Toxics Link
for a toxics-free world

SOILED WITH LEAD

from Battery Recycling

September 2025

About Toxics Link

Toxics Link is an Indian environmental research and advocacy organisation set up in 1996, engaged in disseminating information to help strengthen the campaign against toxics pollution, provide cleaner alternatives and bring together groups and people affected by these problems. Toxics Link has a unique expertise in areas of hazardous, plastic, medical and municipal wastes, international waste trade, and emerging issues of pesticides, Persistent Organic Pollutants (POPs), hazardous heavy metal contamination, etc. We have successfully implemented various best practices and have contributed to policy changes in the aforementioned areas apart from creating awareness among several stakeholder groups.

Toxics Link's Mission Statement - "Working together for environmental justice and freedom from toxics, we have taken upon ourselves to collect and share both information about the sources and the dangers of poisons in our environment and bodies, and information about clean and sustainable alternatives."

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Abbreviation

BLL	Blood Lead Level
CAGR	Compound Annual Growth Rate
CPCB	Central Pollution Control Board
DGFT	Directorate General of Foreign Trade
EPA	Environmental Protection Agency
EVs	Electric Vehicles
HW Rule	Hazardous Waste (Management) Rules
IARC	International Agency for Research on Cancer
ICP MS	Inductively Coupled Plasma Mass Spectrometry
mg/kg	Milligram per kilogram
NABL	National Accreditation Board for Testing and Calibration Laboratories
NCR	National Capital Region
Pb	Lead
ppm	Parts per million
UNEP	United Nations Environment Programme
USD	United States Dollar
WHO	World Health Organization

Introduction

Lead

Lead (Pb) is recognised as one of the most toxic heavy metals as it has a detrimental impact on health and the environment. Despite being a naturally occurring element, it constitutes only about 0.002% of the Earth's crust and is typically present in trace amounts. As a native component of the lithosphere- lead, like other metals, exists in soil primarily due to natural weathering and pedogenic processes.[1]

Lead can be found in both organic and inorganic forms. However, the majority of lead present in modern soils is anthropogenic in origin. The properties including malleability, a relatively low melting point, and resistance to corrosion have made it useful across a wide range of applications.

The global lead industry encompasses mining, refining, and manufacturing of lead-based products. In 2024, the global lead market was valued at approximately USD 22.25 billion and is projected to grow to USD 37.08 billion by 2033, at a compound annual growth rate (CAGR) of 5.84%. This growth is primarily driven by demand for lead-acid batteries, which are widely used in both conventional vehicles and electric vehicles (EVs). According to the United Nations Environment Programme (UNEP), lead-acid batteries accounted for around 86% of global lead consumption in 2022, and refined lead consumption was estimated to reach 13.7 million tonnes in 2023.[2,3]

Asia, particularly China and India, is expected to continue dominating global lead demand, mainly due to rapid industrial expansion and the growing automotive sector. In India, Hindustan Zinc Ltd. is the largest producer of lead and ranks as the second-largest zinc-lead producer globally.[4] In 2023-24, production of primary lead was 215983 tonnes.[5]

According to World Bank data, the country imported approximately 4,417,890 kilograms of lead ore and concentrate in 2023, with the highest volume—around 1,375,150 kilograms—sourced from the United Arab Emirates.[6] Further, data from the Directorate General of Foreign Trade (DGFT) shows that during FY 2023–24, India imported 57,240,052 kilograms of lead and related articles, amounting to a total trade value of approximately USD 55,997.07 million.[7] While a market research agency shared that India has imported 18,523 tonnes of lead scrap in 2024, the top was the US at 6,779 t, followed by Dominican Republic of Congo at 2,041 t, and the UK at 1,664 t. Exports from other countries stood at 8,038 t.[8]

Health impact of lead poisoning

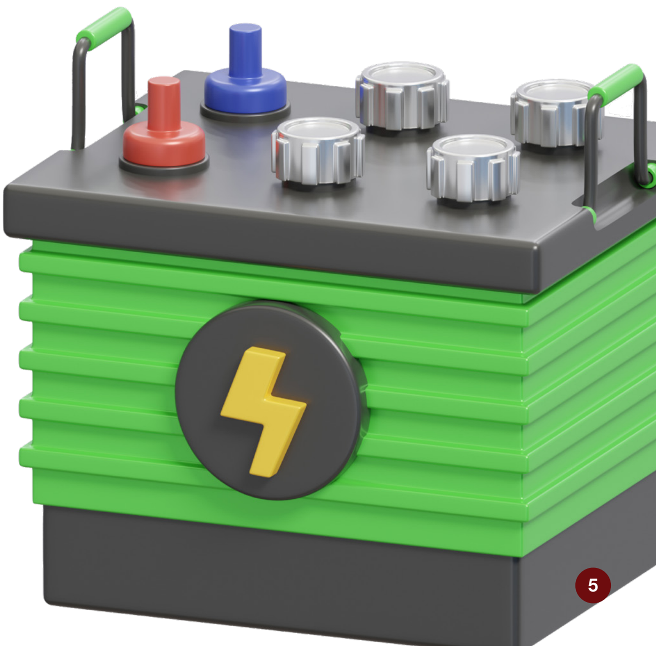
Lead is a cumulative toxicant with no known safe level of exposure in humans. According to the World Health Organization (WHO)[9], lead exposure is among the top ten environmental health threats globally. It is responsible for an estimated 540,000 deaths and 13.9 million Disability-Adjusted Life Years (DALYs) annually (IHME, 2016), with the highest burden borne by low-and middle-income countries.[10] Lead has also been classified as a Group II human carcinogen by the International Agency for Research on Cancer (IARC).[11]

Lead poisoning presents a wide spectrum of symptoms that vary with age, exposure level, and duration. Both acute and chronic exposure can cause significant harm, often without immediate or specific signs, especially at lower levels. Lead is known to mimic calcium in biological processes, disrupting neurotransmission, cell function, kidneys, skeletal system, blood formation pathways and bone development.[12] It affects multiple organ systems, with the nervous system being particularly vulnerable.[13,14]

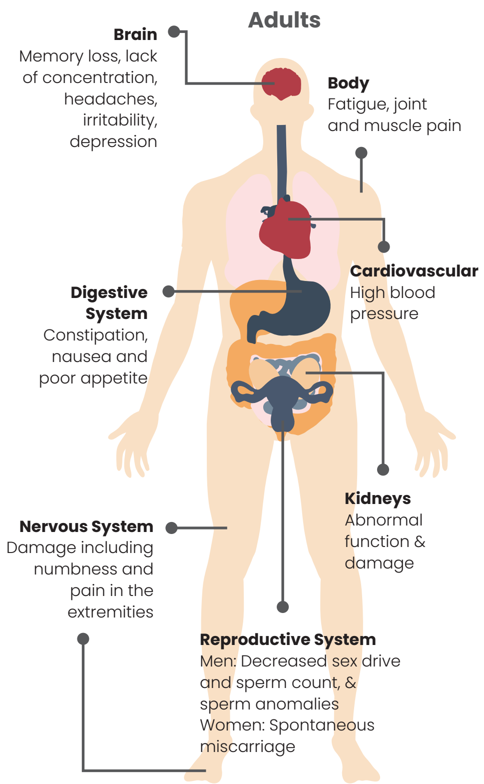
Children and pregnant women are most at risk, as even low levels of lead can disrupt brain development, leading to cognitive impairment, behavioural disorders, attention deficits, and lifelong learning difficulties. Severe exposure can result in coma, convulsions, or death, while survivors may suffer from permanent neurological damage.[15]

There is no safe level of Lead exposure in the blood. Exposure symptoms typically emerge at blood lead levels above 40–50 µg/dL in adults and 60 µg/dL in children, though effects can occur at much lower levels with even 3.5 g/dL linked to decreased intelligence and behavioural issues in children.[16,17,18] Additionally, lead can cross the placenta and enter breast milk, impacting foetuses and infants. Some research also suggests a possible link between leaded gasoline and crime rates.[19]

A global study by NYU estimated an annual loss of $977 billion due to reduced IQ and productivity among lead-exposed children in low- and middle-income countries. For India alone, the estimated economic ***loss is $236 billion*** *per year, or roughly 5% of GDP.*



Health Impacts of Lead



Exposure to high levels of lead can cause severe damage to the brain, blood & kidneys.

Children under six are most at risk from lead poisoning. Even low levels of lead exposure have been found to permanently reduce cognitive ability and cause hyperactivity in children.

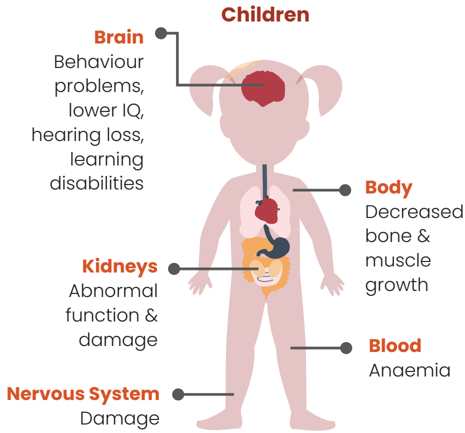


Table 1. Health Impacts due to lead exposure

	Early symptoms	Chronic exposure impacts
Adults	Fatigue, abdominal pain, mood changes, sleep disturbances	Kidney dysfunction, anaemia, and in extreme cases, encephalopathy marked by confusion, seizures, or coma
Children	Impaired cognitive development, behaviour and attention span	Learning disabilities, delayed growth, hyperactivity, or social withdrawal. In extreme cases, neurological damage can be permanent

Exposure route

There are various sources of lead exposure including food, water, soil, dust, air and others. The WHO had reported that the contribution of daily pathways of children's Pb exposure is: air (1 %) < drinking water (6 %) < soil and dust (45 %) < food (47 %).[20]

Humans can be exposed to lead from many non-dietary sources like soil, household dust, old paint, traditional medicines, and even tea leaves. Daily exposure often comes from lead-contaminated surroundings for those not working in industries. Dust from soil or old paint in homes can be inhaled or accidentally swallowed, especially by children who often put their hands in their mouths. This is one of the main reasons young children are at higher risk of lead poisoning.

In industrial workers, lead exposure mainly happens through work-related activities.[21,22] Industrial activities such as battery manufacturing and recycling, metal smelting, and production of ammunition and enamel paints and pipes are major contributors to elevated lead levels in air, water, and soil.[23]

Various sources of lead in the environment

Research has shown that of the total amount of dust particles inhaled, about 30-40% get absorbed by the human body. The dust particles enter the pulmonary alveoli, pass through the wall of the pulmonary alveoli, and enter the circulatory system, leading to elevated blood lead levels (BLLs).[24,25,26]

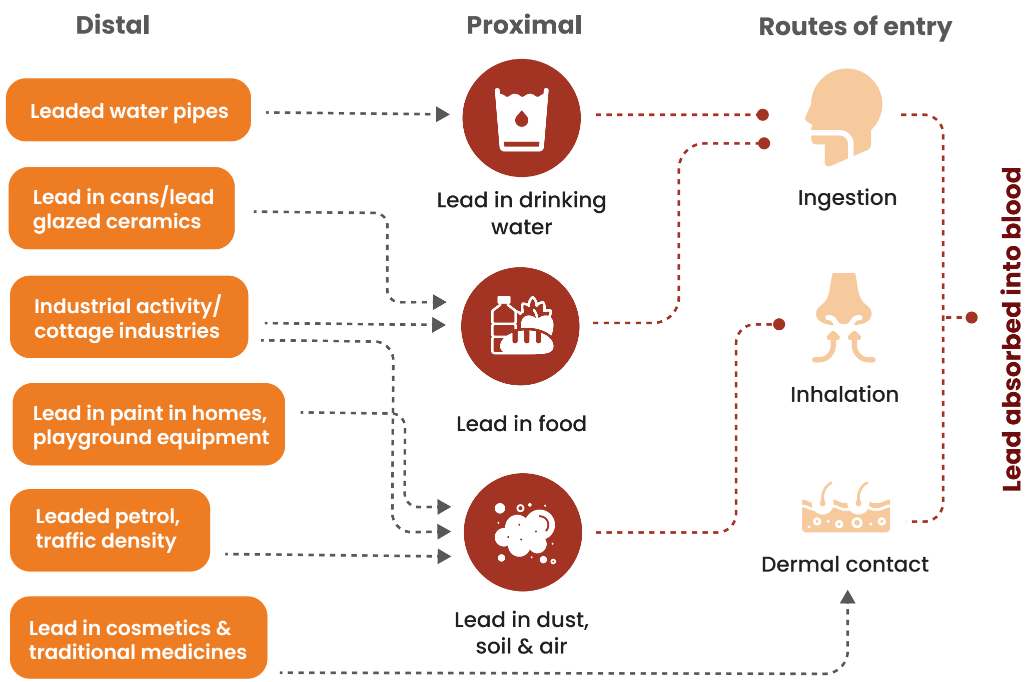
Once released into the air, lead may travel long distances before settling into the soil particles. Older playground equipment coated with old lead-based paint, playground surfaces and artificial turf made from shredded rubber, may also contain lead that releases into soil and air. Lead may leach to the groundwater depending on the type of lead compound and the characteristics of the soil.[27] Through soil & air, lead can easily be taken up by the plants.

Research studies have reported high lead concentration in vegetables and crops grown in contaminated sites.[28,29]

Once lead enters the body—through inhalation, ingestion of contaminated food or dust or through skin contact—it is absorbed and carried through the blood to different body parts. Ingested lead is broken down in the stomach and intestines, before being absorbed into the bloodstream.[30]

Lead can also enter the body through the skin. It reacts with natural oils and fats on the skin, making it easier to be absorbed through hair follicles and into deeper layers of skin. From there, it can reach the blood and raise lead levels.[31]

Figure 1. Major sources and routes of environmental lead exposure. (Adapted from WHO 2021)



Rationale of the Study

Lead-acid batteries have remained a dominant energy storage solution for over 150 years, making the battery sector one of the world's largest consumers of lead. It represents around 40% of the global battery market. These rechargeable batteries are primarily used in automobiles and are also widely deployed in backup power systems such as inverters, uninterruptible power supplies (UPS), telecommunications and railway networks. The spent batteries are sent to recycling units or smelting facilities, both authorised (formal) as well as unauthorised (informal) set-ups, to recover lead, plastic components etc. These recovered materials are often reintroduced into battery manufacturing cycles.

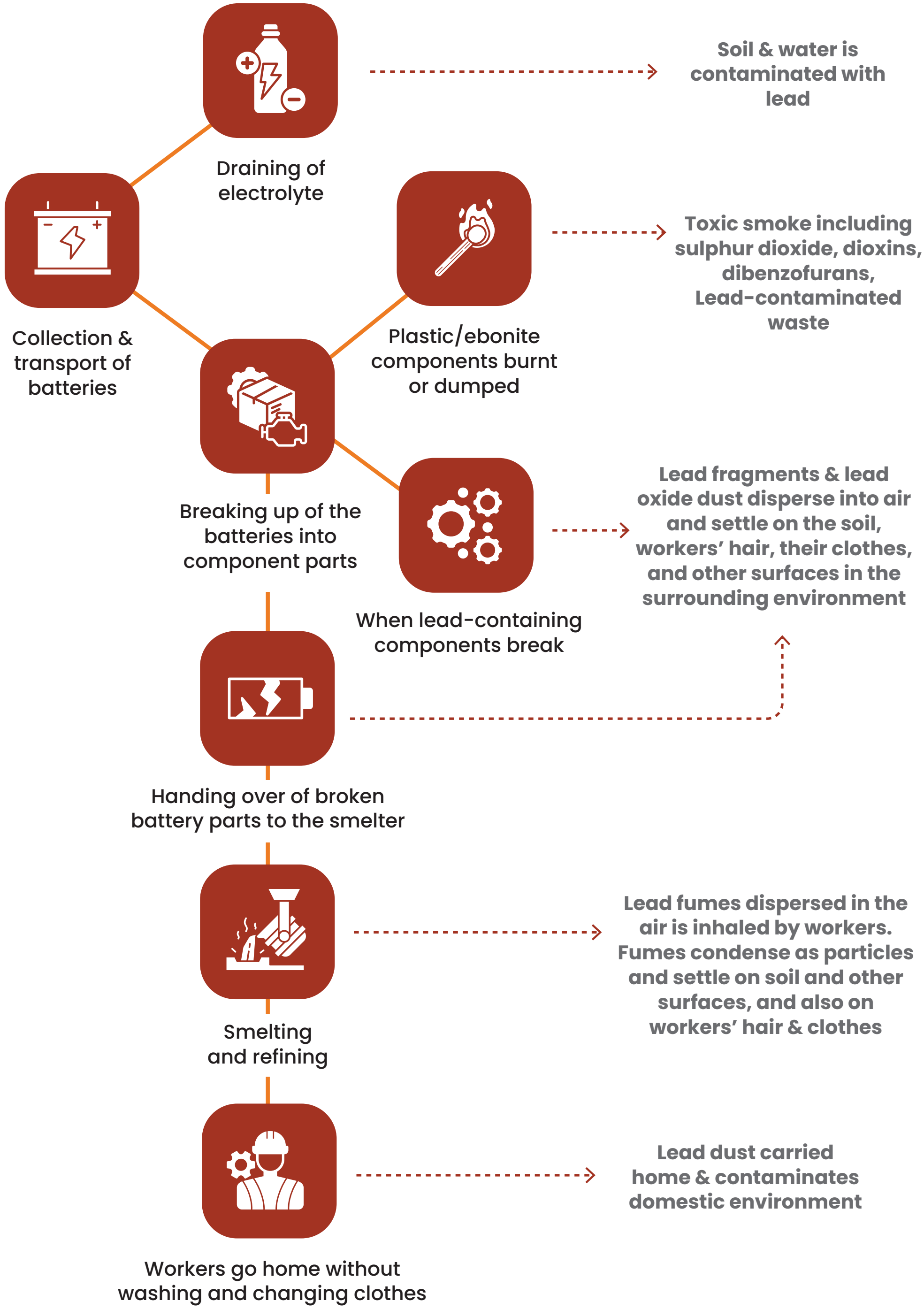
While battery recycling is intended to reduce environmental harm and recover valuable resources, improper handling and poor practices particularly in the unauthorised (informal) sector result in the uncontrolled release of lead into the air, soil, and water.

Studies have reported that manual dismantling releases more lead particles and lead oxide dust. For example, hammermills and shredders may release lead mist, which can dry and release lead dust if disturbed. Similarly, dust settled on vibrating equipment can become re-suspended in air and inhaled. Exposure to these may cause lead poisoning among workers.

These lead dust and particles may also settle in the surrounding soil and may be blown to more distant areas, and becoming a source of exposure to the wider community.[32]

A study by Gottesfeld et.al. (2011) reported that the average BLLs in workers at battery manufacturing plants in 37 developing countries were 47 µg/dL, while workers in recycling facilities had even higher levels, averaging 64 µg/dL. These figures far exceed the threshold of concern. Airborne lead concentrations in these plants averaged 367 $\mu g/m^3$, more than seven times the OSHA (Occupational Safety and Health Administration) permissible exposure limit of 50 $\mu g/m^3$.[33]

Figure 2. Point source at which lead is released during battery recycling. Adopted from World Health Organization, 2017



In 2019, Toxics Link assessed various Indian cities and states to investigate the unauthorised (informal) recycling of lead-acid batteries. The findings indicated that at every stage—from collection and transportation to dismantling, smelting, and waste disposal—activities are not conducted in an environmentally sound manner, and are causing lead contamination in the environment.

In an unauthorised (informal) setup, children often assist with dismantling the batteries and washing components. Most of the time, these unauthorised (informal) setups are located around residential areas and primary schools, which leads to higher exposure in children. Ansari et al. in 2020 reported BLLs of more than 5 μg/dl among 91% of children residing near an unauthorised (informal) lead battery manufacturing unit. Similarly, Gao et al. (2013) reported lead concentrations higher than the prescribed limit in air and vegetables grown near recycling sites, which put the average daily exposure to lead in children at 3.46×10^{-2} mg/kg.[34]

India's Battery Waste Management Rules, 2022 mandate Extended Producer Responsibility (EPR) for safe collection and recycling of waste batteries through authorized facilities[35]. However, unauthorised (informal) recycling persists, often releasing lead into the environment. This study focuses on assessing lead contamination in and around unauthorised (informal) and authorised (formal) battery recycling clusters within the context of these regulations. Such contamination can cause severe health and ecological risks, underscoring the need for stricter enforcement of the 2022 rules.[36]

Sampling

Twenty-three soil samples were collected from areas outside lead-acid battery recycling units that are in close proximity to residential areas, local communities, and primary schools. A standard sampling protocol (EPA 747-R-95-001) was used to collect surface soil from the top 1–2 cm undisturbed areas of bare soil at representative locations within a 100-200 m radius from each facility (Random Sampling).

At each sample location, 5–6 sub-samples were collected in a randomised manner within a one-square-metre area, mixed, and stored in a labelled plastic sampling bag. Coordinates for each sampling site were recorded, along with a brief land survey.

Methodology

The samples were sent to the NABL--certified M/s Vimta Labs Ltd, Hyderabad for analysis of lead. The samples were tested by the EPA 3050B protocol using Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

Results and discussions

Location	No. of Samples
Delhi	6
Haryana	4
Rajasthan	9
Uttar Pradesh	5

Site observations and sampling:

Out of 23 sampling sites, 3 were outside of the authorised (formal) recycling units while rest were from the proximity of unauthorised (informal) recycling units. Samples were collected from the Delhi NCR area that falls under four different states. All the soil samples were conducted at a battery recycling unit located in the Delhi (NCR) region. The soils in this area are predominantly light-textured, comprising of sandy, loamy sand, and sandy loam types, with a smaller proportion of medium-textured soils such as loam and silty loam.

The surface soils are generally light brown to yellowish-brown in color, reflecting their alluvial origin. Such light-textured soils, with relatively higher permeability, may facilitate the downward migration of contaminants. Consequently, the presence of lead from battery recycling activities can percolate through these soils, increasing the likelihood of heavy metal leaching into the underlying groundwater system.

In several unauthorised (informal) unit sites, degraded biota was observed near the sampling locations, including reduced vegetation cover and visibly stressed plant growth, indicating possible ecological impacts from long-term lead contamination.

At 3–4 sites, waste from battery recycling units was openly dumped on bare ground, further aggravating the risk of soil and groundwater contamination. Additionally, children were observed playing in the vicinity of some of the unauthorised (informal) units, highlighting direct human exposure pathways and potential health concerns.

Lead was detected in all samples ranging from 100 ppm to 43800 ppm. On average higher levels of lead were found in samples collected from the proximity of authorised (formal) recycling units than unauthorised (informal) recycling units. As the authorised (formal) set-up is considered to be better designed and organized to handle the lead processing, it is supposed to be less polluting. However, the results show the gaps in the management of the environmental leakage of this heavy metal. Though, the high lead content around the authorised (formal) set-up also represents high load of recycling.

On average, the level of lead was found to be high in soil samples collected from Uttar Pradesh, and the least in Haryana. Since we could not get access to enter these recycling units, the reasons behind such variations could not be inferred.

Figure 3. Average concentration of lead (ppm)

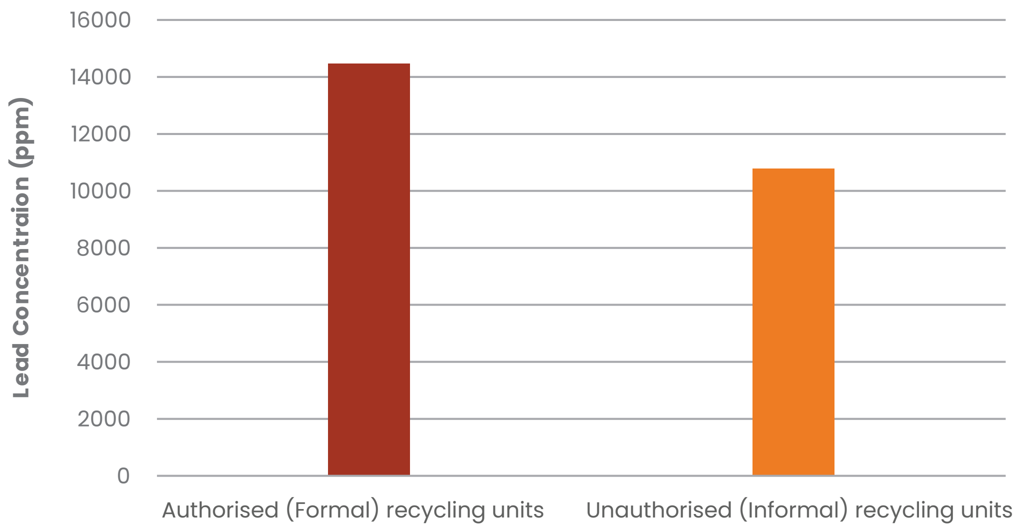


Figure 4. Average concentration of lead (ppm) in soil samples collected from different states

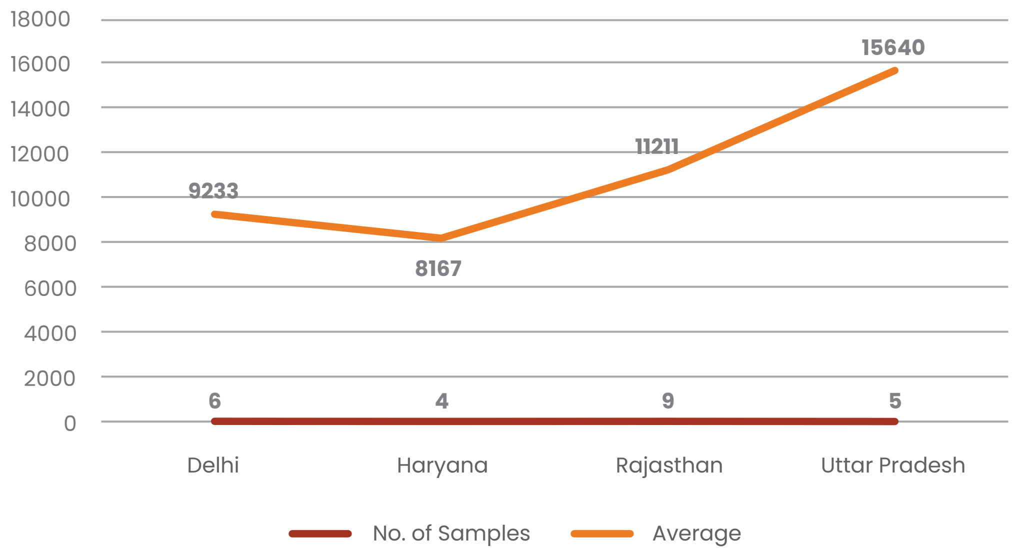


Table 2. Screening & response levels of lead in different location[37] as per CPCB guidelines

Hazardous Waste (levels Schedule II, HW Rules, 2008)	Soil (Screening & Response Levels)				
	Response Levels (Dutch Intervention levels)	Screening levels (Soil quality guidelines for the protection of Environment & Human health)			
		Agricultural	Residential/ parkland	Commercial	Industrial
mg/kg (ppm)	mg/kg (ppm)	mg/kg (ppm)	mg/kg (ppm)	mg/kg (ppm)	mg/kg (ppm)
5000	530	70	140	260	600

With reference to the Central Pollution Control Board (CPCB) Guidance Document for Assessment and Remediation of Contaminated Sites (2015) benchmarks, our findings indicate that 52% of the collected soil samples contained lead concentrations exceeding 5000 ppm, while 31% surpassed the permissible limits for industrial areas. In accordance with CPCB guidelines, these sites qualify for urgent remediation interventions. Such contaminated soils may lead to the pollution of groundwater and surface water via runoff, particularly during periods of heavy rainfall.

Figure 5. Samples containing lead concentration more than 5000 ppm

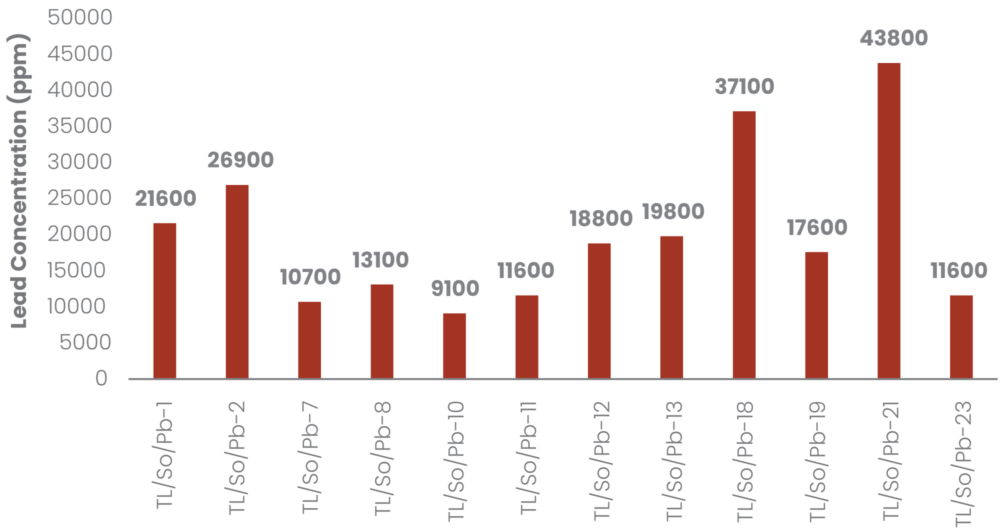
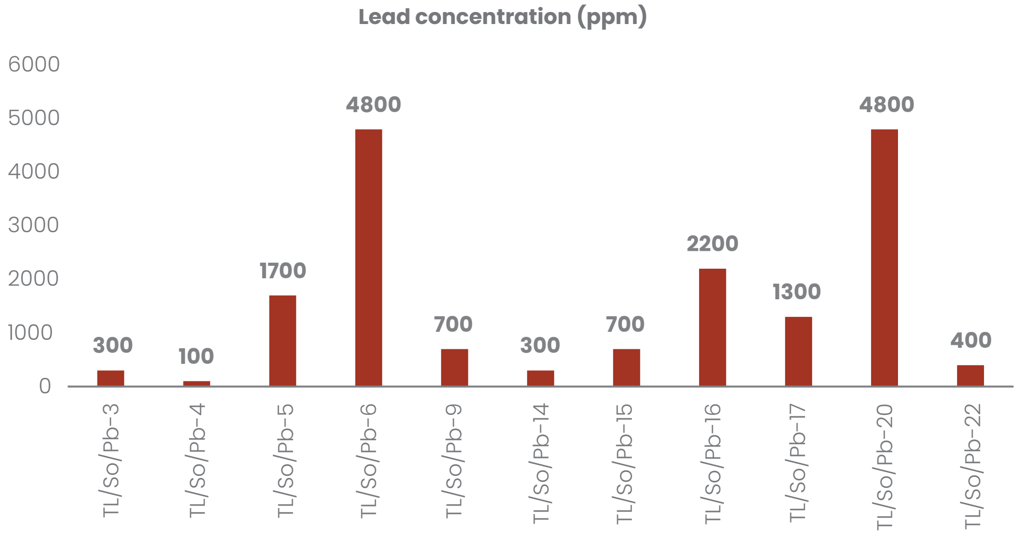


Figure 6. Samples containing lead concentration less than 5000ppm



Recommendation

The findings from this study highlight serious gaps in the enforcement of the Batteries (Management and Handling) Rules in the country. Both the authorised (formal) and unauthorised (informal) sectors are falling short.

- Recycling of lead-acid batteries should not be allowed in unregulated, unauthorised (informal) settings due to the high environmental and health risks involved.
- Stronger implementation and enforcement of EPR guidelines can help prevent leakage into the unauthorised (informal) sector.
- Consumers should be made aware of the hazards of unauthorised (informal) recycling and encouraged to return used batteries through proper channels.
- There is a need for an immediate and comprehensive environmental monitoring programme to assess lead contamination in soil, air, water, and household dust around both authorised (formal) and unauthorised (informal) recycling facilities.
- Regular health assessments, particularly blood lead level (BLL) testing in exposed populations, should also be conducted for immediate treatment.
- A national database of contaminated sites related to lead battery recycling should be developed and linked to actionable remediation strategies under the CPCB framework.

Annexures

Annex I: Lead concentrations in all tested samples

Sample	Lead concentration (ppm)	Hazardous waste levels (levels Schedule II, HW Rules, 2008) (ppm)	Soil (Screening and Response Levels)[38]				
			Response levels (Dutch Intervention levels) (ppm)	Screening levels Soil Quality Guidelines for the Protection of Environmental and Human Health			
				Agricultural (ppm)	Residential/-parkland (ppm)	Commercial (ppm)	Industrial (ppm)
TL/So/Pb-1	21600						
TL/So/Pb-2	26 900						
TL/So/Pb-3	300						
TL/So/Pb-4	100						
TL/So/Pb-5	1700						
TL/So/Pb-6	4800						
TL/So/Pb-7	10700						
TL/So/Pb-8	13100						
TL/So/Pb-9	700						
TL/So/Pb-10	9100						
TL/So/Pb-11	11600						
TL/So/Pb-12	18800	**5000**	**530**	**70**	**140**	**260**	**600**
TL/So/Pb-13	19800						
TL/So/Pb-14	300						
TL/So/Pb-15	700						
TL/So/Pb-16	2200						
TL/So/Pb-17	1300						
TL/So/Pb-18	37100						
TL/So/Pb-19	17600						
TL/So/Pb-20	4800						
TL/So/Pb-21	43800						
TL/So/Pb-22	400						
TL/So/Pb-23	11600						

Annex II- Regulatory framework on used lead-acid batteries

As used lead-acid batteries are regarded as hazardous waste, various laws, decrees and guidelines have been developed at the international level to manage these materials. For used lead-acid batteries, specific legislation is often developed in combination with household batteries. Some of the frameworks are mentioned below:

European Union: Under Directive 2006/66/EC Member States are required to ensure that producers, or third parties, set up schemes to collect automotive batteries from end-users or from an accessible collection point in their vicinity, where collection is not carried out as part of an end-of-life vehicle programme. Furthermore, where the batteries have originated from private, non-commercial vehicles, the schemes may not involve any charge to end-users when discarding waste batteries, nor any obligation to buy a new battery. Member States are also required to ensure that producers of industrial batteries, or third parties, do not refuse to take back waste industrial batteries from end-users, regardless of chemical composition and origin.

United States: Lead-acid batteries are subject to mandatory deposit systems in several states— Arizona, Arkansas, Connecticut, Idaho, Maine, Minnesota, New York, South Carolina and Washington—and voluntary deposit systems in most other areas. Many of the states have used model legislation developed by the Battery Council International (BCI), which recommends that retailers charge a US$10 fee (deposit) on all batteries sold, with the fee waived or returned if the customer brings back a used battery within 30–45 days of purchase.

Canada: The "lead-acid battery product category" is managed in British Columbia in accordance with the stewardship plans approved under the Recycling Regulation. Province-wide lead-acid battery Stewardship Plans have been developed by the Canadian Battery Association[vii] (CBA) and Interstate Battery System of Canada[viii] (IBSC). All costs are borne by CBA and IBSC, and ULABs are accepted for free at participating retailers. To compete with independent recyclers CBA members may implement a business-to-business programme (at the wholesale level) involving a core charge (deposit) to encourage the return of ULABs from the retailer to the manufacturer. Typically, these core charges are CAD$10 per automotive battery with greater amounts for larger sizes.

Basel Convention: The Basel Convention on the control of Transboundary Movements of Hazardous Waste and their disposal was a global treaty adopted on 2nd March, 1989 in Basel, Switzerland. It finally came into force in 1992. It aims to reduce the generation of hazardous waste and promote environmentally sound management of this waste at the site of disposal. It also aims to restrict the transboundary movement of hazardous waste and establish a regulatory system for cases where transboundary movements are permissible.

India: The Batteries (Management and Handling) Rules, 2001, address the collection and recycling of used lead-acid batteries, requiring manufacturers and other stakeholders to report on their activities. Later, Battery Waste Management Rules, 2022, had been notified on Aug 2022 by the MoEF&CC of Government of India. The regulation applies to producers (manufactures & importers), dealers, consumers and recyclers of all types of waste batteries including portable, automative, industrial & EV batteries. As per these Rules, producers (manufacturers, importers) shall have the obligation of Extended Producer Responsibility for the battery they introduce in the market and the Producer shall meet the collection and recycling targets as given in Schedule II of the rules to ensure the attainment of EPR obligations.[39] On Jan 2024, CPCB released SOPs for recycling of used lead-acid batteries.[40]

Endnotes

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