfeeding are vulnerable, with increased risks of neurological and cognitive impairments, developmental delays and long-term behavioural and learning difficulties. This case study highlighted that while water contamination plays a limited role, overall environmental exposure was multifaceted. The high prevalence of elevated lead levels in biological samples calls for urgent interventions such as the following:

- Strengthening monitoring and regulation of food products, especially spices and dairy
- Screening and regulating traditional medicines and cosmetic products
- Expanding public health surveillance for lead exposure
- Organize community awareness campaigns on hidden sources of lead
- Conduct targeted interventions for vulnerable groups (pregnant and lactating women)

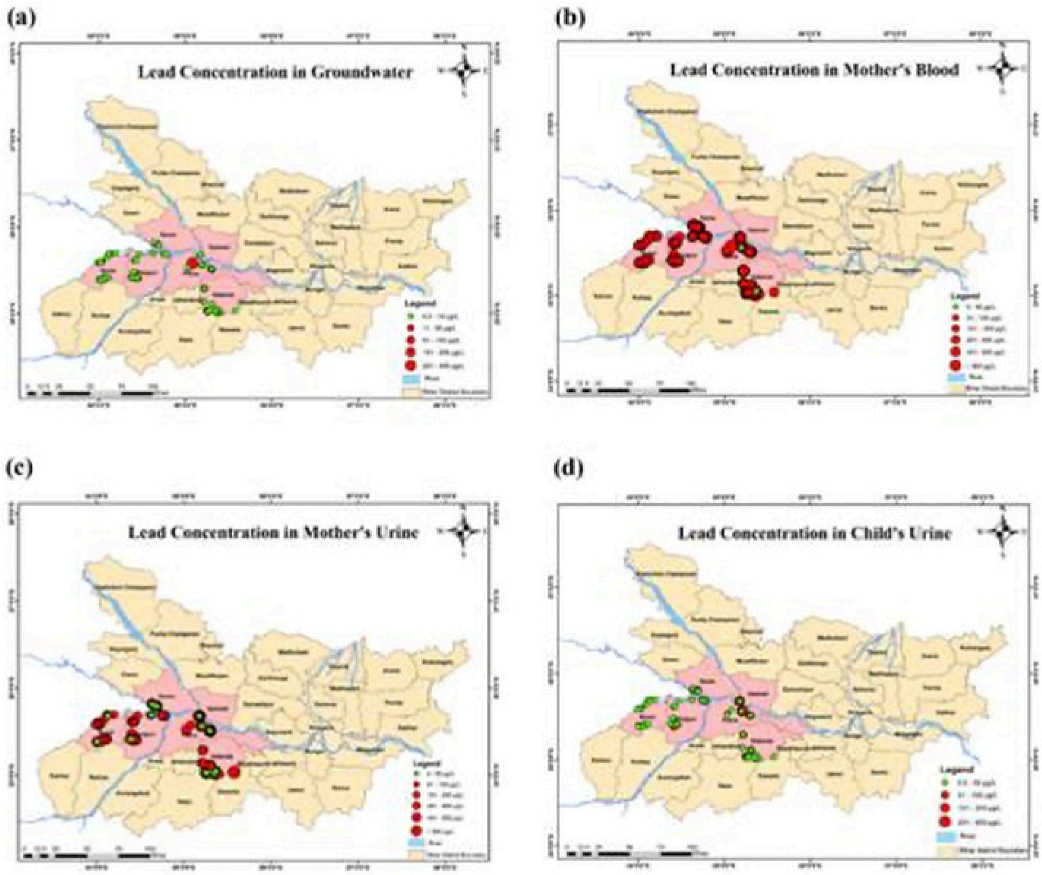

Figure 4: Lead exposure in Bihar, Eastern India *(source: Chayal, 2025)*

5.2 National Case Study 2: Urban lead exposure in Chennai, Tamil Nadu

Rapid urbanisation and industrial expansion in Chennai, Tamil Nadu, have created complex environmental health challenges, including persistent exposure to toxic heavy metals such as lead (Babu et al., 2024). Despite the global phase-out of major sources like leaded gasoline, urban populations still face significant risks from multiple exposure pathways. This case study draws on a human biomonitoring study conducted among urban residents in Chennai to examine the prevalence, sources, and implications of elevated blood lead levels (BLLs).

Study Design and Population

A cross-sectional study assessed 300 healthy adults (aged 18-60 years) in Chennai wherein blood samples were analysed using advanced laboratory techniques (ICP-MS), and detailed questionnaires captured information on socio-economic conditions and potential exposure pathways. The study mostly focuses on adults, but it affects children, who are biologically more vulnerable.

Key Findings: Widespread Elevated BLLs

Lead exposure was found to be not isolated but pervasive across the urban population, even among individuals without known occupational exposure.

- The mean blood lead level was 5.3 μg/dL, exceeding current global reference thresholds.
- 49% of participants had BLLs above 5 μg/dL, indicating widespread exposure.
- A subset (2.7%) had levels exceeding 10 μg/dL, associated with more severe health risks.

The study highlighted that elevated BLLs were driven by a combination of environmental and household-level factors, such as the following, that accounted for 76% of the variation in BLLs:

1. *Industrial Proximity:* Residents living near industrial zones (automobile, electronics, and chemical industries) showed significantly higher BLLs. Industrial emissions and contaminated dust contributed to chronic exposure.
2. *Housing and built environment:* Use of lead-based paints in homes was a key cause of elevated BLLs. Ageing infrastructure and poor housing conditions increase risk, especially for children exposed to peeling paint or dust.
3. *Household practices and consumer products:* Use of metal cookware and storage vessels (including alloys that may leach lead) contributed to exposure. Traditional cosmetics and herbal medicines were identified as potential sources.
4. *Socio-economic and demographic factors:* Socio-economic status, age, and gender influenced exposure levels.

Lessons Learnt

The study demonstrates that urban lead exposure is diffuse, cumulative, and insufficiently monitored. Elevated BLLs across nearly half the population indicate a systemic issue rather than isolated contamination events. Key policy recommendations include the following:

1. Establishing routine blood lead surveillance systems, especially for children
2. Regulating lead in paints, consumer goods, and traditional products
3. Strengthening environmental controls in industrial clusters
4. Promoting safer housing and public education and awareness campaigns
5. Integrating lead exposure into urban health and environmental planning

6. Regulatory Framework

6.1 Indian regulations

India has established several regulatory mechanisms to protect public health from lead exposure arising from consumer products, industrial activities, and environmental contamination. However, unlike some developed countries that have adopted comprehensive lead poisoning prevention programmes, India's regulatory approach remains fragmented, with separate regulations governing drinking water quality, consumer products, industrial emissions, paints, toys, food contact materials, and plumbing infrastructure. Consequently, sector-specific interventions address lead exposure pathways rather than a unified national lead management framework.

Lead contamination of drinking water is particularly challenging because it can originate from both environmental sources (such as industrial discharges, mining, battery recycling, and waste disposal) and infrastructure-related sources (such as plumbing materials, fittings, and storage systems). Therefore, regulations governing lead in drinking water encompass both upstream controls aimed at preventing environmental contamination and downstream measures focused on ensuring the quality of water delivered to consumers.

IS 10500:2012 – Drinking Water Specification: The quality and safety parameters for drinking water in India are ensured by the Bureau of Indian Standards (BIS) under IS 10500:2012. It provides limits for various physical, chemical and microbiological parameters to ensure the water supplied for human consumption is safe, palatable and wholesome. This standard specifies acceptable and permissible limits in the absence of an alternative source and adheres to the WHO Guidelines for Drinking Water Quality, 2018. According to the guidelines, Lead must not exceed 10 μg/L in drinking water, and there is no permissible relaxation, even if no other water source is available .

Lead Stabiliser in Polyvinyl Chloride (PVC) Pipes and Fittings Rules, 2021: The rule was notified in November 2019 under section 3 and section 6 of the Environment (Protection) Act, 1986. It became effective in May 2021. It bans the use of lead or lead compounds as stabilisers in the manufacture, sale, and import of PVC pipes and fittings. The rule also specified the lead extraction limit for all types of PVC pipes and fittings. It should not be more than 1 ppm during the first extraction and 0.005 ppm in the third extraction.

The State Pollution Control Board (SPCB) and Pollution Control Committee (PCC) are the nodal agencies for the implementation and enforcement of the provisions of these rules (MoEF&CC, 2021).

6.2 Global Regulations

Given the severity and persistence of the issue of lead in drinking water, many countries around the world, like India, have introduced comprehensive policies and guidelines. Some of these policies and guidelines are in Table 1:

Table 1: Global regulations policies and guidelines

Authorities	**Limit/ Regulation**	**Reference**
WHO	10 µg/L	WHO, 2022
USEPA	In 1974, the Safe Drinking Water Act (SDWA) was established to protect the quality of all water sources designated for drinking. The 1986 amendment prohibited the use of leaded plumbing components, requiring all plumbing to be "lead-free". Currently, "lead -free" is defined as a weighted average of 0.25% lead across the wetted surfaces of a pipe, pipe fitting, plumbing fitting, and fixture, and 0.2% lead for solder and flux. In line with the SDWA framework, the US EPA set the Maximum Contaminant Level Goal (MCLG) for lead at zero, acknowledging that there is no safe level of lead exposure. In 1991, the Lead and Coper Rule (introduced by the EPA) set an action level of 15 ppb for lead concentrations. If exceeded in more than 10% of sampled homes, it prompted mandatory treatment and remediation measures. This has been further compounded by a "trigger level" at 10 ppb, which came into effect in 2024. Exceedance of this level prompts the replacement of 3% lead service line annually until the system measures below 15 ppb for four consecutive monitoring periods.	US EPA, 2020 US EPA, 2025 US EPA, 2026

Authorities	Limit/ Regulation	Reference
European Union (EU)	The limit is currently 10 µg/L, with the aim of reducing the parametric value to 5 µg/L by 2035 REACH regulation (EC) No 1907/2006 restricts lead in PVC products, including pipes, to a maximum of 0.1% by weight	Water Directive (EU) 2020/2184, 2020 European Commission, 2003
Canada	Maximum Acceptable Concentration of 5 µg/L The National Plumbing Code of Canada banned lead pipes for new installations in 1975 and prohibited lead solder in 1986.	Health Canada, 2019 Health Canada, 2016
China	The national standard lead in drinking water, as specified in GB 5749-2022, is 10 µg/L	National Standard of the People's Republic of China, 2022

7. Testing Methods

Laboratory-based analytical techniques are considered the most reliable approaches for the detection and quantification of lead (Pb) due to their high sensitivity and precision.

7.1 Lab-Based Testing Methods

7.1.1 Atomic Absorption Spectroscopy (AAS)

Atomic Absorption Spectroscopy has been one of the most widely employed methods for lead quantification since the mid-twentieth century. It measures the absorption of light by free atoms in a sample and is available in two primary forms: flame AAS and graphite furnace AAS (GFAAS). Among these, GFAAS provides superior sensitivity, with detection limits in the low- to sub-ppb range, making it particularly suitable for biological samples such as blood and urine. Consequently, GFAAS has been widely used for trace-level lead analysis in environmental and biological matrices (ATSDR, n.d.; Skoog et al., 2014).

7.1.2 Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

Inductively Coupled Plasma Mass Spectrometry (ICP-MS) is widely regarded as the gold standard for trace-level lead analysis because of its exceptional sensitivity and precision. The technique atomises samples in a high-temperature plasma and separates ions according to their mass-to-charge ratio, enabling the detection of lead at extremely low concentrations. Comparative studies have demonstrated that ICP-MS generally performs better than GFAAS for blood lead determinations. In drinking water analysis, lead detection commonly follows EPA Method 200.8 (ICP-MS) or EPA Method 200.9 (Graphite Furnace AAS). The technique is also extensively used for monitoring lead contamination in food, biological samples, and environmental matrices (Kim & Lee, 2015; EPA, 1994, 2007; Khan et al., 2020).

7.2 Field-Based Testing Methods

7.2.1 Colorimetric Field Kits

Portable colorimetric kits such as LeadCheck™ and D-Lead® provide convenient screening tools for on-site lead detection. Although useful for rapid assessments, their accuracy is lower than laboratory-based techniques, and they may fail to detect lead beneath multiple paint layers or at very low concentrations. Consequently, positive or inconclusive results should be confirmed using laboratory methods or portable XRF analysis. Because of the potential for false results, these kits are generally unsuitable as standalone methods for regulatory compliance or occupational exposure assessments (EPA, 2020; OSHA, 2008).

7.2.2 Portable X-Ray Fluorescence (XRF) Analyzers

Portable X-ray fluorescence (XRF) analysers bridge the gap between rapid field screening and laboratory analysis by providing non-destructive, real-time measurements with greater accuracy than colorimetric kits. EPA, NIOSH, and OSHA have recognised their value in high-volume environmental and occupational screening applications. However, factors such as surface condition, sample thickness, and material homogeneity can influence analytical performance. Therefore, laboratory methods such as ICP-MS or AAS remain necessary when definitive measurements or regulatory compliance are required (EPA, 2007; NIOSH, 2003; OSHA, 2008).

7.3 Biomonitoring and the Importance of Regular Surveillance

Biomonitoring, particularly through blood lead level (BLL) testing, is central to lead exposure surveillance. Serial measurements provide a more reliable assessment of long-term exposure than a single test. Because no safe blood lead level has been established, the CDC recommends confirmatory venous testing following elevated capillary screening results and continued follow-up monitoring when required. Similarly, WHO recommends identifying and eliminating exposure sources when blood lead concentrations exceed 50 µg/L (CDC, 2024; WHO, 2021).

Laboratory methods such as ICP-MS and GFAAS remain the preferred techniques for accurate lead quantification, while field kits and portable XRF analysers serve as valuable screening tools. Together, these approaches support effective environmental monitoring, biomonitoring, and public health protection (WHO, 2024; CDC, 2024)

8. Challenges

Ageing infrastructure and old piping systems: India's urban water distribution infrastructure reportedly comprises ageing pipelines, containing legacy materials like lead-based pipes, solder, and plumbing fixtures. The *CPHEEO Manual on Water Supply and Treatment* by the Ministry of Housing and Urban Affairs notes that in older parts of Indian cities, even where metallic pipes are used, pipe joints often weaken over time due to ageing and deteriorated jointing systems (CPHEEO, 2023). In many urban and peri-urban areas, older infrastructure integrates with newer water supply (pipeline) networks, which leads to corrosion and leakage. Also, intermittent water supply is common across Indian cities, which results in contamination of water in the pipeline during non-supply hours. Frequent fluctuations in water pressure can accelerate pipe corrosion and dislodge contaminants like lead into the drinking water supply. In addition, household-level plumbing components (like taps, storage tanks, fittings, and connectors) may also contribute to lead contamination, particularly where manufacturing quality standards and regulatory oversight are inconsistent.

Weak regulatory enforcement: India does not have a dedicated policy for lead pollution control but does it through a combination of environmental, public health, product safety, and drinking water regulations. The Bureau of Indian Standards (BIS Standards) prescribes permissible limits for lead in drinking water, paints, food products, toys and consumer goods, and plumbing materials. For drinking water, BIS Standard IS 10500 sets the acceptable lead limit at 10 μg/L. Despite these regulations, regulatory oversight is often fragmented, leading to gaps in accountability and coordination:

- Compliance monitoring is often irregular and inadequately enforced, allowing unregulated lead exposure.
- Drinking water can become contaminated through aging urban water infrastructure with legacy lead plumbing
- Penalties for violations or non-compliance are either limited or inconsistently applied.
- Informal water providers (tankers and private borewells) operate outside formal regulatory frameworks.
- Lack of mandatory corrosion control protocols in distribution systems and limited enforcement of product standards (for plumbing materials, paints, and fixtures) allow potential sources of lead to persist in the environment.

Low public awareness: A key gap in addressing lead contamination in India is the low level of public awareness on exposure pathways, associated health risks, and preventive measures. (IHAT, 2026). Many households are often unaware of the following:

- Lead exposure can occur even when water appears clean and odorless
- Plumbing materials, storage practices, and water-handling practices can influence contamination levels

- Chronic low-level exposure poses serious risks, especially for children and pregnant women

There is also an absence of community awareness of public health risks of lead contamination and a lack of knowledge on managing contaminated water systems through avoidance, filtration, treatment, or rehabilitation measures. This knowledge gap reduces public demand for water quality testing and delays in the adoption of behavioural practices such as the use of certified filters or replacement of unsafe materials.

Insufficient monitoring data: Another major challenge is the lack of reliable and consistent monitoring systems and datasets for lead exposure to drinking water and associated environmental pathways. Existing monitoring frameworks focus on source water quality and not so much on distribution networks, where lead contamination occurs the most. It is further constrained by inadequate testing of household tap water and plumbing systems and limited biomonitoring and health surveillance data. The absence of such critical datasets limits the ability to identify exposure hotspots, detect emerging areas, and support evidence-based policymaking.

9. Mitigation Strategies

Water is a state subject in India; therefore, the primary responsibility for adopting mitigation strategies and ensuring the provision of safe, lead-free drinking water rests with the state governments. However, the Central Government has an important role in establishing national policies, standards and support mechanisms to protect citizens from lead exposure through drinking water. State-specific interventions tailored to local conditions and needs can complement these national efforts. Some key measures for ensuring safe drinking water, identification, and reporting are mentioned below:

Replacement of legacy lead-containing infrastructure

Identification, mapping and systematic replacement of lead-containing components in drinking water systems where lead has accumulated over time and replacing them with low-lead or lead-free alternatives is an effective and permanent solution to lead in drinking water. In 1997, Frankfurt, Germany, launched an ambitious programme to eliminate lead from its drinking water infrastructure. At the time, the city comprised 8000 properties with lead drinking-water installations. The goal was eventually reached in 2010 after the property owners covered the costs of pipe replacement. The project was estimated to cost the city about €400,000 (WHO, 2022).

However, comprehensive mapping and replacement can be both costly and logistically challenging, especially for developing countries such as India, with limited budget allocations and densely populated settlements and informal housing areas with undocumented and inaccessible pipelines. Therefore, a risk-based and phased approach to mapping and replacement should be adopted, prioritising vulnerable areas including older urban neighbourhoods, schools, healthcare facilities, childcare centres, and low-income settlements.

Any "Lead-free" alternatives used for replacement must be suitable for drinking-water use, with lead concentrations within prescribed regulatory limits. If the parts are made of PVC, they must adhere to the Lead Stabiliser in Polyvinyl Chloride (PVC) Pipes and Fittings Rules of 2021. Corrosion-resistant materials and low-lead plumbing parts should be installed in areas where the water is naturally corrosive. Additionally, if service lines are to be replaced, the remaining lead lines should not be connected to other galvanic metals, as galvanic interactions may accelerate corrosion and increase lead release (WHO, 2022).

Promotion and mandatory use of lead-free materials

Several countries of the world, especially North America and Europe, have adopted stringent standards on materials to be labelled "Lead-free" and have established certification programs for drinking water system components. For example, the certification from the National Sanitation Foundation (NSF), accredited by the American National Standards Institute and the Standards Council of Canada, for drinking water system components. NSF is a globally recognised organisation for public health standards. They conduct regular evaluations to evaluate contaminations, such as phthalates, lead, etc., in the products. If regulated chemicals are detected, they must be less than the U.S. EPA's and Health Canada's acceptable levels. For unregulated contaminants, NSF/ANSI/CAN 61 sets health-based pass/fail levels. In the case of lead, pipes and fittings certified by NSF do not contain lead (NSF, 2022). Similar approaches are required in India to ensure that new infrastructure materials, regardless of cost, do not introduce lead into drinking water.

The use of certified lead-free pipes, fittings, fixtures, solders, and storage tanks should be made mandatory in all public water supply systems, construction projects, and household plumbing installations. This is particularly important in rapidly urbanising areas and informal settlements, where substandard plumbing materials are often used because of lower costs and non-uniform regulatory enforcement. Strengthening market surveillance and enforcing standards through regular inspections can help prevent the circulation of low-quality and lead-containing products

Implementation of Jal Jeevan Mission (JJM)

Har Ghar Jal, implemented by the Ministry of Jal Shakti, in collaboration with states in 2019, is an important initiative for providing contamination-free potable tap water to every rural household of the country in adequate quantity, of prescribed quality and on a regular & long-term basis (Ministry of Jal Shakti, 2025). JJM includes several measures that are relevant for addressing lead and other chemical contaminants in drinking water

1. Under the initiative, the Bureau of Indian Standards (BIS) specification IS 10500 has been adopted as the prescribed standard for drinking-water quality, with an acceptable limit of lead of 10 µg/L.
2. While allocating funds to states and Union Territories, additional weightage (10%) is provided for populations living in habitations affected by chemical contaminants.
3. The "Drinking Water Quality Monitoring and Surveillance Framework" was developed and disseminated to states in October 2021 to strengthen local monitoring systems.
4. 2,180 water-testing laboratories have been established across the country to support water-quality monitoring. In addition, five persons, preferably women, are identified and trained from each village to test water samples using Field Test Kits (FTKs). States and Union Territories have been advised to conduct regular water-quality testing and take remedial measures wherever contamination is detected, though Lead testing is not performed using FTKs.
5. Community Water Purification Plants have also been encouraged as an interim solution in water-quality-affected habitations to ensure access to safe drinking water until permanent infrastructure improvements are completed.

6. Improving groundwater quality through artificial recharge, source protection, and catchment management measures can further help reduce contamination risks in vulnerable regions.

As of 2025, JJM was able to provide access to safe tap water to 157.2 million households and averted almost 14 million DALYs. Following the objectives, 2843 water testing laboratories across India tested 3.87 million samples in 2025-26, ensuring stringent water quality monitoring (PIB, 2025). Lead testing usually is performed at state-level water testing laboratories.

The Annual Ground Water Quality Report of 2025, prepared by the Central Ground Water Board under the Ministry of Jal Shakti (Government of India), analysed a total of 2,537 groundwater samples (pre- and post-monsoon) across India to assess lead contamination and detected lead concentrations exceeding the permissible limit of 0.01 mg/L in 0.95% of samples during pre-monsoon and 0.79% during the post-monsoon period (Central Ground Water Board, 2025). Although progress has been gradual, the expansion and effective enforcement of such programs can help address groundwater contamination, improve access to safe drinking water for vulnerable communities, and support remediation of contaminated sites.

Public awareness campaign

Public awareness and consumer participation are critical for the successful phase-out of lead-containing plumbing materials and for reducing exposure risks. Many households remain unaware that ageing pipes, taps, storage tanks, paints, or plumbing fittings may contribute to lead contamination in drinking water. Awareness campaigns should therefore educate communities on the health impacts of lead exposure, safe plumbing practices, and the importance of regular water testing. Consumers should also be encouraged to replace ageing plumbing fixtures, flush stagnant water before use, avoid storing drinking water in uncertified containers, and report visible deterioration in pipelines or water quality.

Besides consumers, other stakeholders such as plumbers, contractors, local government officials and community leaders can play a critical role in promoting behaviour change and compliance with safe plumbing practices. In some settings, involvement of national academic institutions may be useful to support quality control activities relating to sampling and analysis (WHO, 2020). Community engagement, combined with transparent reporting of water-quality data, can improve accountability and strengthen local participation in water safety management.

10. Recommendations and Way Forward

India's policy framework on lead-related sources and issues is fragmented, comprising policies that address different sectors, such as drinking water, industrial emissions, etc. This fragmentation has created gaps in monitoring, prevention and enforcement, especially for contamination pathways that cut across sectors. In the case of drinking water, lead exposure may originate from diverse sources, including groundwater contamination associated with industrial discharge and mining, recycling of LABs, electronic waste recycling as well as construction materials such as lead pipes and substandard lead-containing plumbing materials. To address the problem of lead poisoning while there is need of more holistic approach focusing on industrial safety standards, E-waste regulation, emission control mechanisms, formalizing re-cycling sectors, site-remediation solutions to healthcare approached, the following recommendations are proposed primarily to strengthen existing regulatory and implementation mechanisms from drinking water point of view.

Strengthen regulatory enforcement

India has established stringent standards spanning drinking water quality, industrial discharge, hazardous waste disposal, and plumbing materials, including PVC products. Accordingly, implementation should be strengthened through coordinated enforcement and surveillance across the sector. Regulatory bodies should impose stricter penalties for non-compliance and ensure clear accountability across water utilities, pollution control authorities, and municipal agencies. Since national standards for lead in drinking water are already in place, the immediate priority should be their consistent and effective enforcement.

At the national level, efforts should begin with the identification of high-risk districts, followed by systematic testing of major water supply sources and health sector institutions and school water points, replacement of unsafe plumbing in public buildings, and mandatory use of lead-safe materials in public procurement. Data should be used not only to document contamination but also to guide targeted intervention. For example, the informal sector can be mapped, and baseline data can be generated on the results of random testing for lead content of uncertified PVC pipes and plumbing materials. This ensures protection of consumers from substandard materials. Effective enforcement depends on robust data, traceability, and sustained regulatory oversight.

Expand nationwide water testing programs

Water is a state subject. The implementation of policies is expected to be variable throughout the country, depending primarily on the requirements of the state. However, programs such as nationwide water testing programs provide a platform to build data, which will then inform policy implementation, programs suited for vulnerable communities and other relevant stakeholders, and budget allocation for remediation.

While programs such as Jal Jeevan Mission have improved access and monitoring, their current objectives and source-testing scope remain insufficient to fully address lead contamination in drinking water. Therefore, there is a need for a systematic, risk-based testing program for lead in both rural and urban settings. Testing should cover source water, distribution networks, household taps, borewells, and community water points, since lead exposure can occur at multiple stages. The program should also include standardised sampling protocols, laboratory quality assurance, public reporting of results, and mandatory corrective action when contamination is detected. Isolated testing is inadequate, particularly in areas where lead contamination has already been reported in multiple states.

Promote research and surveillance

Given the gravity of public health issues related to lead and its use across different sectors, monitoring should be integrated into a long-term surveillance system that tracks both concentration levels and exposure patterns over time. Surveillance should also identify the principal pathways of contamination, including plumbing, groundwater, industrial waste, and corrosion.

In a developing country like India, however, monitoring and surveillance can be challenging because of limited budgets, inadequate laboratory infrastructure, and the country's vast geographical scale. These constraints can delay data collection, narrow spatial coverage, and reduce the effectiveness of monitoring programs. To address this, research institutions, accredited laboratories, and universities should be supported to conduct scientifically robust monitoring studies under a decentralised framework. Such an approach would expand geographic coverage, improve data quality, increase ownership of data and generate region-specific evidence to inform policy and remediation plans. Additionally, research should focus on safer alternatives to lead-based PVC pipes and plumbing materials so that lead-containing products can be phased out from drinking-water systems over time.

Engage communities in monitoring efforts

Community participation is essential, as residents are often the first to notice repeated taste, oduor, discolouration, or illness linked to water quality. Therefore, the establishment of a dedicated hotline is important to collect firsthand observations, register complaints, and enable prompt follow-up by the relevant authorities. This will empower local groups, schools, and resident associations to report issues and support basic field screening, especially where official monitoring is limited or delayed.

In rural areas, village communities and schoolteachers can be trained to use simple test kits, report abnormal results, and share findings through local meetings or mobile-based reporting systems. In urban areas, resident welfare associations, municipal ward offices, and school networks can be engaged to identify recurring water-quality problems, report suspected contamination, and support targeted sampling in vulnerable localities. Public communication should be provided in local languages, and grievance redress mechanisms should be linked to corrective action so that community participation leads to a visible response rather than isolated reporting.

Annexure:

Annex I: Research studies on Lead in drinking water

Year	Title	Authors	Type of sample	Key findings	Reference
2011	Heavy metal contamination of drinking water in Kamrup district, Assam, India	Sutapa Chakrabarty and Hari Prasad Sarma	Drinking water	The maximum lead concentration observed in BDL was 0.11 ppm. Lead levels at 14 sampling stations exceeded the EPA guideline value of 0.015 ppm, indicating widespread contamination above the recommended limit.	Chakrabarty and Sarma, 2011).
2026	Human health implications of metal pollution in the Betwa–Yamuna river system, India: evidence from Monte Carlo risk modelling	K. Prasanna, M. S. Amal, Kagiso S. More, Ravi Rangarajan, Anupam Sharma & Ashwani Kumar Tiwari	Surface Water	Lead values were mostly below 5 µg/L, but occasional peaks reached 10.8 – 12.4 µg/L, going over the WHO threshold	(Prasanna et al., 2026)
2026	Heavy metal contamination in water and sediment of a tropical urbanizing landscape: Insights from Akkulam-Veli Lake, southwest coast, India	Arsha, Pooja Pradeep, S.G. Dhanil Dev, E. Shaji, P.K. Krishna Prasad, S. Swetha, S. Arya, V. Deepchand, Mohammed Noohu Nazeer	Sediment	Sediments exhibited elevated concentrations of Pb (66-260 mg/kg) lead exceeding permissible limits by up to 6.5 times	(Pradeep et al., 2026).

Year	Title	Authors	Type of sample	Key findings	Reference
2025	Assessment of Water, Sediment, and Fish Contamination by Metals in the Lentic Ecosystems of a Mineral-Rich State in India	Preeti Kumari, Vishal Kumar Parida, Deep Raj, Pavan Kumar, Madhusudan Narayan, Umang Gupta	Water and sediment	Concentration of Pb in water was found in the range of 23-81 µg/L, whereas sediment has 93.44-581.38 mg/kg Pb concentration in it.	(Kumari et al., 2025)
2025	Disposition of Uranium and Other Heavy Metals in the Groundwater in the Baran District of Rajasthan, India	Ashu Rani Ramet Meena, Kiran Parashar, Shobhana Sharma, Ankit Sharma, Nepal Chandra Mondal, and Sushil Kumar Sharma	Ground water	Average lead concentration decreased from 0.0924 ppm in the pre-monsoon season to 0.0218 ppm in the post-monsoon season, indicating post-monsoon dilution effects	(Rani et al., 2025)
2025	Global Perspectives on Lead Contamination and Health Risks in Surface Water, Rice Grains, and Soils.	Amit Kumar, Vinod Kumar, Monika Thakur, Kirpal Singh, Rakesh Jasrotia, Rupesh Kumar, Maja Radziemska	Surface water		(Kumar et al., 2025)

References

1. Agency for Toxic Substances and Disease Registry. (n.d.). Toxicological profile for lead. U.S. Department of Health and Human Services. https://www.atsdr.cdc.gov/
2. Babu, J., Aravindalochanan, V., Sendhil, S., & Balakrishnan, K. (2024). Assessment of lead exposure and associated risk through human biomonitoring among urban communities in Chennai, Southern India. Cureus, 16(11), e73785. https://doi.org/10.7759/cureus.73785
3. U.S. Environmental Protection Agency. (2026, February 24). Basic information about lead in drinking water. https://www.epa.gov/ground-water-and-drinking-water/basic-information-about-lead-drinking-water#regs
4. Bureau of Indian Standards. (2012). IS 10500:2012: Drinking water – Specification (2nd ed.).
5. Brown, M. J., Patel, P., Nash, E., Dikid, T., Blanton, C., Forsyth, J. E., et al. (2022). Prevalence of elevated blood lead levels and risk factors among children living in Patna, Bihar, India, 2020. PLOS Global Public Health, 2(10), e0000743. https://doi.org/10.1371/journal.pgph.0000743
6. Central Ground Water Board. (2025). Annual ground water quality report (ISBN: 978-81-984761-5-9). Ministry of Jal Shakti, Government of India. https://www.jalshakti-dowr.gov.in/static/uploads/2025/11/2d2afc1bcaa06de10de2f1ffe3276780.pdf
7. Centers for Disease Control and Prevention. (2024a). Lead exposure and prevention. https://www.cdc.gov/
8. Centers for Disease Control and Prevention. (2024b, April 8). Story: Flint water crisis. https://www.cdc.gov/casper/php/publications-links/flint-water-crisis.html
9. Chan, S. N., Chang, L., Choi, K. W., Lee, J. H. W., Fawell, J. K., & Kwok, K. Y. T. (2020). Unravelling the causes of excess lead in drinking water supply systems of densely populated high-rise buildings in Hong Kong. Environmental Science & Technology, 54(22), 14322–14333. https://doi.org/10.1021/acs.est.0c03232
10. Chayal, N. K., Kumar, A., Verma, K. S., Kumar, D., Agarwal, R., Kumar, K., Pandey, T., Ali, M., Srivastava, A., & Ghosh, A. K. (2025). Lead exposure in Bihar, Eastern India: A risk assessment study. Environmental Geochemistry and Health, 47(9), 368. https://doi.org/10.1007/s10653-025-02687-3
11. Conterato, G. M. M., et al. (2023). Intermittent lead exposure induces behavioral and cardiovascular alterations associated with neuroinflammation. Cells, 12(5), 818. https://doi.org/10.3390/cells12050818
12. Cornwell, D. A., Brown, R. A., & Via, S. H. (2016). National survey of lead service line occurrence. Journal – American Water Works Association, 108(4), E182–E191.
13. Chakrabarty, S., & Sarma, H. P. (2011). Heavy metal contamination of drinking water in Kamrup district, Assam, India. Environmental Monitoring and Assessment, 179(1), 479–486

14. Element 84. (2017). Interpolating lead levels from tap water samples following Flint water crisis. https://element84.com/geospatial/spatial-analysis/interpolating-lead-levels-from-tap-water-samples-following-flint-water-crisis/
15. Ericson, B., Dowling, R., Dey, S., Caravanos, J., Mishra, N., Fisher, S., Ramirez, M., Sharma, P., McCartor, A., Guin, P., Taylor, M. P., & Fuller, R. (2018). A meta-analysis of blood lead levels in India and the attributable burden of disease. Environment International, 121, 461–470. https://doi.org/10.1016/j.envint.2018.08.047
16. European Commission. (2023). Commission Regulation (EU) 2023/923 of 3 May 2023 amending Annex XVII to Regulation (EC) No 1907/2006 of the European Parliament and of the Council as regards lead and its compounds in PVC (Text with EEA relevance). EUR-Lex.
17. GBD 2023 Lead Collaborators. (2026, March 30). Lead-attributable cardiovascular disease burden: Global Burden of Disease Study 2023. JAMA. https://doi.org/10.1001/jama.2026.2197
18. Gorgees, S. S., et al. (2019). Trophic transfer and bioaccumulation of lead along a soil-plant-aphid-ladybird food chain. Environmental Science and Pollution Research. https://pubmed.ncbi.nlm.nih.gov/31201701/
19. Hayes, C. R., & Skubala, N. D. (2009). Is there still a problem with lead in drinking water in the European Union? Journal of Water and Health, 7(4), 569–580.
20. Health Canada. (2016). Water talk: Reducing your exposure to lead in drinking water. Water Quality, Health Canada, Ottawa, Ontario. https://publications.gc.ca/collections/collection_2016/sc-hc/H144-34-2016-eng.pdf
21. Health Canada. (2025). Guidelines for Canadian drinking water quality—Summary tables. Water and Air Quality Bureau, Healthy Environments and Consumer Safety Branch, Health Canada, Ottawa, Ontario. https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-guideline-technical-document-lead.html
22. IMARC. (2025). India PVC pipes market size, share & industry growth, 2034. https://www.imarcgroup.com/india-pvc-pipes-market
23. India Health Action Trust. (2026). Evidence brief on addressing lead toxicity in Uttar Pradesh. https://www.ihat.in/wp-content/uploads/2026/04/Evidence-Brief-on-Addressing-Lead-Toxicity-in-Uttar-Pradesh.pdf
24. Institute for Health Metrics and Evaluation. (2024). Global burden of disease study: Lead exposure results. https://www.healthdata.org/
25. Jankie, S., et al. (2023). Trophic transfer, bioaccumulation, and detoxification of lead and zinc in food chains. Water, Air, & Soil Pollution. https://doi.org/10.1007/s11270-023-06531-1
26. Jan Sahyog Manch v. Union of India & Ors., M.A. No. 1064/2018 in Original Application No. 13/2018 (National Green Tribunal 2018).

27. Jarvis, P., & Fawell, J. (2021). Lead in drinking water – An ongoing public health concern? Current Opinion in Environmental Science & Health. https://doi.org/10.1016/j.coesh.2021.100239
28. Jarvis, P., Quy, K., Macadam, J., Edwards, M., & Smith, M. (2018). Intake of lead (Pb) from tap water of homes with leaded and low lead plumbing systems. Science of the Total Environment, 644, 1346-1356.
29. Khan, A., et al. (2020). Lead toxicity: Health hazards, influence on food chain, and sustainable remediation approaches. International Journal of Environmental Research and Public Health, 17(7), 2179. https://doi.org/10.3390/ijerph17072179
30. Kim, H.-C., & Lee, B.-K. (2015). Evaluation and management of lead exposure. Annals of Occupational and Environmental Medicine, 27, 30. https://doi.org/10.1186/s40557-015-0065-9
31. Kumar, A., Kumar, V., Thakur, M., Singh, K., Jasrotia, R., Kumar, R., & Radziemska, M. (2025). Global perspectives on lead contamination and health risks in surface water, rice grains, and soils. Land Degradation & Development, 36(7), 2159-2169.
32. Kumar, D., Awasthi, S., Mahdi, A. A., Singh, S., Pandey, A. K., Agarwal, G. G., Anish, T. S., Somashekar, A. R., Kar, S., Nair, S., Mathew, J. L., Bhat, M. A., Mahanta, B. N., Singh, K., & Singh, C. M. (2023). Assessment of blood lead level of school children in cities of India: A cross-sectional study. Indian Journal of Pediatrics. https://doi.org/10.1007/s12098-023-04864-7
33. Kumar, R., Kapley, A., Gupta, A., & Kumbhare, H. (2022). Assessment of lead impact on human and India's response. Council of Scientific and Industrial Research; NITI Aayog. https://www.pureearth.org/wp-content/uploads/2022/06/Lead-Report-India-CSIR-NITI-Ayog-June-2022.pdf
34. Lustberg, M., & Silbergeld, E. (2002). Blood lead levels and mortality. Archives of Internal Medicine, 162(21), 2443-2449.
35. Michigan Department of Health and Human Services, Centers for Disease Control and Prevention, & partners. (2016, July). Community assessment for public health emergency response (CASPER) after the Flint water crisis: May 17-19, 2016, Flint, Michigan: Final report. State of Michigan. https://www.michigan.gov/-/media/Project/Websites/flintwater/documents/2016/CASPER_Report.pdf
36. Ministry of Environment, Forest and Climate Change. (2021). The Lead Stabilizer in Polyvinyl Chloride (PVC) Pipes and Fittings Rules, 2021 (G.S.R. 228(E)).
37. Ministry of Housing and Urban Affairs, & Central Public Health and Environmental Engineering Organisation. (2023). Manual on water supply and treatment systems (Drink from Tap), Part A: Engineering – Planning, design and implementation (4th rev. ed.). Government of India.
38. Ministry of Environment, Forest and Climate Change. (2025, July 24). Environment Protection Management of Contaminated Sites Rules, 2025 (S.O. 3401(E)). The Gazette of India: Extraordinary, Part II, Section 3, Sub-section (ii). https://moef.gov.in/storage/tender/1753451385_S.O.3401(E)_Rules_2025.pdf
39. Mudgal, V., et al. (2021). Sources, mobility, reactivity, and remediation of heavy metal pollution: A review. Advances in Environmental and Engineering Research, 2(4). https://doi.org/10.21926/aeer.2104033

40. National Institute of Environmental Health Sciences. (2026, April 7). Lead: Health & education. https://www.niehs.nih.gov/health/topics/agents/lead
41. National Institute for Occupational Safety and Health. (2003). NIOSH manual of analytical methods (NMAM). https://www.cdc.gov/niosh
42. Standardization Administration of the People's Republic of China, & State Administration for Market Regulation. (2022). GB 5749-2022: National standard of the People's Republic of China for drinking water quality. https://www.chinesestandard.net/PDF.aspx/GB5749-2022
43. Natural Resources Defense Council. (2025). Flint water crisis: Everything you need to know. https://www.nrdc.org/stories/flint-water-crisis-everything-you-need-know
44. NSF. (2022, May 6). Health effects monitoring of PVC pipe and fittings. https://www.nsf.org/ca/en/knowledge-library/health-effects-monitoring-of-pvc-pipe-fittings
45. Occupational Safety and Health Administration. (2008). Lead standard (29 CFR 1926.62). https://www.osha.gov
46. Press Information Bureau, Delhi. (2025, October 26). Jal Jeevan Mission: With ₹2.08 lakh crore central outlay, delivering tap water to over 15.72 crore rural households. https://www.pib.gov.in/PressReleasePage.aspx?PRID=2182568&reg=3&lang=2
47. Prasanna, K., Amal, M. S., More, K. S., Rangarajan, R., Sharma, A., & Tiwari, A. K. (2026). Human health implications of metal pollution in the Betwa-Yamuna river system, India: Evidence from Monte Carlo risk modelling. Scientific Reports, 16, 5058. https://doi.org/10.1038/s41598-025-34780-z
48. Pradeep, P., Dev, S. D., Shaji, E., Prasad, P. K., Swetha, S., Arya, S., … Nazeer, M. N. (2026). Heavy metal contamination in water and sediment of a tropical urbanizing landscape: Insights from Akkulam-Veli Lake, southwest coast, India. Evolving Earth, 100112.
49. Rani, A., Meena, R., Parashar, K., Sharma, S., Sharma, A., Mondal, N. C., & Sharma, S. K. (2025). Disposition of uranium and other heavy metals in the groundwater in the Baran District of Rajasthan, India. Journal of Sustainable Water in the Built Environment, 11(1), 04024014.
50. Roy, A., Bellinger, D., Hu, H., Schwartz, J., Ettinger, A. S., Wright, R. O., & Balakrishnan, K. (2009). Lead exposure and behavior among young children in Chennai, India. Environmental Health Perspectives, 117(10), 1607-1611.
51. Roy, S., & Edwards, M. A. (2019). Preventing another lead (Pb) in drinking water crisis: Lessons from the Washington D.C. and Flint MI contamination events. Current Opinion in Environmental Science & Health, 7, 34-44.
52. Ruckart, P. Z., Ettinger, A. S., Hanna-Attisha, M., Jones, N., Davis, S. I., & Breysse, P. N. (2019). The Flint water crisis: A coordinated public health emergency response and recovery initiative. Journal of Public Health Management and Practice, 25(Suppl. 1, Lead Poisoning Prevention), S84-S93. https://doi.org/10.1097/PHH.0000000000000871

53. Saleh, H., Braida, W., Zhang, Z., Datta, R., & Sarkar, D. (2026). Geochemical fate of lead in contaminated residential soils following application of amendments for lead immobilization. Frontiers in Chemistry, 14, Article 1742013. https://doi.org/10.3389/fchem.2026.1742013
54. Sanders, T., Liu, Y., Buchner, V., & Tchounwou, P. B. (2009). Neurotoxic effects and biomarkers of lead exposure: A review. Reviews on Environmental Health, 24(1), 15–45.
55. Sharma, S., et al. (2025). Global perspectives on lead contamination and health risks in soil and water systems. Land Degradation & Development. https://doi.org/10.1002/ldr.5510
56. Singh, P. S., Government of India, Ministry of Environment, Forest and Climate Change, & Vardhan, H. (2018). Use of lead in PVC pipes. In Lok Sabha. https://sansad.in/getFile/loksabhaquestions/annex/14/AS114.pdf?source=pqals
57. Skoog, D. A., Holler, F. J., & Crouch, S. R. (2014). Principles of instrumental analysis (6th ed.). Cengage Learning.
58. The European Parliament and the Council of the European Union. (2020). Directive (EU) 2020/2184 of the European Parliament and of the Council on the quality of water intended for human consumption (recast). Official Journal of the European Union [Legislative acts]. http://viega.com/content/dam/viegadm/download-assets/en_com/CELEX_32020L2184_EN_TXT%20(1).pdf
59. Todd, A. C. (1991). Toxicokinetics of bone lead. Environmental Health Perspectives, 91, 17–24. https://doi.org/10.1289/ehp.919117
60. Toxics Link. (2025). Soiled with lead from lead recycling. https://toxicslink.org/wp-content/uploads/2026/04/Toxics%20Link%20-%20Soiled%20With%20Lead.pdf
61.Toxics Link, & IPEN. (2023). Lead in solvent-based paints for home use in India. https://toxicslink.org/wp-content/uploads/2023/08/India%20Lead%20Paint%20Report%20Summary%20(October%202023).pdf
62. Subramanian, K. S., & Connor, J. W. (1991). Lead contamination of drinking water: Metals leaching from soldered pipes may pose health hazard. Journal of Environmental Health, 54(2), 29–32. http://www.jstor.org/stable/44540365
63. UNICEF, & Pure Earth. (2020, July). The toxic truth: Children's exposure to lead pollution undermines a generation of future potential. UNICEF.
64. U.S. Environmental Protection Agency. (1994). Method 200.9: Determination of trace elements by stabilized temperature graphite furnace atomic absorption.
65. U.S. Environmental Protection Agency. (2007). Method 200.8: Determination of trace elements in waters and wastes by ICP-MS; Method 6200: Field portable X-ray fluorescence (XRF) spectrometry.
66. U.S. Environmental Protection Agency. (2020). Lead test kits and recognition program. https://www.epa.gov

67. U.S. Environmental Protection Agency. (2020). Understanding the Lead and Copper Rule. https://www.epa.gov/sites/default/files/2019 10/documents/lcr101_factsheet_10.9.19.final_.2.pdf
68. U.S. Environmental Protection Agency. (2026, February 24). Basic information about lead in drinking water. https://www.epa.gov/ground-water-and-drinking-water/basic-information-about-lead-drinking-water
69. U.S. Environmental Protection Agency. (2025, May 27). Use of lead-free pipes, fittings, fixtures, solder, and flux for drinking water. https://www.epa.gov/sdwa/use-lead-free-pipes-fittings-fixtures-solder-and-flux-drinking-water
70. Wani, A. L., Ara, A., & Usmani, J. A. (2015). Lead toxicity: A review. Interdisciplinary Toxicology, 8(2), 55–64. https://doi.org/10.1515/intox-2015-0009
71. World Health Organization. (2021). Guideline for clinical management of lead exposure. https://www.who.int
72. World Health Organization. (2022, September 5). Lead in drinking-water: Health risks, monitoring and corrective actions(Technical brief). https://iris.who.int/server/api/core/bitstreams/83ed089d-b086-4ea1-9a9a-88efaf280415/content
73. World Health Organization. (2024, September 27). Lead poisoning and health [Fact sheet]. https://www.who.int/news-room/fact-sheets/detail/lead-poisoning-and-health
74. World Health Organization. (2024). Lead poisoning and health. https://www.who.int
75. World Health Organization. (n.d.). Inorganic lead toxicokinetics. https://www.inchem.org
76. Yang, T., et al. (2023). Environmental contamination characteristics of heavy metals from mining regions. Frontiers in Earth Science, 11, 1082714. https://doi.org/10.3389/feart.2023.1082714
77. Zhu, M., et al. (2021). Effectiveness of remediation strategies for lead-contaminated soil. Science of the Total Environment, 801, 149427. https://doi.org/10.1016/j.scitotenv.2021.149427